Naval Education and Training Command

NAVEDTRA 10531-D
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Training Manual (TRAMAN)

Machinery Repairman 1 & C

Nonfederal government personnel wanting a copy of this document must use the purchasing instructions on the inside cover.

The terms training manual (TRAMAN) and nonresident training course (NRTC) are now the terms used to describe Navy nonresident training program materials. Specifically, a TRAMAN includes a rate training manual (RTM), officer text (OT), single subject training manual (SSTM), or modular single or multiple subject training manual (MODULE); and an NRTC includes nonresident career course (NRCC), officer correspondence course (OCC), enlisted correspondence course (ECC), or combination thereof.

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text.

ERRATA FOR NAVEDTRA 10531-D

To avoid confusion as you read this text, make the following changes:

1. Pages 2-12 and 2-13: Switch the figure numbers and titles. The figure on page 2-12 is actually figure 2-12, not figure 2-11. The figure on page 2-13 is figure 2-11, not figure 2-12.

2. Page 2-18, second line under "Rolling the Gear Blank": change "waterline" to "center line"

3. Page 2-21, step number 9: change "diameter" to "radius"

Naval Education And Training Program Management Support Activity

MACHINERY REPAIRMAN 1 & C

NAVEDTRA 10531-D

1988 Edition Prepared by
MRCM Rey R. Romero

PREFACE

This Rate Training Manual and Nonresident Career Course (RTM/NRCC) form a self-study package to teach the theoretical knowledge and mental skills needed by the Machinery Repairman First Class and Chief Machinery Repairman. To most effectively train Machinery Repairmen, this package may be combined with on-the-job training to provide the necessary elements of practical experience and observation of techniques demonstrated by more senior Machinery Repairmen.

Completion of the NRCC provides the usual way of satisfying the requirements for completing the RTM. The set of assignments in the NRCC includes learning objectives and supporting questions designed to help the student learn the materials in the RTM.

1988 Edition

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

CREDITS

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CHAPTER 1

THE MACHINERY REPAIRMAN

This rate training manual (RTM) has been prepared for members of the Regular Navy and the Naval Reserve. It will help you meet the occupational qualifications for advancement to First Class Machinery Repairman (MR1) or Chief Machinery Repairman (MRC). With each advancement in rating, you accept an increasing responsibility. This chapter covers the advancement system, sources of information, and finally, your role as an MR1 or MRC. Leadership, supervision, and training will be discussed in a later chapter.

PREPARING FOR ADVANCEMENT

Remember that the requirements for advancement may change from time to time. Check with your division officer or with your training officer to be sure you have the most recent requirements. You will be better able to prepare for advancement and to help lower-rated personnel prepare for advancement.

To prepare for advancement, you need to be familiar with the military requirements and the occupational standards given in (1) the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068; (2) Personnel Advancement Requirements (PAR), NAVPERS 1414; (3) appropriate rate training manuals and any other material that may be required or recommended; and (4) the *Bibliography for Advancement Study*, NAVEDTRA 10052. These materials are discussed later in the section of this chapter that deals with sources of information.

SCOPE OF THIS TRAINING MANUAL

Before studying this book, it is a good idea to know its purpose and scope. Here are some things you should know about this training manual.

It is designed to give you information on the occupational standards for advancement to MR1 and MRC.

You must satisfactorily complete its nonresident career course (NRCC) before you can advance to MR1 or MRC, whether you are in the Regular Navy or in the Naval Reserve.

It is not designed to give you information on the military requirements for advancement to PO1 or CPO. Rate training manuals that are specially prepared to give information on the military requirements are discussed in the next section of this chapter, which deals with sources of information.

SOURCES OF INFORMATION

It is very important for you to have an extensive knowledge of the references to consult in preparing for advancement. They contain detailed, authoritative, up-to-date information on all subjects related to the military requirements and to the occupational qualifications of the MR rating.

Some of the publications discussed here are subject to change or revision from time to time—some at regular intervals, others as the need arises. Be sure you have the latest edition, and be sure you have a copy in which all official changes have been entered.

OCCUPATIONAL STANDARDS

The *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068 (with changes), gives the minimum requirements for advancement to each rate within each rating. This manual lists the military requirements that apply to all ratings and the occupational standards that are specific to each rating.

The standards manual is kept current by numbered changes. These changes are issued more frequently than most rate training manuals can be revised; therefore, the training manuals cannot always reflect the latest occupational standards for advancement. When preparing for advancement, always check the latest standards manual and the latest changes to be sure that you know the current requirements for advancement. For your convenience, the occupational standards for MR1 and MRC (current as of the date this text was written) are listed in appendix I.

When studying the occupational standards for advancement, remember these two things:

1. The standards are the minimum requirements for advancement to each rate within each rating. If you study more than the required minimum, you will have a great advantage when you take the written examinations for advancement.

2. Each standard has a designated paygrade—E-4, E-5, E-6, or E-7. You are responsible for meeting all standards specified for advancement to your next paygrade and all standards specified for your current and lower paygrades.

A special form known as the Personnel Advancement Requirements, NAVPERS 1414/4, is used to record the satisfactory completion of the standards, both military and occupational, listed in the standards manual. This form is available for each rating. Whenever you demonstrate your ability to perform a practical factor, appropriate entries must be made in the DATE and INITIALS columns. As an MR1 or MRC, you will often be required to check the performance of lower-rated personnel and to report the results to your supervising officer. To facilitate record keeping, group records of practical factors are often maintained aboard ship. Entries from the group records must be transferred to each individual's record at appropriate intervals.

As changes are made periodically to the standards manual, new forms of NAVPERS 1414/4 are provided when necessary. This information should also be kept in each person's service record and should be forwarded with the service record to the next duty station. Each person should also keep a copy of the record for

NAVAL EDUCATION AND TRAINING (NAVEDTRA) PUBLICATIONS

Rate training manuals (RTMs), nonresident career courses (NRCCs), and other training texts and courses designed to help you become more knowledgeable in your career field are prepared by the Naval Education and Training Program Management Support Activity. This center is a field activity of the Chief of Naval Education and Training, and the training materials are designated as NAVEDTRA publications. Some training materials may be still designated as NAVPERS or NAVTRA publications, but as they are updated their designations will be changed to NAVEDTRA.

The naval training publications described here include some that are absolutely essential for anyone seeking advancement and some that, although not essential, are extremely helpful.

NAVEDTRA 10052

Bibliography for Advancement Study, NAVEDTRA 10052, is a very important publication for anyone preparing for advancement. This publication lists required and recommended RTMs and other reference material to be used by personnel working for advancement. NAVEDTRA 10052 is revised and issued once each year by the Naval Education and Training Program Management Support Activity. Each revised edition is identified by a letter following the NAVEDTRA number. Be sure you have the most recent edition. If extensive changes in standards occur in any rating between the annual revisions of NAVEDTRA 10052, a supplementary list of study material may be issued in the form of a BUPERS notice.

The required and recommended references are listed by rate. Remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

The RTMs that are marked with an asterisk (*) are mandatory at the indicated rate levels. You may complete a mandatory training manual by passing the appropriate NRCC, based on the mandatory training manual.

All references listed in NAVEDTRA 10052, whether mandatory or recommended, may be used as source material for the written exam-

Rate training manuals are written as training information and to help you prepare for advancement. Some manuals are general in nature and are intended for use by more than one rating; others (such as this one) are specific to the particular rating.

Rate training manuals are revised from time to time to bring them up to date. The edition of a rate training manual is identified by a letter following the NAVEDTRA number. You can tell whether a training manual is the latest edition by comparing your manual with the same manual listed in the most recent edition of the *List of Training Manuals and Nonresident Training Courses,* NAVEDTRA 10061.

Some training manuals are specially prepared to present information on the military requirements for advancement. The following manuals are of interest to MR1 and MRC advancement candidates:

- *Military Requirements for Petty Officer First Class*, NAVEDTRA 10046.

- *Military Requirements for Chief Petty Officer*, NAVEDTRA 10047.

Each of the military requirements manuals is mandatory at the indicated rate levels. They contain information on the military requirements and on the enlisted rating structure. They help you learn how to prepare for advancement; how to supervise, train, and lead other people; and how to meet your increasing responsibilities as you advance.

Some of the RTMs that may be useful to you as you prepare to meet the occupational standards for advancement to MR1 and MRC are discussed briefly in the following paragraphs. For a complete listing of RTMs, consult the *List of Training Manuals and Nonresident Training Courses*, NAVEDTRA 10061.

Tools and Their Uses, NAVEDTRA 10085. Portions of this training manual are listed as recommended reading for those preparing for advancement to third class in the MR rating. However, you may wish to review the manual as you prepare for advancement to higher rates.

Blueprint Reading and Sketching, NAVEDTRA 10077. This manual will be useful for review as you prepare for advancement to MR1 and MRC.

and *Mathematics*, volume 2, NAVEDTRA 10071. These two training manuals are very valuable to the MR. If you are not adept at working with numbers, consult volume 1 and chapters 1, 2, 3, and 4 of volume 2. You need to become proficient in the mathematics associated with helical, bevel, and worm gearing. You must be familiar with transposing and logarithms, and be able to use the tables of natural trigonometric functions.

Machinery Repairman 3 & 2, NAVEDTRA 10530. Satisfactory completion of this training manual is required for advancement to MR3 and MR2. You have already met this requirement, but you should at least glance through the latest edition of the manual. Much of the information given in the latest edition of *Machinery Repairman 1 & C* assumes that you are familiar with the contents of *Machinery Repairman 3 & 2*, NAVEDTRA 10530.

Other NAVEDTRA Publications

Some additional and useful NAVEDTRA publications are listed and described in the following paragraphs. You may also want to consult the training manuals for other ratings in occupational fields 3 and 4 (Engineering and Hull). The manuals prepared for Machinist Mate, Engineman, and Boiler Technician are likely to be of particular interest to you. These manuals will add to your knowledge of the duties of others in the engineering department and help you prepare for your next promotion.

Another valuable publication is *The Metric System*, NAVEDTRA 475-01-00-79, which is packaged with a self-study course. Over the next few years, the metric system will be more widely used by the Navy as well as by the civilian world. You will find it easy to work with metrics once you have mastered the basic terms. It will be difficult to translate values from our present system to the metric system, but this operation will become unnecessary once the new measurements are totally adopted. See your educational services officer for information on how to obtain this study package.

Officer Texts

Officer texts that you may find helpful include the latest editions of *Engineering Administration*, NAVEDTRA 10858, and *Principles of Naval Engineering*, NAVEDTRA 10788.

Correspondence Courses

Most rate training manuals and officer texts are used as the basis for correspondence courses. You can complete a mandatory training manual by passing its correspondence course. You may find it helpful to take other correspondence courses. They can help you master the information given in the training manual or text and also give you a pretty good idea of how much you have learned from studying the book.

NAVSEA PUBLICATIONS

The publications issued by the Naval Sea Systems Command (NAVSEA) are of particular importance to engineering department personnel. Although you do not need to know everything in these publications, you should have a general idea of where to find the information in them.

Naval Ships' Technical Manual

The *Naval Ships' Technical Manual* is NAVSEA's basic engineering doctrine publication. Information in this publication is organized by chapters and updated by revisions as often as needed.

The manufacturers' technical manuals that are furnished with most machinery units and many types of equipment are also valuable publication sources. They contain information on operation, maintenance, and repair, and are sometimes given NAVSHIPS numbers.

NAVSEA Deckplate

This is a bimonthly technical magazine published by NAVSEA. It has information on the design, construction, conversion, operation, maintenance, and repair of naval vessels and their equipment. Also, other technical equipment and programs under the authority of the command are discussed. This magazine is very useful because it has additional information that helps explain the subject matter in the *Naval Ships' Technical Manual*. New Developments in naval engineering are also covered in the magazine. The NAVSEA publication *deckplate* was formerly known as the NAVSEA Journal.

You should be familiar with the OPNAV publications discussed in the following paragraphs. These publications are subject to change, and it is important that you use an edition that contains all the changes.

The basic doctrine publication concerning the 3-M Systems is the *Ships' Maintenance and Material Management (3-M) Manual*, OPNAVINST 4790.4, Volumes 1, 2, and 3. Since you are required to have a knowledge of the 3-M Systems, we will briefly discuss it in a later chapter.

OPNAV Instruction 5510.1 (current edition), *Department of the Navy Information Security Program Regulations*, is the basic reference on security matters. As a petty officer, you are required to know the purpose of the security program, the need-to-know concept, regulations for the circulation and control of classified matter, methods of destroying classified material, and the duties of witnessing officials. Regulations covering reproduction of classified material and a number of other matters relating to security are also found in the above publication.

While written mainly as a guide for supervisors, the *Accident Prevention Manual*, OPNAVINST 5101.2, also serves as a basic source of information for all personnel. Its intention is to improve the level of safety throughout the Navy. Safety is a command function that is to be implemented by all subordinate levels of supervision.

PERSONNEL QUALIFICATION STANDARDS (PQS)

The Personnel Qualification Standards (PQS) Program, OPNAVINST 3500.34, is a method of qualifying officer and enlisted personnel to perform assigned duty. The PQS is a written compilation of knowledge and skills required to qualify for a specific watch station, maintain a specific equipment or system, or perform as a team member within the assigned unit. The PQS is in the format of a qualification guide, which asks the questions a trainee must answer to verify readiness to perform a given task. It also provides a record of the progress and final certification. The PQS approach to training is based on individual learning. The learner has the complete written program in hand. The operational supervisor serves as both a source for specific assistance and as quality control over the learning process through certification of completion of each step. NAVEDTRA 43100-1, *Handbook on Personnel Qualification Standards*, provides information on the PQS concept and describes its implementation into the training program of the operational units of the Navy.

TRAINING FILMS

Training films available to naval personnel are a valuable source of supplementary information on many technical subjects. When selecting a film, note its date of issue listed in the film catalog. As you know, procedures sometimes change rapidly. Thus, some films become obsolete rapidly. If a film is obsolete only in part, you may sometimes use it effectively. Before or during its showing, you should carefully point out to trainees the procedures that have changed. For this reason, if you plan to show a training film, try to take a look at it in advance. To identify films that may be of interest to you, review the Department of the Navy *Catalogue of Audiovisual Production Products*, OPNAVINST 3157.1.

CHAPTER 2

GEARS AND GEAR CUTTING

This chapter covers the manufacture of helical gears, bevel gears, stub tooth gears, worms, worm gears, splines, and sprockets.

Before you begin studying this chapter, secure a copy of *Machinery Repairman 3 & 2* and review the portion that deals with the manufacture of spur gears. *Basic Machines* also provides a good review of gearing basics.

THE MANUFACTURE OF GEARS

Gears have always been a highly essential element in machinery used aboard ships and at naval shore facilities. In today's Navy, the emphasis on speed, power, and compactness in naval machinery has created special problems for the machinist cutting a gear. Today's machinists must be able to turn out a noiseless, practically unbreakable gear capable of transmitting large amounts of power in small spaces. Making gears of this type requires skill and precision of a high order.

In some Navy machine shops, gear hobbing machines or gear shapers are used to cut gears. However, most machine shops use the milling machine because of the relatively small number of gears that are manufactured.

Therefore, this chapter will cover only gear cutting practices on a standard milling machine. If you encounter a difficult problem in calculating or cutting gears, consult a machinist's handbook for more detailed information.

MATERIALS USED FOR GEARS

The choice of material for a particular gear is usually based on the function of the gear. This involves considering factors such as the speed of operation, the type of stress to be encountered, the importance of quiet operation, and the need for resistance to corrosion. The easiest way to determine what material to use for a replacement gear is to find out what material was used for the gear you must replace. In most cases, you will have the original gear to go by. If you do not have the original gear, you may have to find the specifications or blueprints for the original gear. In some cases you may even have to consult a machinist's handbook, which prescribes various materials, in order to make certain that the material you are using will actually hold up under the particular stresses the gear will encounter.

Gears are made from ferrous, nonferrous, and nonmetallic materials. Steel, for example, is used whenever great strength and toughness are required. Nonferrous metals such as bronze and brass are often used aboard naval ships for gears that must be resistant to saltwater corrosion.

Monel and aluminum may be used for certain types of gears, where corrosion resistance is of primary importance. Nonmetallic gearing is frequently used where quietness of operation is important. Nonmetallic gears are most effective when used for high-speed use; however, they do not always hold up properly against the wide fluctuations of load and the high shock loads that may be encountered at low speeds. Although gears made of nonmetallic materials have a lower tensile strength than those constructed of metallic materials, their greater resiliency gives them approximately the same power-transmitting capacity as cast iron.

HELICAL GEARS

A helix is a line that spirals around a cylindrical object, like a stripe that spirals around a barber pole.

A helical gear is a gear whose teeth spiral around the gear body. Helical gears are used to transmit motion from one shaft to another. The shafts can be either parallel or set at an angle to each other, as long as their axes do not intersect (fig. 2-1).

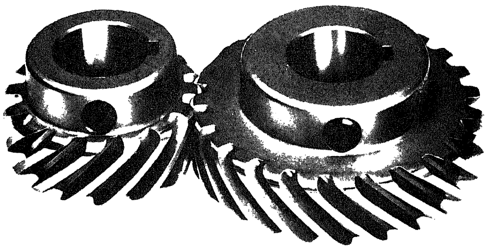
Helical gears operate more quietly and more smoothly than spur gears because of the sliding action of the spiral teeth as they mesh. Also, as helical gears mesh, several teeth make contact at the same time.

This multitooth contact makes a helical gear stronger than a comparable spur gear. However, the sliding action of one tooth on another creates friction that could generate excessive heat and wear. Thus, helical gears are usually run in an oil bath.

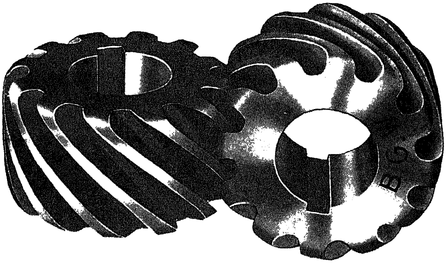
A helical gear can be either right-handed or left-handed. To determine the hand of a helical gear, simply put the gear on a table with its rotational axis perpendicular to the table top. If the helix moves upward toward the right, the gear is right-handed. If the helix moves upward to the left, the gear is left-handed.

Milling a helical gear requires the use of a dividing head, a tailstock, and a lead driving mechanism for the dividing head (fig. 2-2) to cause the gear blank to rotate at a constant rate as the cut advances. This equipment is an integral part of a universal knee and column type of milling machine.

When a helical gear is manufactured correctly, it will mesh with a spur gear of the same diametral pitch (DP), with one gear sitting at an angle to the other. The dimensions of a helical gear would be the same as those of a comparable spur gear if the helical gear's teeth were not cut at an angle.



A. HELICAL GEAR ON PARALLEL SHAFT.



B. HELICAL GEAR ON SHAFT AT ANGLE FROM EACH OTHER.

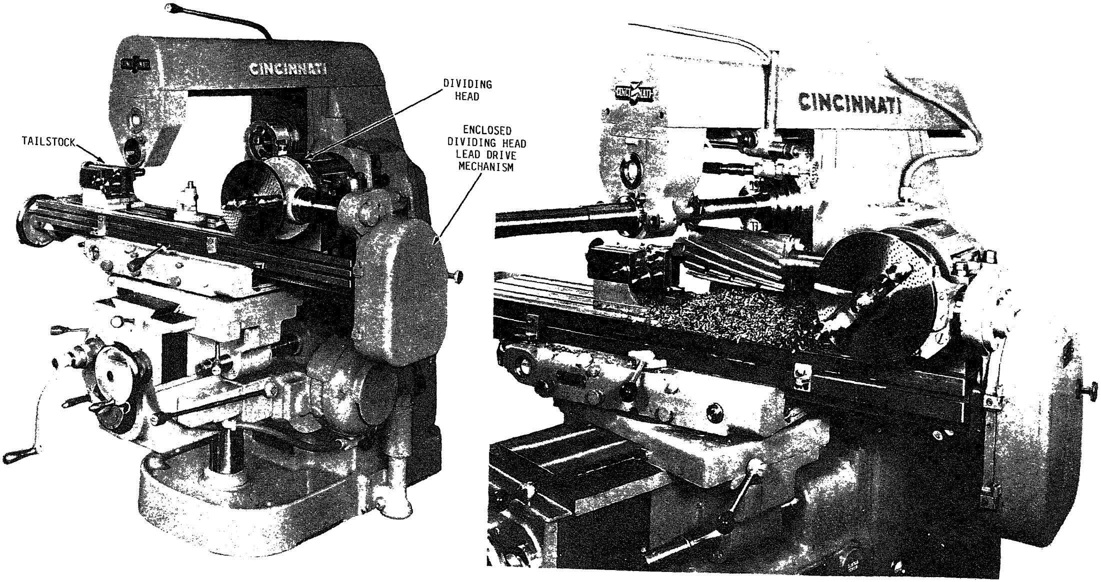


Figure 2-2.—A universal horizontal milling machine equipped for helical milling. The closeup shows the workpiece mounted between the dividing head centers. A fluting cutter is mounted on the arbor. 126.111X

Cutting 20 one-quarter-inch wide slots spaced one-quarter of an inch apart parallel to the gear's axis of rotation requires a 10-inch circular blank. But cutting 20 one-quarter-inch wide slots one-quarter of an inch apart at an angle of 19°22′ to the axis of rotation requires a 10.6-inch circular blank (fig. 2-3).

Helical gears are measured at a right angle to the tooth face in the same manner as spur gears with the same diametral pitch.

DIMENSIONS OF A HELICAL GEAR, REAL AND NORMAL

Every helical gear contains a theoretical spur gear. Any gear element formula used to calculate a spur gear dimension can also be used to determine an equivalent helical gear dimension. However, the helical gear dimension is known as a normal dimension. For example, the number of teeth (NT) on a helical gear is considered a normal dimension. Remember, though, all normal gear elements are calculated dimensions and therefore cannot be measured.

For example:

$$\frac{NT}{DP} = \text{Normal pitch diameter (NPD)}$$

Although most helical gear dimensions are normal dimensions, a few dimensions are real (measurable) dimensions. Examples of real dimensions are the outside diameter (OD), called the real outside diameter (ROD), and the pitch diameter, called the real pitch diameter (RPD).

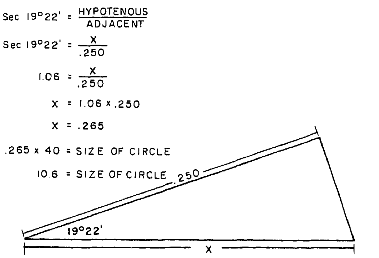


Figure 2-3.—Development of evenly spaced slots with an included angle.

The lead of a helical gear is the longitudin distance a point on the gear travels during o complete revolution of the gear. During the ge manufacturing process, lead relates to the tra of the table.

The helix angle is the angle between a pla parallel to the rotational axis of the workpiece a the helix line generated on the workpiece. Th angle is used in setting the milling machine tab to cut the gear. The helix angle is also used establish the relationships between the re dimensions and the normal dimensions on helical gear.

Determining the Dimensions of a Helical Gear

The easiest helical gear dimension to determi is the RPD. Simply subtract twice the addendu from the ROD, or

$$RPD = ROD - 2\ ADD$$

To determine the other major dimensions, y must relate real and normal dimensio trigonometrically through the helix angle. Th by knowing two of the three components of t trigonometric relationship, you can determine t third component.

Look at figure 2-4, view A, and recall that t helix angle is the angle between the gear's axis rotation and the helix. In this view, the RPD a

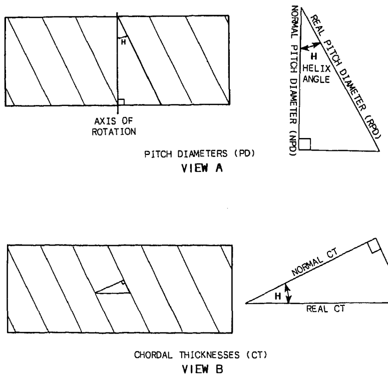


Figure 2-4.—Development of the helix angle.

the NPD are related through the secant and cosine functions. That is,

$$\text{Secant H} = \frac{\text{RPD}}{\text{NPD}} \text{ or Cosine H} = \frac{\text{NPD}}{\text{RPD}}$$

In figure 2-4, view B, the triangle has been mathematically shifted so that we can compare the real chordal thickness (CTR) and the normal chordal thickness (CTN). The CTR is the thickness of the tooth measured parallel to the gear's face, while the CTN is measured at a right angle to the face of the tooth. The two dimensions are also related through the secant and cosine functions. That is,

$$\text{Secant H} = \frac{\text{CTR}}{\text{CTN}} \text{ or Cosine H} = \frac{\text{CTN}}{\text{CTR}}$$

If we could open the gear on the pitch diameter (PD), we would have a triangle that we could use to solve for the lead (fig. 2-5, view A).

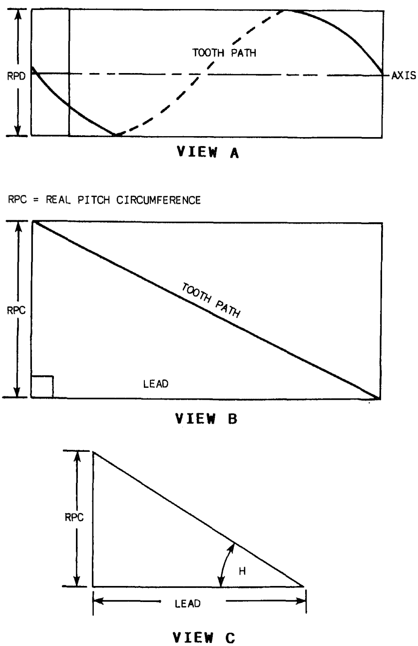


Figure 2-5.—Formulation of a lead triangle and a helix angle.

Figure 2-5, view B, shows a triangle, one leg being the real pitch circumference and the other being the lead. Notice that the hypotenuse of the triangle is the tooth path and has no numerical value.

To solve for the lead of a helical gear, when you know the RPD and the helix angle, simply change RPD to RPC (real pitch circumference) by multiplying RPD by 3.1416 (π) (fig. 2-5, view C), then use the formula:

$$\text{Lead} = \text{RPC} \times \text{Cotangent} \angle \text{H}.$$

Selecting a Helical Gear Cutter

When you cut a spur gear, you base selection of the cutter on the gear's DP and on the NT to be cut. To cut a helical gear, you must base cutter selection on the helical gear's DP and on a hypothetical number of teeth set at a right angle to the tooth path. This hypothetical number of teeth takes into account the helix angle and the lead of the helix, and is known as the number of teeth for cutter selection (NTCS). This hypothetical development is based on the fact that the cutter follows an elliptical path as it cuts the teeth (fig. 2-6).

The basic formula for determining the NTCS involves multiplying the actual NT on the

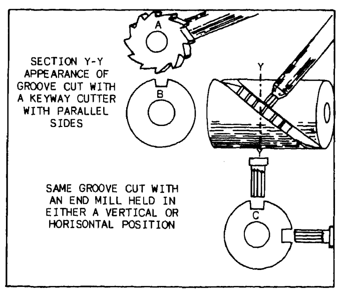


Figure 2-6.—Helix cut with two different cutters.

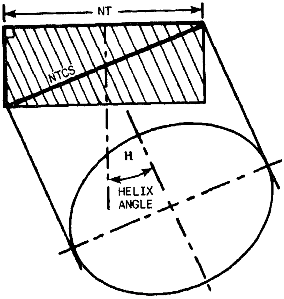


Figure 2-7.—Formation of helical gear cutter selection.

helical gear by the cube of the secant of the helix angle, or

$$NTCS = NT \times \sec \angle H^3$$

This formula is taken from the triangle in figure 2-7.

Computing the NTCS with the above formula is somewhat complicated for some machinist's, so a simplified method to cube the secant of the helix angle was developed (see table 2-1). The simplified method involves multiplying the NT by a factor (K) you obtain from the table.

$$NTCS = NT \times K \text{ (factor)}$$

To determine the constant K, locate on table 2-1 the helix angle you plan to cut. If the angle is other than a whole number, such as 15°6′, select the next highest whole number of degrees, in this case 16°. The factor for 15°6′ is 1.127.

The following section will show you how to use the numerical value of the NTCS to compute corrected chordal addenda and chordal thicknesses.

Corrected Chordal Addendum and Chordal Thickness

As in spur gearing, you must determine corrected chordal addenda and chordal thicknesses since you will be measuring circular distances with a gear tooth vernier caliper that was designed to measure only straight distances.

In helical gearing, the NTCS, rather than the actual NT, is used to select the constant for determining the chordal addendum (CA) and the chordal thickness (CT). Table 2-2 provides these

Table 2-1.—"K" Factor Table

Degrees of Helix Angle	K	Degrees of Helix Angle	K	Degrees of Helix Angle	K
1	1.001	22	1.254	43	2.557
2	1.002	23	1.282	44	2.687
3	1.004	24	1.312	45	2.828
4	1.007	25	1.344	46	2.983
5	1.011	26	1.377	47	3.152
6	1.016	27	1.414	48	3.336
7	1.022	28	1.454	49	3.540
8	1.030	29	1.495	50	3.767
9	1.038	30	1.540	51	4.012
10	1.047	31	1.588	52	4.284
11	1.057	32	1.640	53	4.586
12	1.068	33	1.695	54	4.925
13	1.080	34	1.755	55	5.295
14	1.094	35	1.819	56	5.710
15	1.110	36	1.889	57	6.190
16	1.127	37	1.963	58	6.720
17	1.145	38	2.044	59	7.321
18	1.163	39	2.130	60	8.000
19	1.182	40	2.225	61	8.780
20	1.204	41	2.326	62	9.658
21	1.228	42	2.436	63	10.687

No. of Teeth	Chordal Thickness	Chordal Addenda	No. of Teeth	Chordal Thickness	Chordal Addenda	No. of Teeth	Chordal Thickness	Chordal Addenda
10	1.56434	1.06156	59	1.57061	1.01046	108	1.57074	1.00570
11	1.56546	1.05598	60	1.57062	1.01029	109	1.57075	1.00565
12	1.56631	1.05133	61	1.57062	1.01011	110	1.57075	1.00560
13	1.56698	1.04739	62	1.57063	1.00994	111	1.57075	1.00556
14	1.56750	1.04401	63	1.57063	1.00978	112	1.57075	1.00551
15	1.56794	1.04109	64	1.57064	1.00963	118	1.57075	1.00546
16	1.56827	1.03852	65	1.57064	1.00947	114	1.57075	1.00541
17	1.56856	1.03625	66	1.57065	1.00933	115	1.57075	1.00537
18	1.56880	1.03425	67	1.57065	1.00920	116	1.57075	1.00533
19	1.56901	1.03244	68	1.57066	1.00907	117	1.57075	1.00529
20	1.56918	1.03083	69	1.57066	1.00893	118	1.57075	1.00524
21	1.56933	1.02936	70	1.57067	1.00880	119	1.57075	1.00519
22	1.56946	1.02803	71	1.57067	1.00867	120	1.57075	1.00515
23	1.56958	1.02681	72	1.57067	1.00855	121	1.57075	1.00511
24	1.56967	1.02569	73	1.57068	1.00843	122	1.57075	1.00507
25	1.56977	1.02466	74	1.57068	1.00832	123	1.57076	1.00503
26	1.56984	1.02371	75	1.57068	1.00821	124	1.57076	1.00499
27	1.56991	1.02284	76	1.57069	1.00810	125	1.57076	1.00495
28	1.56998	1.02202	77	1.57069	1.00799	126	1.57076	1.00491
29	1.57003	1.02127	78	1.57069	1.00789	127	1.57076	1.00487
30	1.57008	1.02055	79	1.57069	1.00780	128	1.57076	1.00483
31	1.57012	1.01990	80	1.57070	1.00772	129	1.57076	1.00479
32	1.57016	1.01926	81	1.57070	1.00762	130	1.57076	1.00475
33	1.57019	1.01869	82	1.57070	1.00752	131	1.57076	1.00472
34	1.57024	1.01813	83	1.57070	1.00743	132	1.57076	1.00469
35	1.57027	1.01762	84	1.57071	1.00734	133	1.57076	1.00466
36	1.57030	1.01714	85	1.57071	1.00725	134	1.57076	1.00462
37	1.57032	1.01667	86	1.57071	1.00716	135	1.57076	1.00457
38	1.57035	1.01623	87	1.57071	1.00708	136	1.57076	1.00454
39	1.57037	1.01582	88	1.57071	1.00700	137	1.57076	1.00451
40	1.57039	1.01542	89	1.57072	1.00693	138	1.57076	1.00447
41	1.57041	1.01504	90	1.57072	1.00686	139	1.57076	1.00444
42	1.57043	1.01469	91	1.57072	1.00679	140	1.57076	1.00441
43	1.57045	1.01434	92	1.57072	1.00672	141	1.57076	1.00439
44	1.57047	1.01402	93	1.57072	1.00665	142	1.57076	1.00435
45	1.57048	1.01370	94	1.57072	1.00658	143	1.57076	1.00432
46	1.57050	1.01341	95	1.57073	1.00651	144	1.57076	1.00429
47	1.57051	1.01311	96	1.57073	1.00644	145	1.57077	1.00425
48	1.57052	1.01285	97	1.57073	1.00637	146	1.57077	1.00422
49	1.57053	1.01258	98	1.57073	1.00630	147	1.57077	1.00419
50	1.57054	1.01233	99	1.57073	1.00623	148	1.57077	1.00416
51	1.57055	1.01209	100	1.57073	1.00617	149	1.57077	1.00413
52	1.57056	1.01187	101	1.57074	1.00611	150	1.57077	1.00411
53	1.57057	1.01165	102	1.57074	1.00605	151	1.57077	1.00409
54	1.57058	1.01143	103	1.57074	1.00599	152	1.57077	1.00407
55	1.57058	1.01121	104	1.57074	1.00593	153	1.57077	1.00405
56	1.57059	1.01102	105	1.57074	1.00587	154	1.57077	1.00402
57	1.57060	1.01083	106	1.57074	1.00581	155	1.57077	1.00400
58	1.57061	1.01064	107	1.57074	1.00575	156	1.57077	1.00397

constants. Remember, the numbers listed in the Number of Teeth column are not actual numbers of teeth, but are NTCS values. After you have determined the chordal addendum and chordal thickness constants, you can calculate the corrected chordal addendum by using the following formula:

$$\text{CADD} = \frac{\text{Chordal addendum constant}}{\text{Diametral pitch}} = \frac{\text{CA constant}}{\text{DP}}$$

and the corrected chordal thickness by using this formula:

$$\text{CCT} = \frac{\text{Chordal thickness constant}}{\text{Diametral pitch}} = \frac{\text{CT constant}}{\text{DP}}$$

As an example, calculate the corrected chordal addendum and the corrected chordal thickness for a helical gear with a DP of 10, a helix angle of 15°, and 20 teeth.

$$\text{NTCS} = \text{NT} \times \text{K}$$

$$= 20 \times 1.11 \text{ (constant from table 2-1)}$$

$$= 23$$

NOTE: If the calculated NTCS is other than a whole number, go to the next highest whole number.

From table 2-2, an NTCS of 23 provides the following:

CA constant = 1.0268; CT constant = 1.56958

$$\text{Therefore, CADD} = \frac{1.0268}{10} = 0.102680$$

and

$$\text{CCT} = \frac{1.56958}{10} = 0.156958$$

Backlash Allowance for Helical Gears

The backlash allowance for helical gears is the same as that for spur gears. Backlash is obtained by decreasing the thickness of the tooth at the pitch line and should be indicated by a chordal dimension. Table 2-3 gives maximum allowable backlash in inches between the teeth of the mating gears.

Table 2-3.—Maximum Backlash Allowance

DP	Backlash
4	.011
5	.009
6	.008
7	.007
8	.006
9	.006
10	.005
12	.005
14	.005

A. Maximum Backlash Allowance for Spur and Helical Gear.

DP	Backlash
4	.012
5	.012
6	.008
7	.008
8	.007
10	.007
12	.004
14	.004

B. Maximum Backlash Allowance for Bevel Gear.

To determine the proper amount of backlash, multiply the maximum allowable amount of backlash found in table 2-3A by 2 and add the result to the calculated whole depth. In this case the maximum backlash allowance is a constant.

CENTER-TO-CENTER DISTANCE

We stated earlier in this chapter that the main purpose of gearing is to transmit motion between two or more shafts. In most cases these shafts are in fixed positions with little or no adjustments available. Therefore, it is important for you to know the center-to-center (C-C) distance between the gear and the pinion.

Knowing the tooth elements of a helical gear, we can say that when the real pitch radius of the gear (RPR_g) is added to the real pitch radius of the pinion (RPR_p), we can determine the C-C distance of the two gears (gear and pinion).

The ratio of the NT on the gear and the pinion is equal to the ratio of the PD of the gear and the pinion. This will enable us to solve for the necessary elements of both gear and the pinion, knowing only the C-C distance and the ratio of the gear and the pinion.

GEAR TRAIN RATIO

When a helix is milled on a workpiece, the workpiece must be made to rotate at the same time it is fed into the revolving cutter. This is done by gearing the dividing head to the milling machine table screw. To achieve a given lead, you must select gears having a ratio that will cause the work to rotate at a given speed while it advances a given distance toward the cutter. This distance will be the lead of the helical gear. The lead of the helix is determined by the size and the placement of the change gears, labeled A, B, C, and D in figure 2-8. Gears X and Y are set up to mill a left-handed helix. A right handed helix is set by removing gea Y and reversing gear X.

Before you can determine which gear are required to obtain a given lead, yo must know or determine the lead of the millin machine. The lead of the machine is the distanc the milling machine table must move i order to rotate the spindle of the dividin head one revolution. Most milling machine have a table screw of 4 threads per inc with a lead of 0.250 inch (1/4 inch) an a dividing head (index head) with a 40: worm-to-spindle ratio. When the index hea is connected to the table through a 1: ratio, it will cut a lead of 10 inches. Thus 40 turns of the lead screw are require to make the spindle revolve one complet

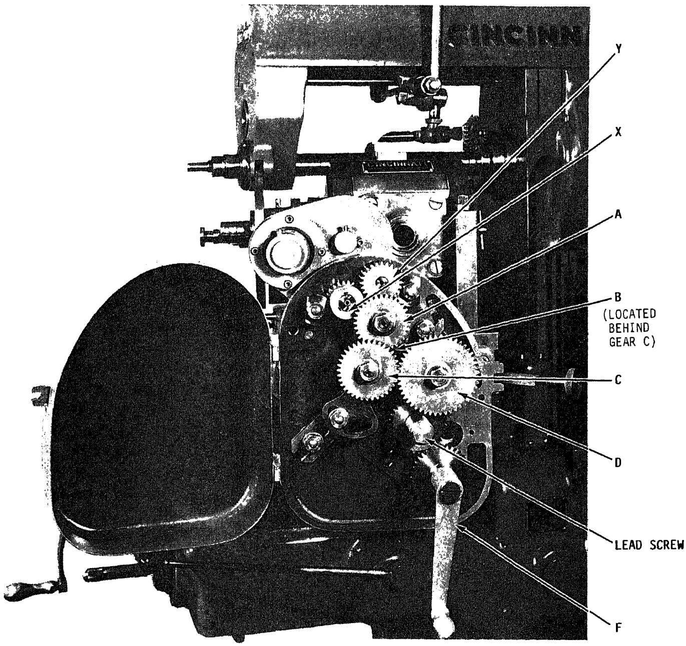


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Figure 2-8.—Standard universal dividing head driving mechanism connected to the dividing head, and showing location o change gear's A, B, C, and D.

revolution (40×0.250 inch $= 10$ inches). Therefore, 10 will be the constant in our gear train ratio formula,

$$GTR = \frac{\text{Lead}}{10}$$

All ratios other than 1:1 require modification of the gear train.

From this formula, we can also say that the

$$\frac{\text{Lead of the machine}}{\text{Lead of the helix to be cut}} = \frac{\text{Product of the driving gears tooth numbers}}{\text{Product of the driven gears tooth numbers}}$$

Example:

Determine the change gears required for a lead of 15 inches. Assume the milling machine has a lead of 10 inches.

$$\frac{\text{Lead of machine}}{\text{Lead of helix desired}} = \frac{10}{15} = \frac{\text{Driving gears tooth numbers product}}{\text{Driven gears tooth numbers product}}$$

If a simple gear train could be used (one driving and one driven gear), a 10-tooth gear on the table screw meshed with a 15-tooth gear on the dividing-head worm shaft would produce the 15-inch lead required. However, gears of 10 and 15 teeth are not available, and the drive system is designed for a compound gear train of four gears. Therefore, the fraction 10/15 must be split into two fractions whose product equals 10/15. This is done by factoring as follows:

$$\frac{10}{15} = \frac{5 \times 2}{5 \times 3} = \frac{\text{Driving gears tooth product}}{\text{Driven gears tooth product}}$$

If gears with 5 and 2 teeth were possible, they would be the driving gears, and gears with 5 and 3 teeth would be the driven gears. But since this is not possible, each of the fractions must be expanded by multiplying both the numerator and the denominator by a number that will result in a product that corresponds to the number of teeth on available gears:

$$\frac{5}{5} \times \frac{8}{8} = \frac{40}{40} \text{ and } \frac{2}{3} \times \frac{12}{12} = \frac{24}{36}$$

or

$$\frac{5 \times 2}{5 \times 3} = \frac{40 \times 24}{40 \times 36} = \frac{\text{Driving gears tooth product}}{\text{Driven gears tooth product}}$$

Thus, gears with 40 and 24 teeth become the driving gears, and gears with 40 and 36 teeth become the driven gears.

These gears would be arranged in the gear train as follows:

Gear A (on the dividing-head worm shaft)
40 teeth (driven)
Gear B (first gear on the idler stud)
24 teeth (driving)
Gear C (second gear on the idler stud)
36 teeth (driven)
Gear D (gear on the table screw)
40 teeth (driving)

The positions of the driving gears may be interchanged without changing their products; likewise, the driven gears. Thus, several different combinations of driving and driven gears will produce a helix with the same lead.

Before starting the entire process of figuring your change gear, check your office library for a ready-made table for the selection of gears devised by the Cincinnati Milling Machine Company. These gears have been determined using the formula, $\frac{\text{lead}}{10}$. If you have already calculated your lead, match it with the lead in the table and select the gears for that lead.

MANUFACTURING A HELICAL GEAR

At this point of the chapter, you are ready to manufacture a helical gear. In a case where you must manufacture a helical gear from a sample, you should do the following:

1. Find the DP.
2. Measure the outside diameter. This is also the ROD.
3. Find the ADD.
4. Find the RPD.
5. Find the NT.
6. Find the NPD.
7. Find the ∠H.
8. Find the RPC.
9. Find the lead.
10. Find the change gear.
11. Find the NTCS.
12. Make sure cutter has the correct DP and cutter number.
13. Find your corrected chordal addendum and chordal thickness.
14. Find your corrected whole depth (WD).
15. Determine what kind of material the sample gear is to be made of.

Now you are ready to machine your gear.

Use the following hints in manufacturing a helical gear:

- Make all necessary calculations that are needed to compute the dimensions of the gear.

- Set up the milling machine attachments for machining.

- Select and mount a gear cutter. Use the formula

$$\text{Sec} \angle H^3 = \frac{NTCS\ (X)}{NT}$$

- Swivel the milling machine table to the helix angle for a right-hand helix; face the machine and push the milling machine table with your right hand. For a left-hand helix, push the table with your left hand.

- Set the milling machine for the proper feeds and speeds.

- Mount the change gears. Use the gear train ratio formula to determine your change gears.

- Mount the gear blank for machining.

- Set up the indexing head for the correct number of divisions.

- Before cutting the teeth to the proper depth, double check the set-up, the alignment, and all calculations.

- Now you are ready to cut your gear.

- Remove and deburr the gear.

BEVEL GEARS

Bevel gears have a conical shape (fig. 2-9) and are used to connect intersecting shafts. Bevel gears with shafts set at less than 90° are shown in figure 2-10, view A. Gears with shafts set at more than 90° are shown in figure 2-10, view B. There are several kinds of bevel gear designs. The one we will be discussing is the straight-tooth bevel gear, which is used most commonly in the Navy. The teeth are straight but the sides are tapered. The centerline of the teeth will intersect at a given point.

Bevel gears are usually manufactured on gear-cutting machines. However, a Machinery Repairman occasionally has to make a bevel gear on a universal milling machine.

This section of the chapter deals with the angle nomenclature of a bevel gear as well as the development of the triangles needed to manufacture a bevel gear.

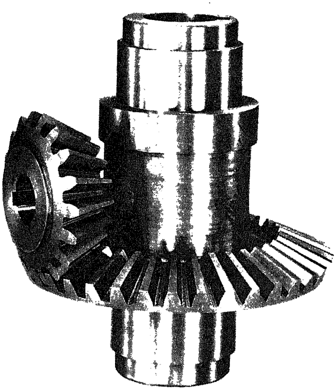

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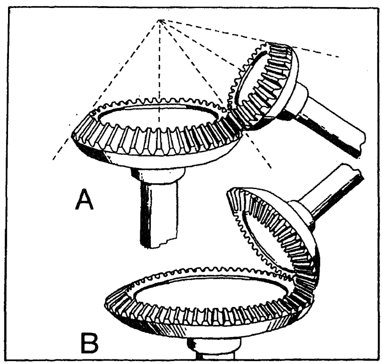
Figure 2-9.—Bevel gear and pinion.



A. With shafts less than 90° apart
B. With shafts more than 90° apart

Figure 2-10.—Other forms of bevel gears.

When two bevel gears whose shaft angles equal 90° are in mesh (fig. 2-11, view A) a triangle is formed. This triangle is called the mating gear triangle. The cones (fig. 2-11, view B) which form the basis of the bevel gears are called the pitch cones. These cones are not visible at all on the finished gear, but are very important elements in bevel gear design.

The angle that is formed at the lower left-hand corner of the triangle (fig. 2-11, view C) is called the pitch cone angle of the pinion. The altitude of the triangle is called the pitch diameter of the pinion, and the base of the triangle is called the pitch diameter of the gear.

The hypotenuse of the triangle is twice the pitch cone radius.

The pitch diameter (gear and pinion), the number of teeth (gear and pinion), and the actual ratio between the gear and the pinion are all in ratio. Therefore, we can use any of these three sets to find the pitch cone angle (PCA).

Example: A 10 diametral pitch (DP) gear with 60 teeth has a pitch diameter (PD) of 6.000 and a 10 DP pinion having 40 teeth has a PD of 4.000. Therefore, the ratio of the gear and the pinion is 3:2.

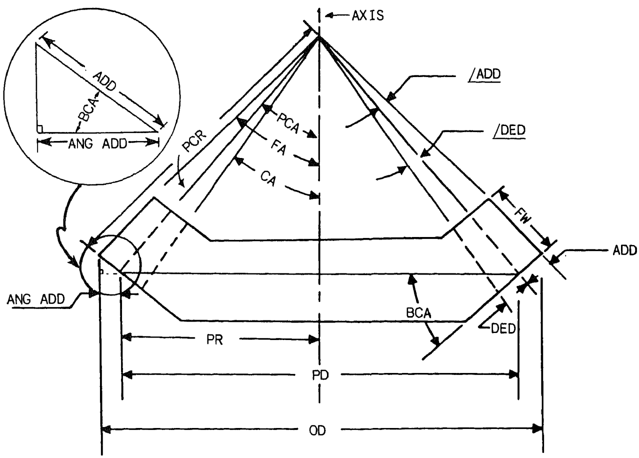
We can determine the PCA by simply substituting the known values into the formula:

$$\text{Tan} \angle PC = \frac{NT_g}{NT_p} = \frac{(60)}{(90)}$$

or

$$\frac{PD_g}{PD_p} = \frac{(6)}{(4)} = \frac{3}{2} \text{ ratio}$$

NOTE: The pitch cone angle of the pinion (PCA_p) is the compliment of the pitch cone angle of the gear (PCA_g).



FA - FACE ANGLE
PCA - PITCH CONE ANGLE
CA - CUTTING ANGLE
/ADD - ADDENDUM ANGLE
/DED - DEDENDUM ANGLE
BCA - BACK CONE ANGLE
PD - PITCH DIAMETER

OD - OUTSIDE DIAMETER
ANG ADD - ANGULOR ADDENDUM
FW - FACE WIDTH
PCR - PITCH CONE RADIUS
PR - PITCH RADIUS
ADD - ADDENDUM
DED - DEDENDUM

Figure 2-11.—Development of the mating gear triangle.

BEVEL GEAR NOMENCLATURE

The dimension nomenclature of the bevel gear is the same as that of a spur gear, with the exception of the angular addendum. Refer to figure 2-12.

1. Face angle (FA)

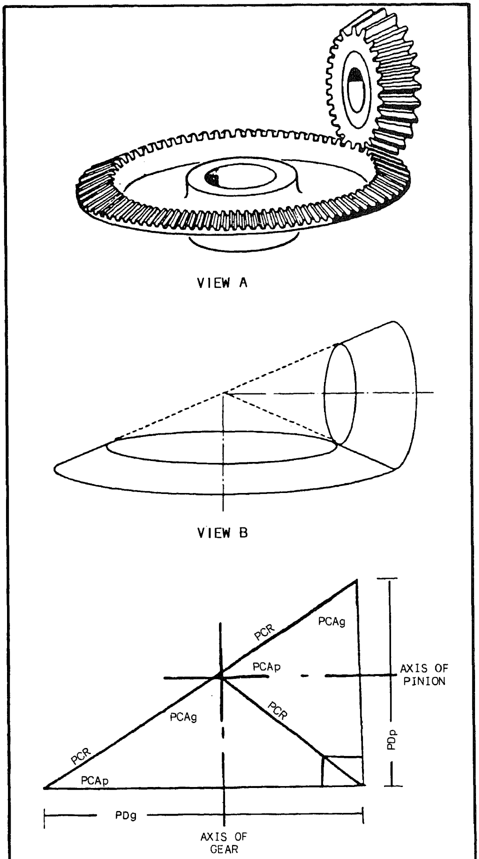
a. This angle is formed by the top edge of the teeth and the axis of the gear.

b. The gear blank is machined to this angle.

c. The face angle is obtained by adding one addendum angle (∠ADD) to the pitch cone angle (∠PC).

2. Pitch cone angle (PCA or ∠PC)

a. This angle is formed by a line down one addendum on the tooth and the axis of the gear.



b. This angle cannot be measured, but it is very important in calculations.

3. Cutting angle (∠C or CA)

a. This angle is formed by the bottom of the tooth and the axis of the gear.

b. The index head is set at this angle when the gear is cut.

c. This angle is obtained by subtracting the dedendum angle (∠DED) from the pitch cone angle (∠PC).

4. Addendum angle (∠ADD)

a. This angle is formed by the top of the tooth and a line one ADD down on the tooth.

b. This angle cannot be measured, but it is used in making calculations for the gear.

c. In the triangle shown in figure 2-13, view A, the side adjacent to the addendum angle is the pitch cone radius and the side opposite is the addendum. Therefore, $\cot \angle ADD = \frac{PCR}{ADD}$.

5. Dedendum angle (∠DED) (fig. 2-12)

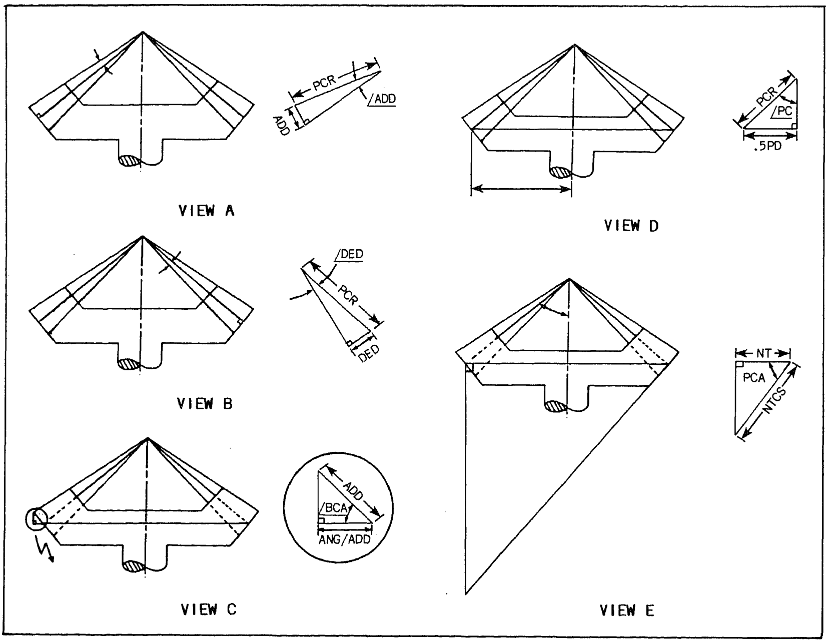
a. This angle is formed by a line one ADD down on the tooth and a line drawn through the bottom tooth.

b. This angle cannot be measured, but it is used in calculations.

c. In the triangle shown in figure 2-13, view B, the side opposite the dedendum angle is the dedendum and the side adjacent is the pitch cone radius. Therefore, $\cot \angle DED = \frac{PCR}{DED}$.

6. Back cone angle (BCA or ∠BC) (fig. 2-12)—This angle is formed by the large end of the tooth and the pitch diameter of the gear. It is equal in value to the pitch cone angle (PCA).

7. Pitch diameter (PD)—This is the diameter of the gear blank one ADD down at the large end of the gear.



8. Outside diameter (OD)

a. This is the maximum diameter of the gear.

b. The gear blank is machined to this OD.

c. The outside diameter is obtained by adding the pitch diameter and twice the angular addendum.

9. Angular addendum (ANG ADD)

a. This is one half the difference between the pitch diameter and the outside diameter.

b. In the triangle shown in figure 2-13, view C, the hypotenuse is the addendum and the side adjacent the angle (BCA) is known as the angular addendum.

c. To obtain the angular addendum (ANG ADD), simply multiply the addendum of the gear by the cosine of angle BCA.

$$\text{ANG ADD} = \text{ADD} \times \text{COS} \angle \text{BCA}$$

10. Tooth dimensions (TD)

a. All tooth dimensions at the large end are the same as a spur gear of the same DP.

b. All tooth dimensions at the small end are a percentage of the large end, depending on the face width ratio.

11. Face width (FW) (fig. 2-12)

a. This is the length of the tooth.

b. The gear blank is machined to this dimension.

12. Pitch cone radius (PCR)

a. This is the length of the side of a cone formed by the bevel gear.

b. This radius is used extensively in calculations.

c. In the triangle shown in figure 2-13, view D, the hypotenuse is the pitch cone radius and the side opposite the pitch cone angle ($\angle$PC) is equal to one-half the pitch diameter (0.5 PD).

d. By using our knowledge of trigonometry, we can obtain the PCR by using the cosec of $\angle$PC and one-half the pitch diameter. PCR = cosec $\angle$PC × 0.5 PD.

13. Pitch cone radius small (PCR_s)—Pitch cone radius small is the difference between the pitch cone radius and the face width. $PCR_s = PCR - FW$.

14. Face width ratio (FWR)

a. This is the ratio of the pitch cone radius and the face width. $FWR = \frac{PCR}{FW}$.

b. The small tooth dimensions are calculated from this ratio.

15. Proportional tooth factor (PTF)—The proportional tooth factor is the ratio between the pitch cone radius small and the pitch cone radius. $PTF = \frac{PCR_s}{PCR}$.

16. Small tooth dimensions—By multiplying any large tooth dimension by the proportional tooth faction, you can obtain the dimension of the small tooth of the gear or pinion.

17. Number of teeth for cutter selection (NTCS)

a. In the triangle shown in figure 2-13, view E, the NTCS is the hypotenuse and the side adjacent is the number of teeth of the gear.

b. The known angle in this case is the pitch cone angle, or the back cone angle.

c. To obtain the NTCS, simply multiply the secant of $\angle$PC by the NT. NTCS = NT × Sec $\angle$PC.

d. The NTCS is taken from the number of teeth on an imaginary spur gear that has a different pitch diameter (PD) than the pitch diameter (PD) of a bevel gear.

e. When your computation for the NTCS contains a decimal number, round the computation to the next higher whole number.

Chordal Addendum and Chordal Thickness

In order for you to measure a manufactured gear tooth accurately, you must first know the chordal addendum and the chordal thickness. These dimensions are used to measure the size of the gear tooth.

Chordal addendum (corrected addendum) a_c—the distance from the top of a gear tooth to the chord across the gear tooth at the pitch circle

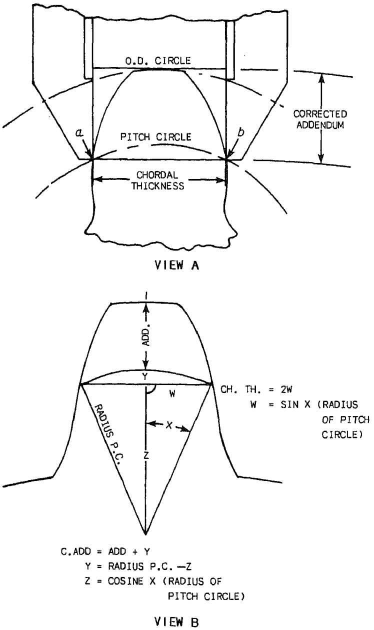


Figure 2-14.—Formulas for calculating chordal thickness.

(fig. 2-14, view A). This is the point at which the chordal thickness is measured.

Chordal thickness of a gear tooth (t_c)—the distance in a straight line (chord) from one side of the tooth to the other side at the points where the pitch circle passes through the gear tooth (fig. 2-14, view A).

The methods for calculating the chordal addendum and the chordal thickness are as follows:

You can calculate the dimensions by using the formulas shown in figure 2-14, view B. However, you can also secure tables (table 2-3B) to make bevel gear calculations. Simply substitute the constant into the following formula:

$$\text{Chordal addendum } (a_c) \text{ (large tooth)} = \frac{\text{Constant} \times \cos \angle PC + 1}{DP}$$

NOTE: Obtain the constant from table 2-3B.

The procedure for solving the chordal thickness of the large tooth of a bevel gear is the same as that for a spur gear.

$$\text{Chordal thickness } (t_c) \text{ (large tooth)} = \frac{\text{Constant}}{DP}$$

You can determine the chordal addendum (corrected addendum) a_c small and the chordal thickness of the small tooth by simply multiplying the value of the large tooth by the proportional tooth factor (PTF).

Backlash Allowance of a Bevel Gear

As you have learned for spur gearing, backlash is the amount (measured by a device) by which the width of a gear tooth space, when two gears are meshed together, exceeds the thickness of the engaging tooth on the pitch circles.

Theoretically, gear teeth when meshed should run without appreciable backlash. However, this is impossible because of manufacturing tolerances of the gears. Space must be provided between the gear teeth for lubrication and for expansion due to temperature changes at high speeds.

Just as with helical gearing, a certain amount of freedom between the gear teeth is required so they will not bind when the gears turn. Table 2-3B shows the recommended backlash allowance corresponding the gear's diametral pitch (DP).

To determine the chordal thickness with backlash at the large end of the tooth, use the following formula:

$$\text{Chordal thickness} = \frac{\text{Constant}}{DP} - \frac{1}{2}\text{ backlash allowance}$$

NOTE: Obtain the constant from table 2-3B.

To determine the corrected working depth (WD) with backlash at the large end of the tooth, use the following formula:

$$\frac{2.157}{DP} + (2 \times \text{backlash allowance})$$

SELECTING A BEVEL GEAR CUTTER

To cut bevel gears on the milling machine, you must use special form relieved cutters. These cutters are similar in appearance and size to those used to cut spur gears, but are made with thinner teeth. Bevel gear cutters are made to cut gears having a face width not greater than one-third nor less than one-eighth of the distance from the back of the gear to the apex of the cone.

The contour of the cutter teeth is made for the large end of the gear. The tooth shape at any other section, then, is only an approximation of the current form for that section. However, it is possible to approximate the dimensions and form of the teeth with sufficient accuracy to meet the repair needs aboard ship.

To obtain the best results in milling bevel gear teeth, you should select a cutter not for the actual number of teeth in the bevel gear, but for the number of teeth in an imaginary spur gear. This imaginary spur gear has an entirely different diameter than the actual bevel gear.

To determine the number of teeth in the imaginary spur gear, multiply the number of teeth in the actual gear by the secant of the pitch cone angle. That is:

$$NTCS = NT \times \text{Sec} \angle PC$$

Where:

NTCS = number of teeth of the imaginary spur gear
NT = number of teeth in the actual bevel gear
$\angle PC$ = pitch cone angle

Suppose you plan to cut a bevel gear having 30 teeth and a 45° pitch cone angle. Using the NTCS formula, you will find the imaginary spur gear to have 43 teeth.

$$\begin{aligned} NTCS &= NT \times \text{Sec} \angle PC \\ &= 30 \times \text{Sec} \angle 45^\circ \\ &= 30 \times 1.4142 \\ &= 42.4260 \text{ or} \\ &= 43 \end{aligned}$$

Therefore, by using a standard chart, you can determine the proper cutter for this gear to be a number 3 cutter having a 6 diametral pitch.

MILLING THE BEVEL GEAR TEETH

Mount the gear blank in the dividing head with the larger end of the blank toward the dividing head. Set the gear blank to the cutting angle by swiveling the dividing head in the vertical plane (fig. 2-15). To determine the cutting angle, subtract the dedendum angle from the pitch cone angle. The cutting angle is not the same angle as the one to which the gear blank was machined in the lathe.

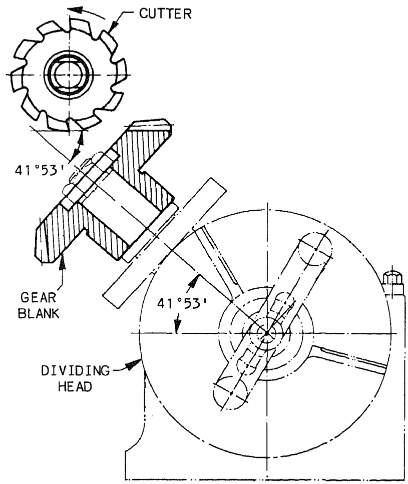


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Figure 2-15.—Bevel gear set to the cutting angle by swiveling the dividing head in the vertical plane.

Milling the bevel gear teeth involves three distinct operations. The teeth are first gashed into the gear blank, and then each side of the teeth is milled to obtain the correct tooth thickness.

In the first operation, center the blank on the selected cutter, which you have mounted on the milling machine arbor. Then bring the milling machine table up to cut the whole depth you determined for the large end of the gear. After you cut the first tooth, index the gear blank in the same manner as you would to cut a spur gear, and gash the remaining teeth.

In the second and third operations, mill the sides of the teeth that were formed in the gashing operation.

When you prepare to cut a bevel gear, remember that the only machine available to you is the milling machine. Therefore, you must take steps like offsetting the cutter (moving the milling machine table a calculated amount) and rolling the gear blank to cut the correct profile on the gear tooth. This section of the chapter will provide you information necessary to calculate the amount of offset in inches and the roll of the gear blank in degrees.

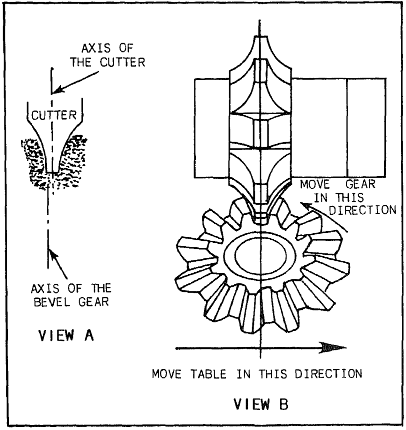

Figure 2-16.—Rolling and offsetting a bevel gear.

OFFSETTING THE CUTTER

One way to produce the correct tooth profile is by offsetting the cutter. Offset the cutter by moving it from the axis of the gear blank a calculated distance, as shown in figure 2-16, view A. Determine the distance to move the cutter by using the following formula:

$$\text{Offset} = \frac{\text{CTL}}{2} - \left(\frac{\text{CTLC} - \text{CTSC}}{2} \times \text{FWR}\right)$$

Where:

CTLC = Tooth thickness, large end
CTSC = Tooth thickness, small end
FWR = Face width ratio

ROLLING THE GEAR BLANK

After you have offset the gear blank, roll it back to the waterline of the small end of the tooth by turning the index crank (fig. 2-16, view B). The roll is always in the opposite direction of the offset. Determine the amount of roll by using the following formula:

$$\text{Roll} = \frac{57.3}{\text{PD}}\left[\frac{\text{CP}}{2} - \left(\frac{\text{PCR}}{\text{FW}} \times (\text{CTLC} - \text{CTSC})\right)\right]$$

Where:

57.3 = constant (degrees per radian)
CTLC = tooth thickness (cutter), large end
CTSC = tooth thickness (cutter) small end
CP = circular pitch
PD = pitch diameter
PCR = pitch cord radius
FW = width
and the roll is expressed in degrees.

To accomplish the roll, you must know the amount of index crank movement. The following formula was developed to aid you in determining the amount of index crank movement.

$$\text{NHR} = \frac{\text{CR} \times \text{NHC}}{9^\circ}$$

Where:

NHR = number of holes to roll
CR = calculated roll in degrees
NHC = number of holes circle to index properly
9° (express in degrees—one turn of the index crank)

Use the largest hole circle available when selecting your number of hole circles because the largest hole circle has less arc between holes.

After you have milled the bevel gear teeth completely, measure the tooth thickness of the pitch line of both the large and the small ends of the gear. These measurements should be equal to the dimensions you previously determined in your basic calculation. If they are not, check the setup and your calculations to identify your errors.

Remember, you cannot machine a perfect bevel gear in a milling machine. As you learned

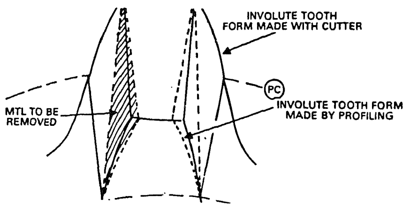

Figure 2-17.—Profiling a bevel gear.

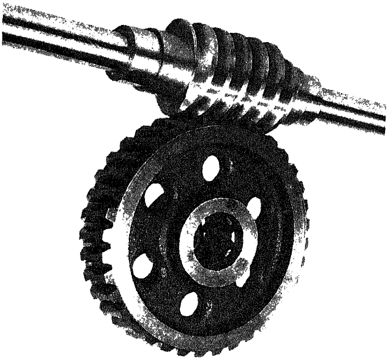

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Figure 2-18.—Worm and worm gear.

earlier, you only use part of the cutter's contour when you machine the small end of the tooth. So, to finish the bevel gear teeth properly you must file the contour as illustrated in figure 2-17. This is known to a Machinery Repairman as profiling the gear.

To file a tooth, start at the top of the large end of the tooth and gradually work to the pitch line at the small end of the tooth.

After you have determined that the gear is properly formed, give the gear a final touch by deburring it.

WORMS AND WORM GEARS

A worm gear, sometimes called a worm wheel, is a gear having teeth cut at an angle to the axis of rotation and radially in the gear face. The teeth on the worm gear are helical and conform to the helix angle of the teeth on the worm.

Worm gears are used for heavy-duty work where a large reduction of speed is required. They are used extensively in speed reducers.

A worm, sometimes called a worm thread, resembles an Acme thread. Worms can be either solid or cylinder-type mounted on a shaft. Both are installed perpendicularly to the worm gear (fig. 2-18). Worms may have single, double, or triple threads. One revolution of a worm having a single thread turns the circumference of the worm gear an amount equal to the distance

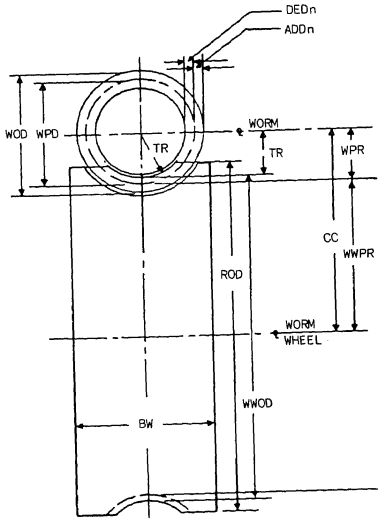
This type of gearing is also known as the "endless screw," with the worm being the driver and the worm gear being driven. Figure 2-19 identifies the parts of a worm and a worm wheel.

WORM AND WORM WHEEL NOMENCLATURE AND FORMULA DEVELOPMENT

The following are terms and formulas you will need to use when you plan and manufacture a worm and a worm wheel.

1. Linear pitch (LP)

a. The distance from a point on one thread to a corresponding point on the next thread.



WOD - WORM OUTSIDE DIAMETER
WPD - WORM PITCH DIAMETER
DEDn - DEDENDUM
ADDn - ADDENDUM
TR - THROAT RADIUS
WPR - WORM PITCH RADIUS
CC - CENTER TO CENTER DISTANCE
ROD - RIM OUTSIDE DIAMETER
WWOD - WORM WHEEL OUTSIDE DIAMETER
WWPR - WORM WHEEL PITCH RADIUS
BW - BLANK WIDTH

Figure 2-19.—Parts of a worm and worm gear.

a. The distance traveled by a thread during one complete revolution of the worm around its axis.

b. The lead and the linear pitch are the same on a single-start worm. On a double-start

c. The number of starts multiplied by the linear pitch equals the lead.

No. of S × LP = Lead

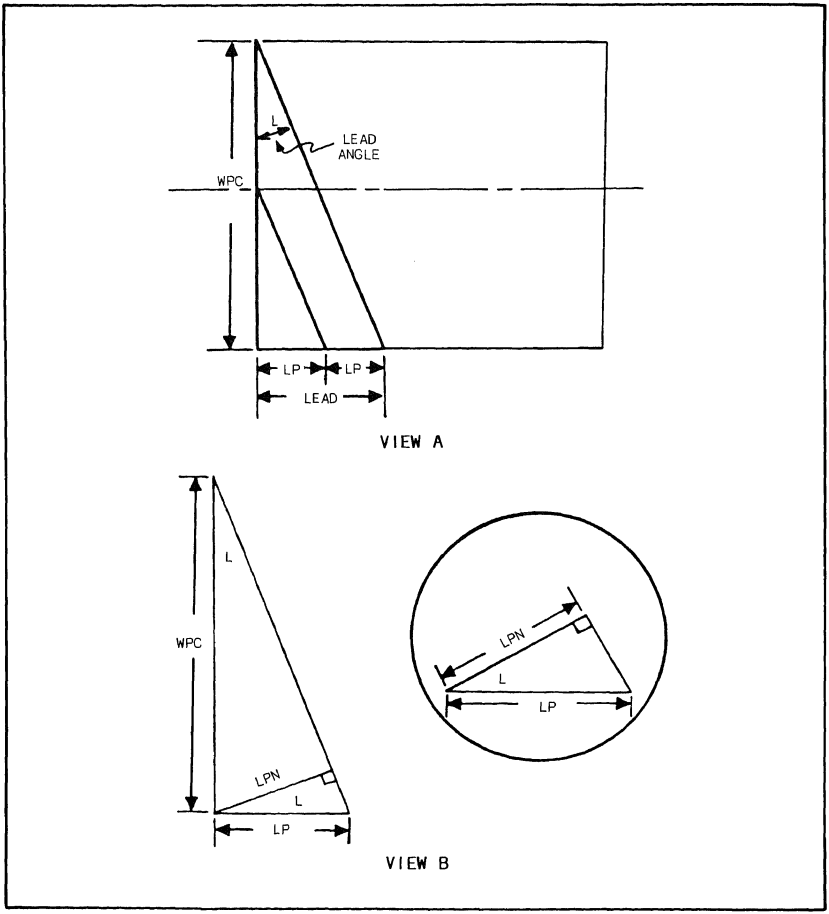


Figure 2-20.—Development of lead angle and linear pitch (normal).

d. The lead is needed to determine the proper gear train ratio for setting the table travel on the milling machine and to perform work on the lathe machine.

3. Lead angle ($\angle L$)

a. The angle formed by the thread and a line drawn at a right angle to the axis of the worm.

b. Can be obtained by dividing the lead into the worm's pitch circle. The result is the cotangent of the lead angle (fig. 2-20, view A).

Therefore: $$\text{COT } \angle L = \frac{\text{WPC}}{\text{Lead}}$$

4. Tooth dimensions

a. Linear pitch normal (LPN)

(1) Measurement of the thread (tooth) at a right angle to its face.

(2) Can be obtained by multiplying the linear pitch by the cosine of the lead angle (fig. 2-20, view B).

$$\text{LPN} = \text{LP} \times \text{COS } \angle L$$

(3) The tooth parts in worm gearing are the same as in spur gearing.

b. The following formulas are used to solve for all normal tooth dimensions.

$$\begin{aligned}
\text{Addendum normal} &= \text{LPN} \times 0.3183 \\
\text{Clearance normal} &= \text{LPN} \times 0.0637 \text{ or} \\
&= \text{ADD}_n \times 0.2 \\
\text{Dedendum normal} &= \text{LPN} \times 0.382 \\
\text{Whole depth normal} &= \text{LPN} \times 0.7 \\
\text{Circular thickness normal} &= \text{LPN} \times 0.5
\end{aligned}$$

NOTE: All worm tooth constants are derived from a worm having a 1-inch linear pitch.

5. Length of the worm (LOW)

a. Obtained by using the following formula:

$$\text{LOW} = [(\text{NT} \times 0.02) + 4.5] \times \text{LP}$$

b. The worm is longer than is required to obtain complete meshing between the worm and the worm wheel.

6. Worm wheel pitch diameter (WWPD)

a. You learned in spur gearing that for every tooth in the gear there is a circular pitch on the pitch circle, and for every tooth on the gear there is an addendum on the pitch diameter.

b. By using this theory, we can derive the following formulas:

(1) $$\begin{aligned}\text{WWPC D (real)} &= \frac{\text{NT} \times \text{CP or (LP)}}{\pi} \\ &= \text{LP} \times 0.3183 \times \text{NT}\end{aligned}$$

(2) $$\text{ADD (real)} = \text{LP} \times 0.3183$$

7. Throat diameter

a. Obtained by adding the worm wheel pitch diameter and twice the addendum normal.

$$\text{WWPD} + 2\ \text{ADD}_n = \text{Throat diameter}$$

b. Measured at the base of the throat radius.

8. Rim diameter

a. For single- and double-start worms, the rim diameter can be obtained by multiplying the linear pitch by the constant 0.4775 and adding the result of the throat diameter.

$$\text{Rim diameter} = (\text{LP} \times 0.4775) + \text{Throat diameter}$$

b. For 3 or more starts, the rim diameter can be obtained by multiplying the linear pitch by the constant 0.3183 and adding the result to the throat diameter.

$$\text{Rim diameter} = (\text{LP} \times 0.3183) + \text{Throat diameter}$$

9. Throat radius

a. Obtained by subtracting one addendum (normal) from the pitch radius of the worm.

$$\text{Throat radius} = \text{pitch diameter (worm)} - 1\ \text{ADD}_n$$

b. This dimension is taken from the worm but is machined on the worm wheel blank.

10. Blank width

a. For single- and double-start worms, the blank width can be obtained by multiplying the linear pitch by the constant 2.38 and adding the result to the constant 0.250.

$$\text{Blank width} = (\text{LP} \times 2.38) + 0.250$$

b. For 3 and more starts, the blank width can be obtained by multiplying the linear pitch by the constant 2.15 and adding the result to the constant 0.20.

$$\text{Blank width (for 3 or more starts)} = \text{LP} \times 2.15 + 0.20$$

worm. The linear pitch and the circular pitch are of equal value.

12. Number of teeth (NT)—The number of teeth in worm gearing is obtained by multiplying the number of starts by the ratio of the worm to the worm wheel.

Number of teeth (NT) = No. of starts × ratio of the worm to the worm wheel.

SELECTING A WORM WHEEL CUTTER

When you machine the throat radius of a worm wheel, select a two or four lip end mill with a radius smaller than the calculated throat radius, because as the cutter is swiveled from its vertical

As you swivel the cutter to a predeterm angle to cut the calculated throat ra you will form a right triangle (fig. 2 By using this triangle, you can obtain the de radius.

Desired radius = Cutter radius × cosec

Where:

∠V = Angle at which the throat radi cut.

To determine the depth of cut, subtract the th diameter from the rim diameter and divide by

$$\text{Depth of cut} = \frac{\text{Rim diameter} - \text{Throat dia}}{2}$$

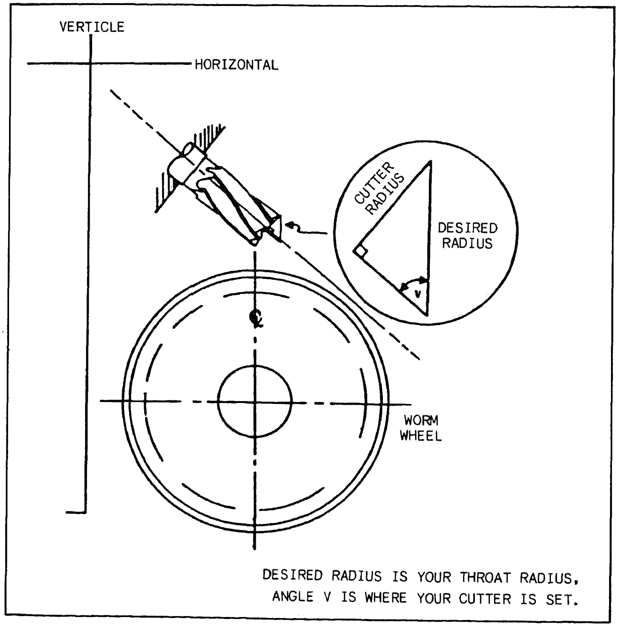


Figure 2-21.—Formulation of desired radius.

CENTER-TO-CENTER DISTANCE (WORM AND WORM WHEEL)

As with other systems of gearing that you have previously studied, worm gearing is designed to transfer motion between two planes at a fix ratio. The majority of spur and helical gears have adjustments for the center-to-center distance and for backlash. In worm gearing, the center-to-center distance between the worm (driven) is of prime importance since worm gearing systems are designed to transfer as much power as possible in the smallest practical space.

This section of the chapter will provide you with information necessary to manufacture a worm and a worm wheel using the center-to-center distance and the ratio between the worm (driver) and the worm wheel (driven).

To obtain the center-to-center distance of a worm and a worm wheel, add the worm pitch radius and the worm wheel pitch radius.

$$\text{C-C} = \text{WPR} + \text{WWPR, or}$$

$$\text{C-C} = \frac{\text{WPD} + \text{WWPD}}{2}$$

WORM WHEEL HOBS

A hob is a cylindrical worm converted into a cutting tool. Hobs resemble worms in appearance and are ideal for cutting a worm wheel. The hob's teeth are cut on the outside of a cylinder following a helical path corresponding to the thread line of a worm. The cutting edges of the hob are formed when flutes are cut into the worm. For small lead angles, flutes are cut parallel to the axis; while for large lead angles (6° and above), flutes are cut helically at a right angle to the thread line of the worm.

As a general rule, there should not be a common factor between the number of starts and the number of flutes. Even numbers of starts (6, 8, or 10) should have odd number of flutes (7 or 11).

You can usually find the approximate number of gashes (flutes) by multiplying the diameter of the hob by 3 and dividing this product by twice the linear pitch.

$$\text{Number of flutes} = \frac{3 \times \text{hob's OD}}{2 \times \text{LP}}$$

There are, however, certain modifications that you may have to make. The number of gashes (flutes) has a relationship to the number of threads in the hob and to the number of teeth in the worm gear. Try to avoid a common factor between the number of threads and the number of gashes. For example, if the worm is a double-thread worm, the number of gashes should be 7 or 9 rather than 8. If the worm is a triple-thread worm, select 7 or 11 gashes rather than 6 or 9, as both 6 and 9 have a factor in common with 3.

It is also best to avoid having a common factor between the number of threads in the hob and the number of teeth in the worm gear. For example, if the number of teeth is 28, a triple thread would be satisfactory since 3 is not a factor of 28.

The cutter you select for gashing the hob should be 1/8 to 1/4 inch thick at the periphery, depending on the pitch of the hob thread. The width of the gash at the periphery of the hob should be about 0.4 times the pitch of the flutes. The depth of the gash should be about 3/16 to 1/4 inch below the root of the thread.

Types of Hobs

The three types of hobs are as follows:

1. Shell—has a straight bore with a keyway to hold the arbor that drives the hob.
2. Straight shank—is the integral part of the shaft. It is used between centers.
3. Tapered shank—has a milling machine taper (Brown and Sharpe). The outside end is supported by either a line or a dead center.

Hob Nomenclature

Since the hob is a cutting tool, the top of the tooth on the hob is a dedendum. The bottom of the hob tooth forms the top of the worm wheel tooth and must be provided with a clearance. Therefore, it also equals a dedendum of the gear you are cutting. The working depth of the hob (cutting portion) is the addendum plus the dedendum of the gear you are cutting.

The following nomenclature of the hob is the same as that of the worm:

Chordal thickness (normal), linear pitch, lead, pressure angle, and the pitch diameter. The outside diameter of the hob has two clearances, and both are larger than the worm's outside diameter:

$$\text{WPD} + 2\ \text{DED}$$

Hobs can be ordered through the supply system or bought commercially, as well as made by a machinist. If you order a hob, furnish drawings or blueprints of both the worm and the worm wheel and any information such as bore size for the shell type hob in order to get the right hob.

CUTTING WORM WHEEL TEETH ON A MILLING MACHINE

The teeth of a worm gear may be cut on a milling machine. Usually, two operations are necessary. The first is called gashing the teeth (fig. 2-22, view A). Seat an involute spur-gear cutter of the correct pitch and number according to the number of teeth and pitch of the worm gear. The gashing operation requires that the milling machine table be set at an angle equal to the lead or helix angle of the worm thread. Be sure to center the gear blank under the cutter. Perform the gashing operation by raising the table a distance equal to the whole depth of the tooth. You can obtain uniformity of depth for each tooth by using the graduated vertical feed dial. Index each tooth, using the dividing head with a dog clamped to the mandrel to drive the gear blank.

The second operation for finishing the gear teeth is called hobbing (fig. 2-22, view B). First, mount the hob on a cutter arbor. Then set the table back to zero, or at a right angle to the machine spindle. Remove the dog so the gear blank can rotate freely. Line up the gear blank so the hob meshes with the gashed slots. When you start the machine, the rotating hob will rotate the gear blank. As the hob and gear blank rotate, raise the table gradually until the teeth are cut to the correct depth. Use the worm to be used with the worm gear to obtain the correct center-to-center distance before you remove the worm gear from the milling machine.

STUB TOOTH GEARS

Stub tooth gears are widely used throughout the automotive industry in transmissions because their great strength enables them to transmit maximum power. Cranes and rock crushers are examples of high-torque equipment that use stub tooth gears. This type of gear has a 20-degree pressure angle and is short and thick. A stub tooth gear compared to other gears has a shorter addendum (ADD). This results in a stronger tooth, but causes the gears to operate with more noise.

Stub tooth gears come in two forms. One form has straight teeth, like spur gears. The other form has teeth similar to those on helical gears. Gears with helically shaped teeth are used when smooth operation is required.

The basic rule you should learn for spur, helical, and bevel gears is that the statement "for every tooth on the gear, there is a circular pitch (CP) on the pitch circle" also applies to stub tooth gearing systems.

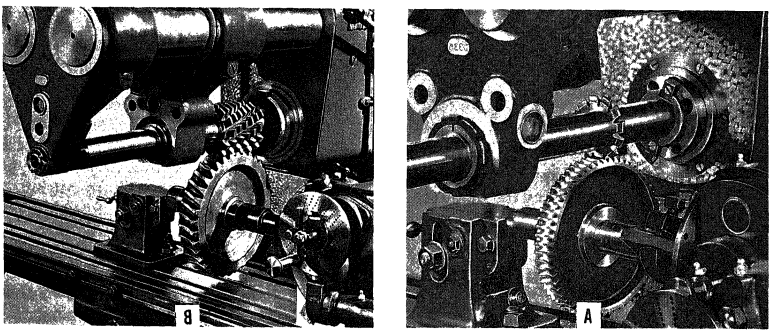


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Figure 2-22.—Milling machine set up for gashing and hobbing of a worm gear teeth.

We will discuss three stub tooth gearing systems: The American Standard System, the Fellows Stub Tooth Gears System, and the Nuttals Stub Tooth System.

AMERICAN STANDARD SYSTEM

This system bases tooth dimensions on specific formulas:

1. The tooth depth or whole depth (WD) equals 1.8 divided by the diametral pitch (DP).

$$WD = \frac{1.8}{DP}$$

2. To find the outside diameter (OD), add 1.6 to the number of teeth and then divide by the diametral pitch (DP).

$$OD = \frac{NT + 1.6}{DP}$$

3. To find the addendum, divide 0.8 by the diametral pitch.

$$ADD = \frac{0.8}{DP}$$

4. To find the clearance, divide 0.2 by the diameter pitch.

$$CL = \frac{0.2}{DP}$$

5. When the addendum (ADD) is added to the clearance (CL) the result is the dedendum (DED).

$$DED = ADD + CL$$

6. All circular measurements of a stub tooth gear, including the number of teeth and the pitch diameter, are the same as those of a spur gear. To obtain the pitch diameter, simply divide the number of teeth (NT) by the diametral pitch (DP).

$$PD = \frac{NT}{DP}$$

7. To get the circular pitch (CP), divide π (3.1416) by the diametral pitch (DP).

$$CP = \frac{3.1416}{DP}$$

8. To get the circular thickness, divide 1.5708 by the diametral pitch (DP).

$$CT = \frac{1.5708}{DP}$$

FELLOWS STUB TOOTH GEARS

This system was introduced by the Fellows Stub Tooth Gear Company. The system uses a 20-degree pressure angle and is based on the use of two diametral pitches (DP). In the formulas we will use, the numerator (DPL) is the circular measurement, which consists of the pitch diameter (PD) and the number of teeth (NT). The denominator (DPS) is the radial measurement.

There are eight standard pitches in this system. They are 4/5, 5/7, 6/8, 7/9, 8/10, 9/11, 10/12, and 12/14.

The formulas for the basic dimensions are as follows:

1. Addendum (ADD) $= \frac{1}{DPS}$

2. Outside diameter (OD) $= \frac{NT}{DPL} + \frac{2}{DPS}$

3. Whole depth (WD) $= \frac{2.25}{DPS}$

4. Clearance (CL) $=$ WD $-$ 2 ADD

5. Dedendum (DED) $=$ ADD $+$ CL

6. Circular pitch (CP) $= \frac{3.1416}{DPL}$

7. Circular thickness $= \frac{1.5708}{DPL}$

8. Number of teeth (NT) $=$ DPL $\times$ PD

9. Diametral pitch

9. a. $TPL = \dfrac{NT}{OD - \left(\frac{2}{DPS}\right)}$

b. $DPS = \dfrac{NT}{OD - \left(\frac{NT}{DPL}\right)}$

Remember, all radial teeth dimensions are based on circular pitch (CP) times a constant.

1. ADD = 0.250 × CP
2. DED = 0.300 × CP
3. CL = 0.050 × CP
4. WD = 0.550 × CP

On the other hand, circular measurements are derived using standard spur or helical gear formulas, i.e., PD, NT, CP, and CT.

5. Outside diameter (OD) = PD + 2 ADD
6. Diameter pitch (DP) = $\frac{3.1416}{CP}$

METHOD OF MANUFACTURE

The procedure for manufacturing a straight or helical stub tooth gear is the same as that for spur and helical gearing when you use a stub tooth gear cutter that is bought commercially. Fly cutting is one method for cutting the gear. When you use this method, grind a single-point tool bit to the desired shape by using the old gear as a pattern.

A properly fitted gear must have a setover and a depth increase, which you should calculate after you have selected a cutter. The only way to select a cutter is by sight. Obtain a large selection of bevel gear cutters. Then match a bevel gear cutter to the side of a good tooth.

To find the amount of setover, first establish the circular pitch angle ($\angle CP$). One circular pitch equals 360°. Therefore, dividing 360° (one circular pitch) by the number of teeth (NT) will give you the circular pitch angle ($\angle CP$). You can solve for the amount of setover by using the triangle in figure 2-23, view A.

$$\text{Setover} = \text{Root radius} \times \text{Tan } \angle CP$$

Where the root radius is the outside diameter (OD) divided by 2 minus the whole depth (WD).

$$\text{Root radius} = \frac{OD}{2} - WD$$

To find the amount of depth increase set up the triangle shown in figure 2-23, view B. In this multiplied by the cosine of the circular pitch angle ($\angle CP$).

$$\text{Side X} = \text{Root radius} \times \text{Cos } \angle CP$$

To determine the depth increase, subtract side x from the root radius: Depth increase = Root radius − Side X. The cutting procedure is as follows:

1. Center the cutter on the gear blank.
2. Offset the calculated setover away from the column. The direction of the offset is optional.
3. Move the cutter down to the whole depth of the tooth, plus the calculated amount of depth increase in increments to suit the machine and the setup. Cut the teeth all the way around the blank until one side of the tooth is complete.
4. Move the cutter back to the center line and offset toward the column face the calculated amount of setover. Cut to the full depth of the tooth plus the amount of depth increase. At this time, your stub tooth gear is ready to be deburred.

SPLINES

A splined shaft has a series of parallel keys formed integrally with the shaft that mate with corresponding grooves cut in a hub or fitting; this is in contrast to a hub or fitting having a series of keys or feathers fitted into slots cut into the shaft. This latter construction weakens the shaft to a considerable degree because of the slots cut into it and, as a consequence, reduces its torque-transmitting capacity.

Splined shafts are most generally used in three types of applications: (1) for coupling shafts when relatively heavy torques are to be transmitted without slippage; (2) for transmitting power to sliding or permanently fixed gears, pulleys, and other rotating members; and (3) for attaching parts that may require removal for indexing or change in angular position.

Splines having straight-sided teeth have been used in many applications; however, the use of splines with involute teeth has increased steadily. Splines with involute teeth are becoming more popular because (1) involute spline couplings have greater torque-transmitting capacity than any

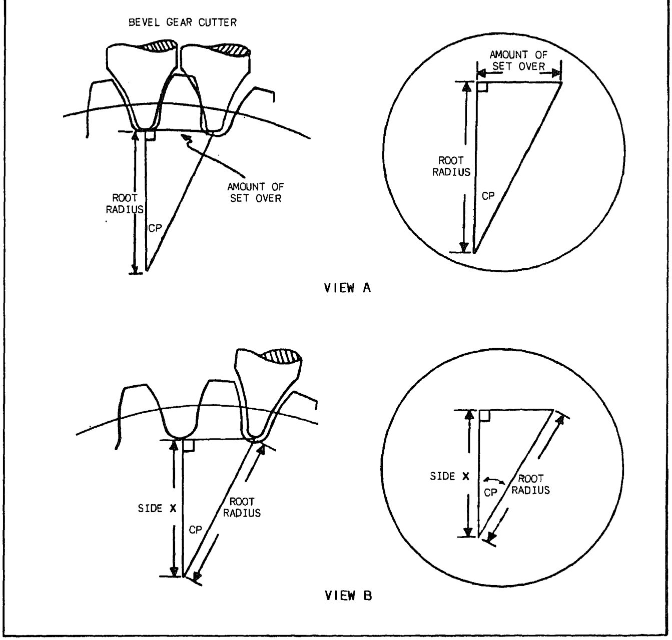

Figure 2-23.—Development of set-over and depth increase.

other type; (2) they can be produced by the same techniques and equipment used to cut gears; and (3) they have a self-centering action under load, even when there is backlash between mating members.

These splines or multiple keys are similar in form to internal and external involute gears. The general practice is to form external splines by hobbing, rolling, or on a gear shaper, and internal splines either by broaching or on a vertical shaper. The internal spline is held to basic dimensions, and the external spline is varied to control the fit. Involute splines have maximum strength at the base; they can be accurately spaced and are self-centering, thus equalizing the bearing and stresses; and they can be measured and fitted accurately.

TOOTH NUMBERS

The American National Standard covers involute splines having tooth numbers ranging from 6 to 60 with a 30 or 37.5-degree pressure angle and from 6 to 100 with a 45-degree pressure angle. In selecting the number of teeth for a given spline application, keep in mind that there are no advantages to be gained by using odd numbers of teeth and that the diameters of splines with odd tooth numbers, particularly internal splines, are troublesome to measure with pins since no two spaces are diametrically opposite each other.

SPROCKETS

Webster's dictionary defines a sprocket wheel as "a wheel with cogs or sprockets to engage with

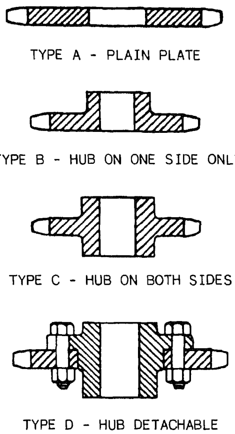

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Figure 2-24.—Types of sprockets.

the links of a chain." Most sprockets are of one of the four types shown in figure 2-24. The following is a discussion of the classes and the manufacture of sprocket wheels (simply referred to as sprockets). Should you desire a more in-depth study of sprockets, refer to ANSI B29.1 (American National Standard) and to *Machinery's Handbook*.

CLASSES OF SPROCKETS

The ANSI B29.1 (American National Standard) provides two classes of sprockets, commercial and precision. The use of commercial or precision sprockets is a matter of drive application judgment. The usual moderate to slow speed commercial drive is adequately served by commercial sprockets. Where a combination of extremely high speed and high load is involved, or where the drive involves fixed centers, critical timing, or register problems, or close clearance with outside interference, the use of precision sprockets may be more appropriate.

MATERIAL FOR SPROCKETS

For large sprockets, cast iron is commonly used, especially in drives with large speed ratios, since the teeth of the larger sprockets are subjected to fewer chain engagements in a given time. For severe service, cast steel or steel plate is preferred.

The smaller sprockets of a drive are usually made of steel. With this material, the body of the sprocket can be heat-treated to produce toughness for shock resistance, and the tooth surfaces can be hardened to resist wear.

Stainless steel or bronze may be used for corrosion resistance, and formica, nylon, or other suitable plastic materials for special applications.

MANUFACTURE OF SPROCKETS

Cast sprockets have cut teeth, and the rim, hub face, and bore are machined. The smaller sprockets are generally cut from steel bar stock and are finished all over. Sprockets are often made from forgings or forged bars. The extent of finishing depends on the particular specifications that are applicable. Many sprockets are made by welding a steel hub to a steel plate. This process produces a one-piece sprocket of desired proportions and one that can be heat-treated.

CHAPTER 3

GRINDING INSPECTIONS

Grinding inspections are conducted for two primary purposes: (1) to identify injury to ground surfaces and (2) to evaluate surface finishes. You as a machinist, must know the surface finish symbols used in grinding. you will also have to interpret the surface quality specifications indicated on drawings and blueprints. General information on grinding wheels, grinding machines, and the principles of grinding operations are provided in *Machinery Repairman 3 & 2*, NAVEDTRA 10530.

As an MR1, you will be required to inspect, or to supervise the performance of, grinding or grinding-related operations. These operations include the repair of valves in place, miscellaneous portable grinding, and various inspections for detecting injuries to ground surfaces.

INJURY TO GROUND SURFACES

A metal surface may be injured during the grinding operation in several ways; it may be cracked, burned, or left in a highly stressed condition. There are other undesirable effects that may result from grinding; however, they are not necessarily injurious. Effects of grinding are injurious only if they render a piece useless or if they shorten the useful life of the piece.

SURFACE BURNS

The most common injury to a ground surface is burning. Burn marks are an indication that high surface temperatures were reached during the grinding operation. This may leave the surface of the piece in a highly stressed condition that could result in failure of the piece during service. Hardened steel tools, such as milling cutters or tool bits, may soften due to burning, resulting in tool failure or premature dulling of the cutting edge. Severe burning may also cause softening and almost simultaneous re-hardening, resulting in an extremely hard and brittle surface.

Burn marks can be removed from the surface of a part; however, this does not remove the effects of the burn. If, after removing burn marks, you apply a solution of nital (nitric acid and ethyl alcohol) to the area of the burn, the surface of the burned area will darken. This experiment shows that removal of the burn marks will not eliminate the effects of the burn on the temper of the material.

Mild burning that does not penetrate deeply usually does no real harm. Even on tool bits or cutters, a slight discoloration may not affect the tool's life or its cutting efficiency. No specific rules are written concerning whether or not a burn is harmful. Therefore, to eliminate the possibility of injury from burning, select the correct wheel for the job, keep it sharp and free-cutting, avoid too severe a grinding action, and where possible, use a cutting fluid to carry off heat generated during grinding.

GRINDING CRACKS

A less common, but generally much more serious, form of injury encountered in grinding operations is cracking. A very slight crack, upon being subjected to the high pressures generated during operating conditions, may enlarge and become an extremely weak area; so you must avoid causing even the smallest cracks.

Not all cracks found in a ground surface are a result of the grinding operation. Some of these cracks may be the result of heat treatment. These heat treatment cracks are usually long and deep. Generally, grinding cracks (or checks) are short and shallow. Their pattern is similar to the pattern of the grain marks left by the grinding wheel. You should attempt to find heat treatment cracks prior to the grinding operation. You can do this by using the methods described later in this chapter.

SURFACE STRESSES

In the majority of applications, surface stresses have no effect on the life or the usefulness of a ground part. There are, however, some instances where surface stress may cause the part to fail prematurely or where it might cause cracks to develop because of the stressed condition. You can lessen the possibility of surface stress considerably by using the correct wheel and by avoiding too severe a grinding action.

METHODS OF DETECTION

There are a number of nondestructive inspection tests that may be used in detecting cracks in metal. These tests include visual inspection, magnetic particle inspection, and liquid penetrant inspection. Some of these tests and inspections are used throughout the Navy. Note, however, that for all critical work, final acceptance or rejection should only be made by a qualified nondestructive inspector, if one is available.

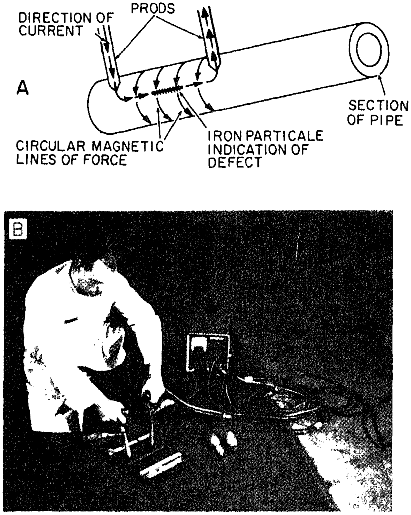
VISUAL INSPECTION

Visual inspection is useful for detecting large cracks only. Even with the use of a powerful magnifying glass there may be cracks that cannot be detected, even by an experienced inspector. If, during visual inspection, you find any imperfections that may be cracks, you should follow up with one of the more positive methods of detecting injuries. Two of these methods are the magnetic particle inspection and the liquid penetrant inspection.

MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection can be used to detect weld defects in metals or alloys in which magnetism can be induced. While the test piece is magnetized, finely divided iron powder is applied to it. As long as the magnetic field is not disturbed, the iron particles will form a regular pattern on the surface of the test piece. If the magnetic field is disturbed by a crack or some other defect in the metal, the pattern is interrupted and the particles cluster around the defect.

The test piece may be magnetized either by having an electric current pass through it (fig. 3-1), or by having an electric current pass through a coil of wire that surrounds the test piece (fig. 3-2).



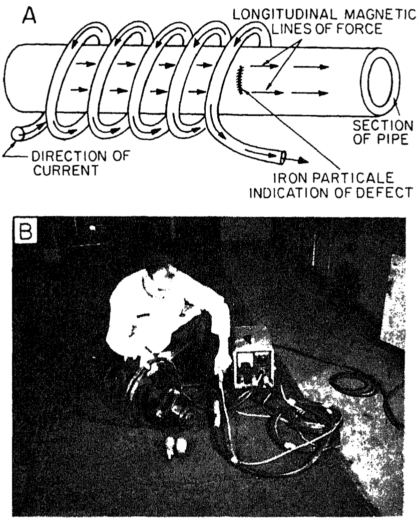
18.80.1

Figure 3-1.—Circular magnetization—prod method.

In order for a defect to show up as a disturbance in the patterns of the iron particles, the direction of the magnetic field must be nearly at a right angle to the major axis of the defect. Since the orientation of the defect is unknown, different current directions must be used during the test. When an electric current flows in a straight line from one contact point to the other (fig. 3-1, view A), magnetic lines of force are formed in a circular direction. This circular magnetism is used to locate lengthwise cracks. When the current flow is through a coil around the test piece (fig. 3-2, view A), longitudinal magnetic lines of force are induced through the tèst piece to locate transverse cracks.

In general, magnetic particle inspection is satisfactory for detecting surface cracks and cracks that are not more than 1/4 inch below the surface.

The type of magnetic particle inspection unit most commonly used in the Navy is the portable unit shown in figures 3-1 and 3-2. It is a high-amperage, low-voltage unit having a maximum magnetizing current output of 1000 amperes, either alternating or direct current. It is ready to



18.80.2

Figure 3-2.—Longitudinal magnetization—coil method.

operate when it is plugged into the voltage supply specified by the manufacturer. The unit consists of a magnetizing current source, controls, indicating meters, three 10-foot lengths of flexible cable for carrying the current to the test piece, and a prod kit. The prod kit includes an insulated prod grip fitted with an ON-OFF relay or current control switch, a pair of heavy copper contact prods, and two 5-foot lengths of flexible cable. Cable fittings are designed so that either end of any cable may be fitted to the unit, to the prods, or to any other cable. The unit has three outlets on the front panel for the operator to use in selecting either alternating current or direct current. The outlet on the left is labeled A.C., the center is COMMON, and the right is D.C. One cable will always be plugged into the COMMON outlet, with the other cable plugged into the A.C. or D.C. outlet, as required. For most work, alternating current magnetization effectively locates fatigue cracks and similar subsurface defects extending to the surface. When more sensitive inspection is required to detect defects below the surface, direct current is used.

The unit can be used in either of two ways: (1) with prods, attached to the flexible cable, used as contacts through which current is passed into and out of a portion of the test piece, setting up circular magnetization between the prod contact points, or (2) with flexible cable wrapped around the work to form a coil which induces longitudinal magnetism in the part of the workpiece that is surrounded by the coiled cable.

Although either of these two methods may be used, the prod test is usually easier to apply. In most instances, it effectively serves to detect surface defects. With the prods, however, only a relatively small area of the test piece can be magnetized at any one time. This magnetized area is limited to the distance between prod contact points and to a few inches on each side of the current path. To check the entire surface, it is necessary to successively test adjacent areas by changing the location of the prod contact points after a given area has been tested. Each area of the test piece must be inspected twice— once with the current passing through the metal in one direction and once with the current passing through the metal in a direction at right angles to the direction of the first test. One of the advantages of the prod method of magnetic particle inspection is that the current can be easily passed through the metal in any desired direction. Thus, if a given area is suspected of being defective, magnetic fields of various orientations can be established during the test.

To use the prod method, adjust the unit for a current output suitable for the particular metal you wish to test. The amperage setting depends on the distance between prod contact points. If you use the prod kit supplied with the unit, set the space between the prod contact points at 4 to 6 inches. For this space, select a current setting between 300 and 400 amperes if the material you will test is less than 3/4 inch thick. If the material is 3/4 inch thick or greater, use 400 to 600 amperes. To obtain the same magnetic field force, less amperage is required if the prod contact points are closer together. With prods constantly at the same spacing, a greater amperage will induce a stronger field.

After adjusting the unit, place the prods in position. Hold them in firm contact with the metal and turn on the current. Then, apply magnetic particles to the test area with the duster bulb and observe any indicator patterns. With the current still on, remove the excess particles from the test area with a blower bulb and complete the inspection. Do not move the prods until after the

the current to arc, resulting in a flash similar to that occurring in arc welding.

Through the use of magnetic particle inspection, hairline cracks that are otherwise invisible are readily detected, since the particles form an unmistakable outline of the defect. Large voids beneath the surface are more easily detected than small voids, but any defect below the surface is more difficult to detect than one that extends to the surface. Since false indications occur frequently, you must be able to accurately interpret the particle indications you observe.

Factors that can help you interpret the test results include the amount of magnetizing current applied, the shape of the indication, the sharpness of the outline, the width of the pattern, and the height or buildup of the particles. Although these characteristics do not determine the seriousness of the indication, they can help you identify the kind of defect indicated.

The indication of a crack is a sharp, well-defined pattern of magnetic particles having a definite buildup. This indication is produced by a relatively low magnetizing current. Seams are revealed by a straight, sharp, fine indication. The buildup of particles is relatively weak, and the magnetizing current must be higher than that required to detect cracks. Small porosity and rounded indications or similar defects are difficult for the inexperienced inspector to detect. A high magnetizing current continuously applied is usually required. The particle patterns for these defects are fuzzy in outline and have a medium buildup.

Whether or not an indicated defect is to be chipped or ground out and repaired by welding depends on the specifications governing the job. Surface cracks are always removed and repaired. You should evaluate all indications of subsurface defects detected by magnetic particle inspection. If you believe the indication is positive, it is usually best to grind or chip down to solid metal and make the repair. Until you have had considerable experience and can differentiate accurately between true and false indications, you should restrict your application of magnetic particle inspection to the detection of surface defects. For this application, magnetic particle inspection is almost foolproof.

After indicated defects have been repaired, reinspect the areas to ensure that the repair is sound. The final step in magnetic particle inspection is to demagnetize the workpiece. This is especially important when the workpiece is made when direct current has been used to induce the magnetic field. It is not as necessary when alternating current has been used in the test. In fact, the usual demagnetization procedure involves placing the workpiece in an ac coil or solenoid and slowly withdrawing it while the current passes through the coil.

Demagnetization can be done with the portable unit, if a special demagnetizer is not available. To demagnetize with the portable unit, form a coil or flexible cable around the workpiece. Be sure the cable is plugged into the unit's A.C. outlet. Set the current regulator to deliver a current identical to that used for the inspection, and turn on the unit. Then gradually decrease the amperage until the ammeter indicates zero. If the piece is large, it may be necessary to demagnetize a small portion of the work at a time.

You may check for the presence of a magnetic field (and thus the need for demagnetization) by using a small compass. A deviation of the needle from its normal position when the compass is held near the workpiece is an indication that a magnetic field is present.

LIQUID PENETRANT INSPECTION

Liquid penetrant inspection is used to inspect metals for surface defects similar to those revealed by magnetic particle inspection. Unlike magnetic particle inspection, which can reveal subsurface defects, liquid penetrant inspection reveals only those defects that are open to the surface. In general, the only metals that are inspected by liquid penetrant methods are nonferrous metals and nonmagnetic steels.

Four groups of liquid penetrants are used. Group I consists of nonwater-washable dye penetrants. Group II consists of water-washable dye penetrants. Groups III and IV consist of fluorescent penetrants. Always follow the appropriate MIL-STD-271 document whenever you perform liquid penetrant tests. Follow the directions prescribed for each penetrant carefully, since there are some differences in procedure and some differences in safety precautions associated with the various penetrants.

Before using a liquid penetrant to inspect a weld, remove all slag from the surface. Except where a specific finish is required, it is not necessary to grind the weld surface as long as the weld surface meets applicable specifications and as long as the weld contour blends into the base metals without undercutting. If a specific finish is required, you MAY make a liquid penetrant inspection before the surface is finished to detect defects that extend beyond the final dimensions; but you MUST make a final liquid penetrant inspection AFTER the surface is finished.

Before using a liquid penetrant, clean the surface of the material—including areas adjacent to the inspection area—very carefully. You can clean the surface by swabbing it with a clean, lint-free cloth saturated in a nonvolatile solvent, or by dipping the entire piece into a solvent. After you have cleaned the surface, remove all traces of the cleaning materials. It is extremely important that you remove all dirt, grease, scale, lint, salts, or other material, and make sure that the surface is entirely dry before you use the liquid penetrant.

You MUST maintain the temperature of the liquid penetrant and of the piece to be inspected in the temperature range of 50° to 100°F. Do NOT attempt to use liquid penetrant if you cannot maintain this temperature range. Do NOT use an open flame to increase the temperature, since the liquid penetrant materials are flammable.

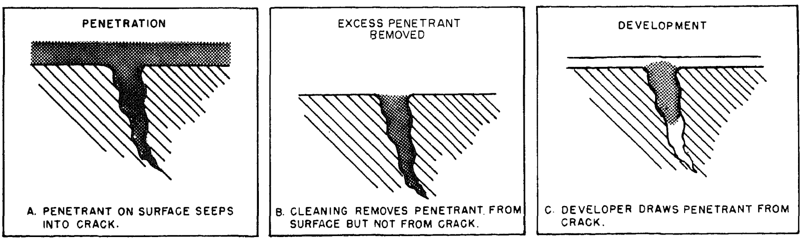
After thoroughly cleaning and drying the surface, coat the surface with the liquid penetrant. You may spray or brush the penetrant on the piece, or you may immerse the entire piece in the penetrant. In order to allow time for the penetrant to get into all cracks, crevices, or other defects that are open to the surface, keep the surface of the piece wet with the penetrant for a minimum of either 15 minutes or 30 minutes, depending upon the group of penetrants you use. Follow the instructions prescribed by the appropriate MIL-STD-271 document concerning the length of time the surface must be kept wet.

After keeping the surface wet with the penetrant for the required length of time, remove the excess penetrant from the surface with a clean, dry cloth or absorbent paper towel. Then, dampen a clean, lint-free cloth or absorbent paper towel with penetrant remover and wipe the remaining excess penetrant from the test surface. Dry the test surfaces after removing the excess penetrant only by normal evaporation or with the clean, lint-free cloth or absorbent paper towel mentioned above. In drying the surface, be very careful to avoid contaminating the surface with oil, lint, dust, or other materials that would interfere with the inspection.

After the surface has dried, apply the "developer." The developer (powder or liquid) must stay on the surface for a minimum of 7 minutes before you start the inspection, but it should not remain on the surface for more than 30 minutes, thus allowing you a total of 23 minutes to evaluate the indications.

Let's stop and go back for a moment and examine what takes place when these penetrant materials are applied. First, the penetrant, normally red in color, applied to the surface of the material will seep into any passageway open to the surface (fig. 3-3, view A). Next, the excess penetrant is removed from the surface of the metal with the penetrant remover and a lint-free absorbent material. Only the penetrant on top of the metal surface is removed (fig. 3-3, view B), leaving the penetrant that has seeped into the defect.

Finally, the white developer is applied to the surface of the metal (fig. 3-3, view C). The developer, an absorbing material, will actually draw the penetrant from the defect. Therefore, the red penetrant in the white developer indicates



A. PENETRANT ON SURFACE SEEPS INTO CRACK.

B. CLEANING REMOVES PENETRANT FROM SURFACE BUT NOT FROM CRACK.

C. DEVELOPER DRAWS PENETRANT FROM CRACK.

Courtesy of MAGNAFLUX Corporation.

the defective area(s). The amount of red penetrant drawn from the defective area(s) will give an indication of the size and, sometimes, the type of defect.

When dye penetrants are used, the lighting in the test area must be bright enough so that you can see any indications of defects shown on the test surface.

Be sure to interpret and evaluate carefully the indications you observe during a liquid penetrant inspection. In almost any inspection, some insignificant indications are present. Most of these insignificant indications are caused by failure to remove all excess penetrant from the surface. At least 10 percent of all indications must be removed from the surface to determine whether defects are actually present or whether the indications are merely caused by excess penetrant. If a second liquid penetrant inspection does not reveal indications in the same locations, you may usually assume that the first indications were not really indications of defects.

Remove all penetrant inspection materials as soon as possible after you make the final inspection. Use water or solvent, as appropriate.

A number of safety precautions are associated with liquid penetrant materials. Since the materials are flammable, they must not be used near open flames and they must not be applied to any surface that is at a temperature higher than 100°F. In addition to being flammable, many of the solvents are poisonous in the vapor form and are highly irritating to the skin in the liquid form. Handle all penetrant inspection materials with due regard for their hazardous nature.

SURFACE FINISHES AND MEASUREMENT

The smoothness of a machined surface has always been of concern to the machinist. Serious consideration was given to surface smoothness wherever two machined surfaces came in contact with each other—for example, in a set of dies.

Prior to the development of a means to measure surface roughness accurately, machined surfaces in contact with each other had to be broken in before they could operate at full efficiency. When observed through a microscope, a seemingly smooth machined surface appeared as a series of hills and valleys. When two surfaces, such as a shaft and a sleeve or a shaft and a bearing, were fitted together, they fitted to a close tolerance. After a short period of running time, the ridges wore off of each surface, resulting in excess clearance. The machinery had to be stopped so the surfaces could be adjusted to compensate for the wearing in of the ridges.

Developments in machining operations brought smoother finished surfaces but did not eliminate the problem of surface roughness. The automobile industry conducted extensive research programs to discover methods for achieving smoother surface finish. Machining techniques were modified to reduce the breaking-in time of the new automobile engine. Owners were advised to drive new automobiles only at slow speeds for the first 500 miles so that the bore of the engine's cylinders could be worn to a smooth finish. Engines and bearings had to be overhauled or replaced after a few thousand miles because of reduced efficiency. The only method for determining the quality of a finished surface was to note the amount of resistance given by the ridges when a thumbnail edge was scraped across a machined section. Machine operations and engineers alike used this "method." Great strides had been made in developing accuracy in measurement, but nothing had been done in the field of measuring surface roughness up to this time.

The SKF Ball Bearing Company engaged the services of E. J. Abbott, who in 1936 perfected an instrument that could accurately measure the irregularities on a machined surface. He called the instrument a profilometer. Abbotts' contribution led to continuous improvement in the methods and techniques of obtaining surfaces that are almost free of any irregularities. Since that time other instruments have been developed to measure surface roughness.

Every machining process leaves its peculiar markings on the machined surface. Each type of cutting tool leaves its own individual pattern of finely spaced irregularities which can be identified easily by the experienced machinist. This pattern is known as surface finish, or surface roughness. Every machined surface is composed of tiny ridges or hills and valleys (or bumps and dents). Whether the surface is the result of turning, milling, shaping, grinding, honing, or polishing can be determined by close investigation. Surface finish is important because improper surface characteristics can make a workpiece unsuitable for some kinds of work.

Surface irregularities are directly related to the quality of the machining operation. It is well known that this quality depends, in large measure, upon the correct grinding of the cutting tool—correct clearance, rake, and cutting angle. Surface irregularities are also caused as the chip is forced from the work by the cleaving action of the cutting tool. The shape of the job can also have a contributing effect, for the vibrations of both the job and the cutting tool leave their marks on the finished surface. Even the wear on improperly machined ways can be observed in the finish of the job. An efficient grinding job depends largely upon the selection of the correct wheel for the metal being ground and the proper dressing of the wheel. The quality of the surface finish is affected by the same factors of proper selection and wheel condition.

The most important factors contributing to the quality of a surface finish are as follows:

- The keenness and uniformity of the tool's cutting edge

- The smoothness of (1) the tool surfaces that come in contact with the job or (2) the chip during the machining operations

- The feed given by the machine to the cutting tool as it transverses the job

- The condition of the machine ways that guide the cutting tool along its path

Recall that a finished surface is seldom perfectly flat. Close examination with surface finish measuring instruments shows the surface to be formed of irregular waves. On top of the waves are other smaller irregularities known as peaks and valleys. These peaks and valleys are used to determine the surface roughness measurements of height and width. The larger waves are measured to determine the waviness height and width measurements. Figure 3-4 illustrates the general location of the various areas for surface finish measurements and the relationship of the symbols to the surface characteristics.

The following are terms related to the surface finish itself.

Surface texture—A group of repetitive or random deviations from the nominal surface, which form the pattern of the surface. Surface texture includes roughness, waviness, lay, and flaws.

Surface—The boundary that separates the object from another object, substance, or space.

Nominal surface—The intended surface contour, the shape and extent of which are usually shown and dimensioned on a drawing or descriptive specification.

Measured surface—A surface whose finish has been checked with an instrument or by some other accepted means of measurement.

Profile—The contour of a surface in a plane perpendicular to the surface, unless some other angle is specified.

Nominal profile—The profile disregarding surface texture.

Measured profile—The contour of a surface in a plane perpendicular to the surface obtained by an instrument of other means.

Center line—The line where roughness is measured. It is a line parallel to the direction of the profile within the limits of the roughness-width cutoff.

Microinch—One millionth of an inch (0.000001 inch). Microinches may be abbreviated as mu (μ) in.

Roughness—The finer irregularities in the surface texture. These include the traverse feed marks and other irregularities within the limits of the roughness-width cutoff.

Roughness height—Roughness height is the average deviation from the specified height expressed in microinches measured on the center line of each ridge.

Roughness width—Roughness width is the distance parallel to the surface between peaks or ridges that makes up the pattern of the roughness of a surface. Roughness width is measured in inches.

Roughness-width cutoff—The distance over which roughness height is averaged. Most surface finish averaging instruments allow the roughness width cutoff to be selected.

Roughness - Width cutoff is a characteristic of the surface finish averaging instruments rather than that of the surface being measured (fig. 3-4, view G).

Waviness—The widely spaced part of surface texture and is generally wider than the roughness-width cutoff. Some examples are machine or work deflections, vibration, chatter, heat treatment, or warping strains. Roughness may be considered as superimposed on a "wavy" surface.

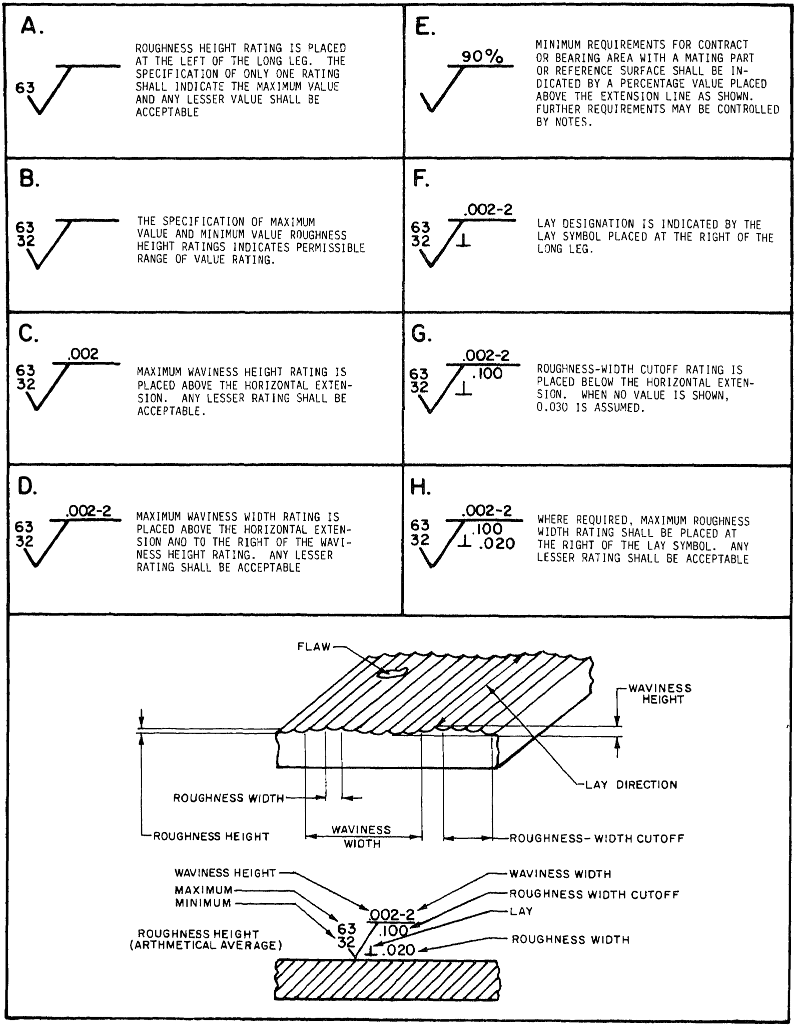


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Figure 3-4.—Relation of symbols to surface characteristics.

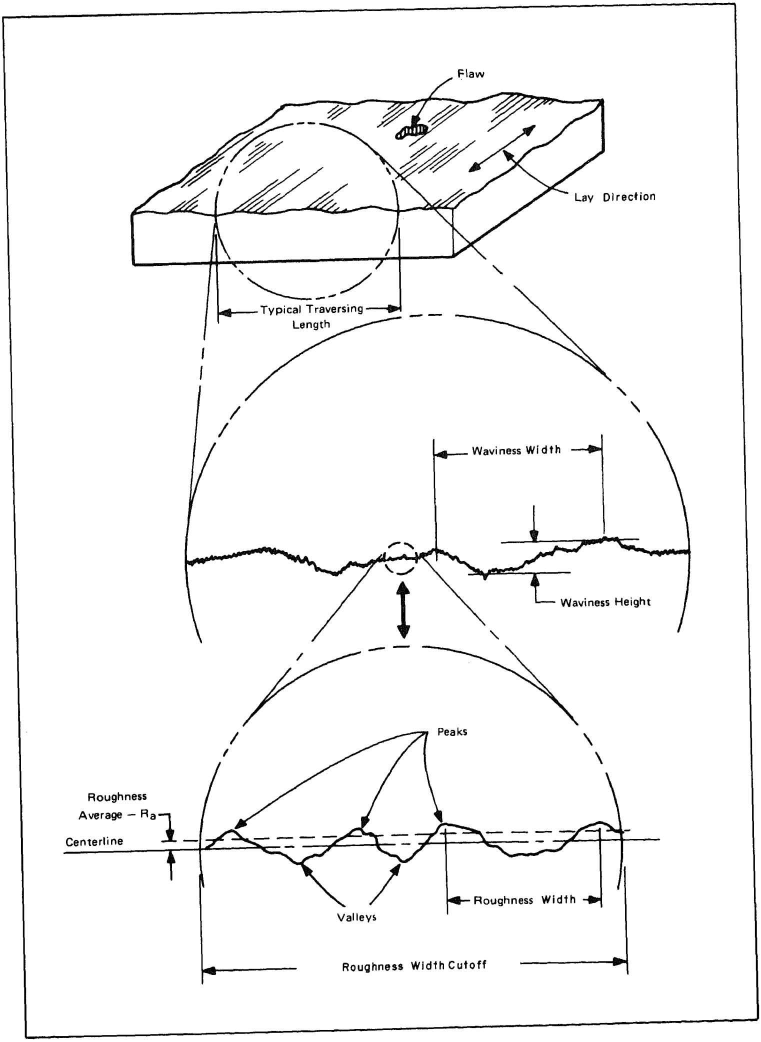

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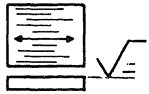
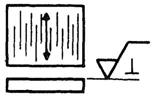
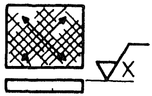
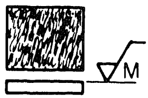
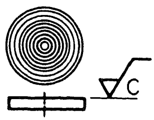
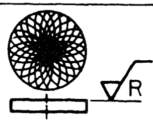
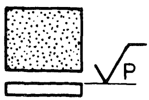
Figure 3-4.—Relation of symbols to surface characteristics—Continued.

Waviness height—The peak to valley distance, measured in inches.

Waviness width—The spacing of successive wave peaks or successive wave valley, measured in inches.

Lay—The direction of the predominant surface pattern produced by the tool marks. The symbol indicating lay is placed to the right and slightly above the point of the surface roughness symbol. Figure 3-5 shows the seven symbols that are used to indicate the direction of lay.

Flaws—Irregularities which occur at only one place or at relatively infrequent or widely varying intervals in a surface. Flaws include such

Lay Symbol	Meaning	Example Showing Direction of Tool Marks
=	Lay approximately parallel to the line representing the surface to which the symbol is applied.	
⊥	Lay approximately perpendicular to the line representing the surface to which the symbol is applied.	
X	Lay angular in both directions to line representing the surface to which the symbol is applied.	
M	Lay multidirectional.	
C	Lay approximately circular relative to the center of the surface to which the symbol is applied.	
R	Lay approximately radial relative to the center of the surface to which the symbol is applied.	
P[3]	Lay particulate, non-directional, or protuberant.	

defects as cracks, blowholes, checks, ridges, and scratches. Unless otherwise specified, the effects of flaws will not be included in the roughness-height measurement.

There are occasions when visual comparison with the naked eye will disclose that one surface is rougher than another. This is possible, however, only in cases of widely differing surfaces. Some of the more dependable methods you may use to evaluate surface roughness are as follows:

- Touch comparison inspection. Move a fingernail along the surface of the job and make a mental note of the amount of resistance and the depth of irregularities. Then move your fingernail across a series of master roughness scales that have numbers corresponding to their measurement in microinches (fig. 3-6). The machining finish must compare satisfactorily with the correct master.

- Aided visual inspection. You can make a visual comparison inspection with the aid of illuminated magnifiers (fig. 3-7).

- Interference microscope inspection. This inspection uses a microscope in conjunction with an optical flat plate and a monochromatic light (fig. 3-8). The microscope allows you to observe the height of the surface irregularity in light reflected between the microscope objective and the surface of the job. The interference fringes indicate the intersection of the wave fronts reflected between the job and the front surface of the microscope objective. The distance between

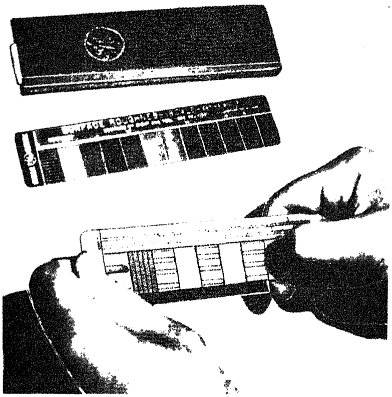


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Figure 3-6.—Finger comparison scales.

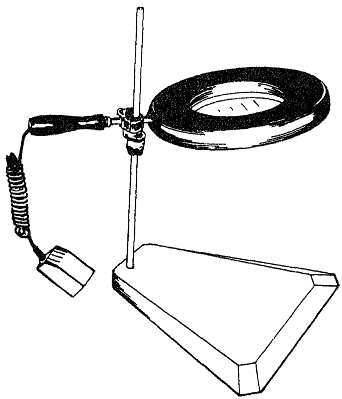
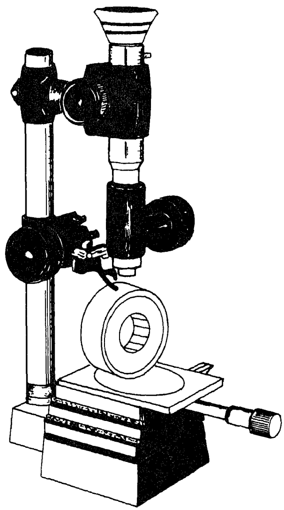


Figure 3-7.—Magnifier with illuminator for surface



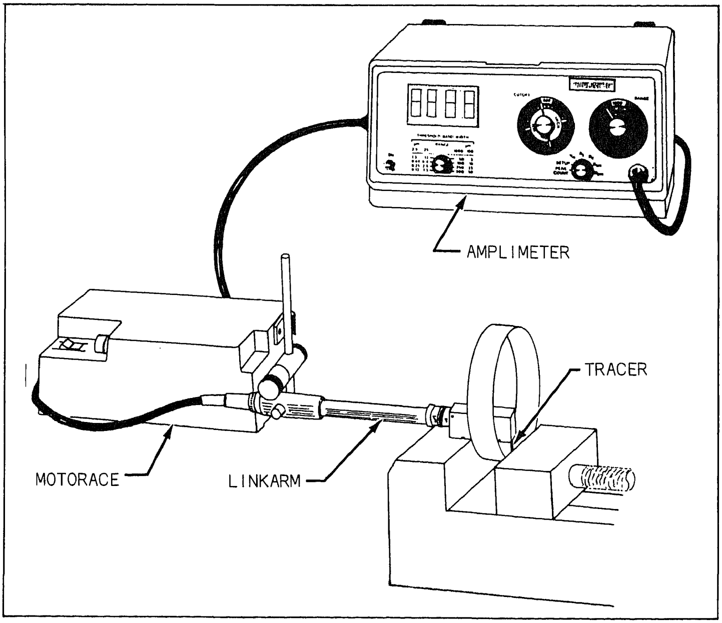
the fringes represents 11 microinches. The interference microscope is used primarily in laboratories, so you will seldom have contact with it. But you should be aware of the instrument in case you encounter it during your career.

● The profilometer test. The profilometer (fig. 3-9) is the most commonly used instrument for finding the degree of surface roughness. It is one of the instruments that uses the tracer method and actually measures the differences in the depth of the surface irregularity. The profilometer is a mechanical-electronic instrument that can be used both in the shop and in the laboratory.

The two main units of the profilometer are the tracer and the amplimeter. Tracers are made in several designs to measure a variety of shapes. The tracer has a stylus with a very small radius at its tip. As the tracer is moved across the surface being measured, the stylus follows the contours of the irregularities left by the machine tool. These up and down movements of the tracer stylus are converted into a small fluctuating voltage. The voltage is fed into the amplimeter where it is amplified to actuate the microinch meter on the front panel. The meter shows the variations in the average roughness height in microinches. A motor-driven unit, the motorace, (fig. 3-9), provides mechanical movement of the tracer and its stylus when manual operation is not possible or not practical.

The radius of the stylus used on the surface-roughness measuring instruments must conform to the standard: 0.000500 ± 0.000150 inch.

As the tracer moves along the surface of the job, the profilometer automatically places a center line through the roughness profile of the surface,



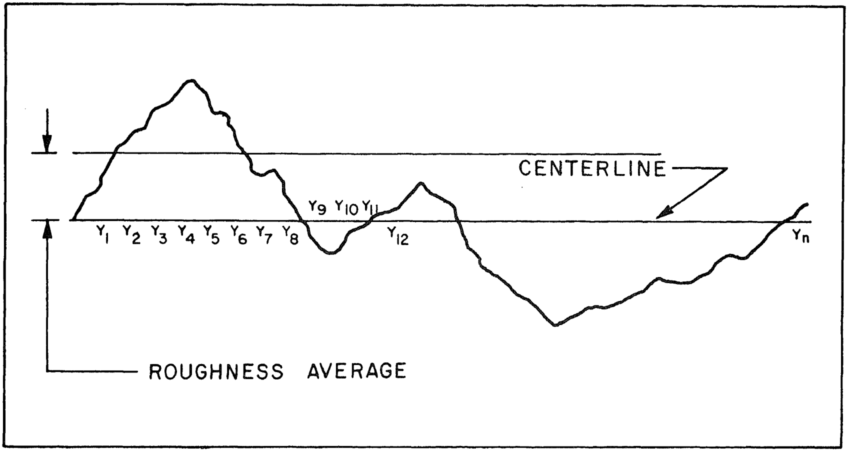


Figure 3-10.—Representative portion of a surface profile.

nverts the portion of the profile below the center ne, remembers the last two hundred irregularities hat the tracer passed over, computes the average eight of these irregularities, and shows this verage height-figure on the meter in microinches. n this way the profilometer shows the variations n average roughness height that occur on most urfaces.

Figure 3-10 represents a magnified rough-ess profile of a short portion of a surface. \ center line is established from which the verage-height measurement of this curve can e plotted. The area above this center line s equal to the area below the line. The qually spaced vertical lines, Y1, Y2, Y3, nd so on, show the deviations of the sur-ace from the center line. In order to etermine the average, the parts below the ne are treated exactly the same as the arts above the line. The measurement of ne height of surface roughness is determined y the average deviation from the center ne.

The two methods of obtaining the average eviation are (1) the arithmetical average height nd (2) the root-mean-square (rms) average eight. The formula for the arithmetical average height of the surface profile shown in figure 3-10 follows:

$$\text{Average height (arithmetic)} = \frac{Y_1 + Y_2 + Y_3 + Y_4 \ldots Y_n}{n}$$

where n is the total number of vertical measurements.

The root-mean-square (rms) average height is about 11 percent higher than the arithmetical average; this difference is of little importance in most cases. The formula for the rms average height of the profile shown in figure 3-10 follows:

$$\text{Average height (rms)} = \frac{Y_1^2 + Y_2^2 + Y_3^2 + Y_4^2 \ldots Y_n^2}{n}$$

where n is the total number of vertical measurements.

The rms average was more commonly used when the tracer method of measuring surface roughness was in its infancy; arithmetical average is now considered the standard rating throughout the world.

You can set the profilometer to mea-sure average roughness in either arithmetical

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Figure 3-11.—The profilometer amplimeter control panel.

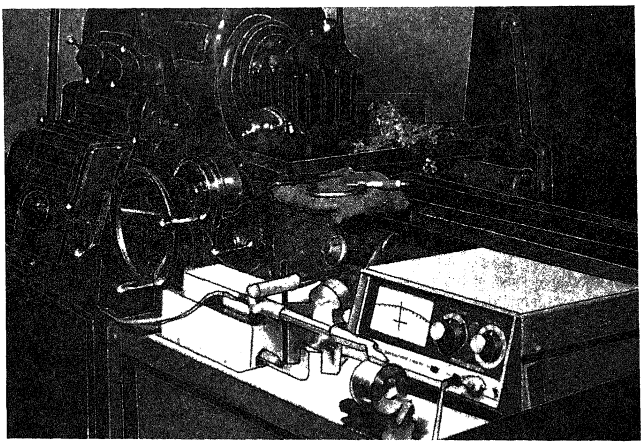
average or rms standards by moving a switch (fig. 3-11).

No technical knowledge or special skill is needed to operate these types of instruments. You can set up the instrument on a bench or cabinet beside the production machine (fig. 3-12) and check the workpiece manually on the job while it is in the machine (fig. 3-13). You can also check work at on-the-floor inspection units (fig. 3-14).

You should always be interested in the quality of the finish that a cutting tool has given to the surface of the machined job. The smoothness and regularity of the finished surface will indicate the efficiency of the cutting tool, whether the tool is correctly ground, and the approaching breakdown of the cutting edge (or the dulling, loading, and glazing of the grinding wheel). Finish smoothness will also indicate changes in product size and whether or not additional machining is required.

By using a quick, reliable method of checking surface roughness, you can save both time and effort.

Several instruments are used for checking the quality of surface finish. The surface analyzer (fig. 3-15) is as a practical shop instrument designed for the accurate measurement of surface finish roughness. Like the profilometer,



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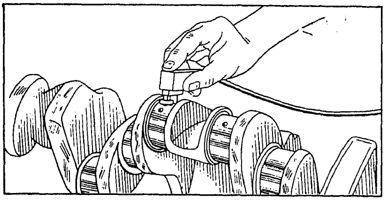

Figure 3-13.—Checking surface finish on the machine.

the surface analyzer measures the irregularities of the surface finish and records them in microinches. This is done by a tracer stylus, which registers the rise and fall of the peaks and valleys on the finished surface. These variations are amplified and indicated on an electrical meter, which is calibrated to read in microinches. The surface analyzer can be calibrated to read directly in arithmetical average or root-mean-square average and can be fitted with various accessories for use in specialized areas.

The simplest method of judging the roughness of a surface has always been the fingernail test. The human fingernail is very sensitive and will detect the result of a tearing cut, as well as the ridges that contribute to the roughness of the finished surface. In order to give machinists some kind of a reference surface with which they could compare their work,

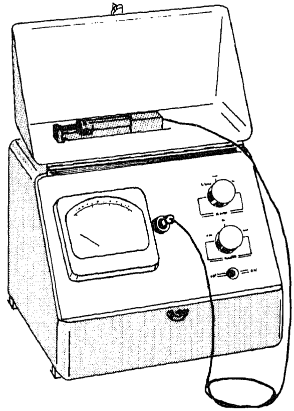

Figure 3-15.—Surface analyzer.

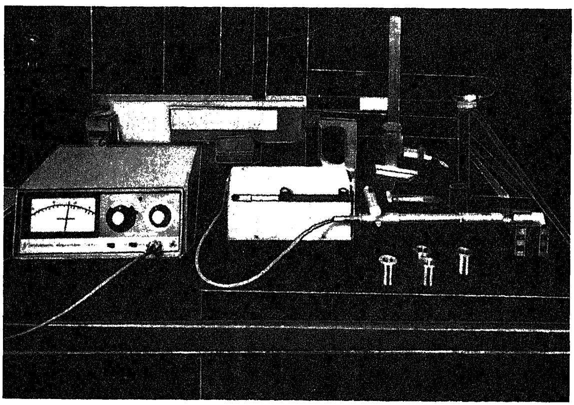

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Figure 3-14.—On-the-floor inspection of surface finish.

surface roughness scales were developed (fig. 3-16). By using touch and sight to compare the surface of the job with the matching part of the scale, you can determine whether or not the job conforms to blueprint specifications. The scales are made to duplicate machined surface standards in appearance, pattern, and roughness value. The scales are made of flat steel and are pocket size. To identify its correct degree of surface roughness, each pattern is engraved with a number representing the arithmetic average deviation from the mean surface in microinches—that is, 8 represents 8 microinches roughness. A curved set of reference scales simplifies the measurement of cylindrical surfaces, both internal and external (fig. 3-17). A further development of this method of measuring surface roughness is shown in figure 3-18. Each pattern of the reference scale is marked with a number representing the degree of surface roughness in microinches and a code letter indicating the machining process; for example, 63M denotes 63 microinches, milled. The reference scale can be used by sight or touch, but as an added advantage the manufacturer supplies a 10x hand magnifier with built-in illumination. This complete kit consists of two scales on which

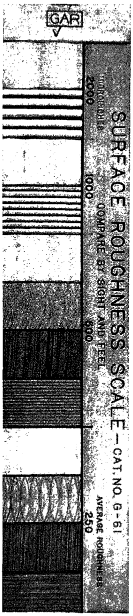

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Figure 3-16.—Flat roughness scale.

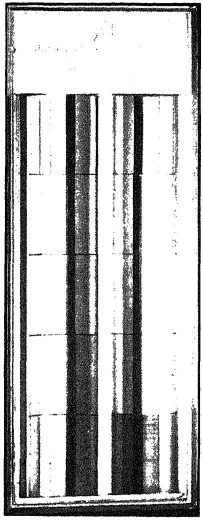

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Figure 3-17.—Cylindrical roughness scales.

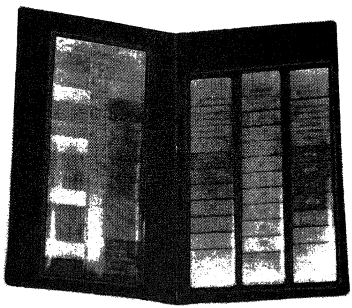


Figure 3-18.—Surface-finish comparator kit, which allows comparison of surface roughness either by touch or by optical enlargement.

are machined 22 specimens of a variety of finishes, the 10x optical magnifier, and a carrying case.

SURFACE TEXTURE SYMBOLS

Figure 3-19 shows different surface texture symbols. Figure 3-20 shows typical examples of surface symbols on a drawing. Figure 3-21 shows a convenient method of specifying roughness for several operations on the same surface.

The study of surface roughness is still in a state of development; however, the future should bring many refinements in machining processes and in the measurement of surface finishes.

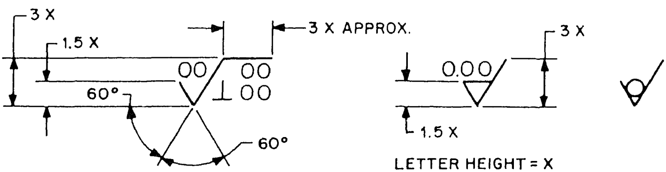
Symbol	Meaning
(a) 	Basic Surface Texture Symbol. Surface may be produced by any method except when the bar or circle (Figure 1b or 1d) is specified.
(b) 	Material Removal By Machining Is Required. The horizontal bar indicates that material removal by machining is required to produce the surface and that material must be provided for that purpose.
(c) 3.5 	Material Removal Allowance. The number indicates the amount of stock to be removed by machining in millimeters (or inches). Tolerances may be added to the basic value shown or in a general note.
(d) 	Material Removal Prohibited. The circle in the vee indicates that the surface must be produced by processes such as casting, forging, hot finishing, cold finishing, die casting, powder metallurgy or injection molding without subsequent removal of material.
(e) 	Surface Texture Symbol. To be used when any surface characteristics are specified above the horizontal line or to the right of the symbol. Surface may be produced by any method except when the bar or circle (Figure 1b and 1d) is specified.
(f) 	

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Figure 3-19.—Surface texture symbols and construction.

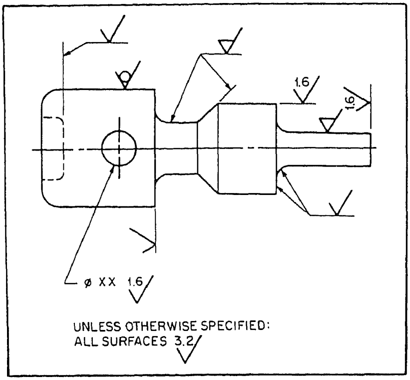

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Figure 3-20.—Application of the surface symbols.

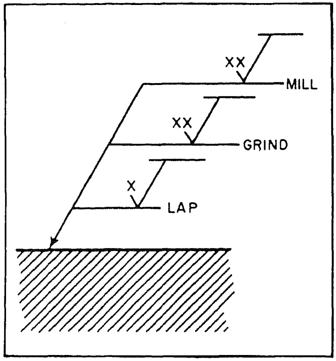

Figure 3-21.—Convenient method of specifying roughness for several operations on the same surface.

CHAPTER 4

ALIGNING AND BALANCING

One of the biggest problems that will confront you, as a Machinery Repairman, is that of maintaining the alignment of machine equipment aboard ship and in shore machine shops. Maintaining equipment alignment aboard ship is especially difficult, due to the lack of stability of the deck on which the equipment is mounted. Some of the alignment problems, however, can be greatly diminished at the time of installation.

This chapter includes information on maintaining proper alignment, adjustment, and leveling of some of the more prominent machines that you will be using. Also included in this chapter are the study of mechanical unbalance, the theory of balancing, and the correction of unbalance. Although portable balancing equipment is still in use in some tenders, it will not be discussed in this chapter due to its limited use. If you need an in-depth study of a portable balancing machine, consult the technical manual provided by the manufacturer.

LEVELING, ALIGNING, AND ADJUSTING MACHINE TOOLS

Levelness, alignment, and adjustment must be checked constantly to ensure proper operation of all machine tools. The information provided in this manual pertains to lathes and horizontal boring, drilling, and milling machines. You should always follow the manufacturer's instructions when performing any of the three previously mentioned operations. However, since you are basically a shipboard machinist, some of these instructions do not apply. The information provided in this manual is intended to supplement the instructions that do apply.

LEVELING LATHES FOR ALIGNMENT

The three basic methods of leveling lathe type machines are spirit level, optical, and test bar. The optical method requires special equipment not normally found on board ships and therefore will not be discussed in this manual. You should remember that the spirit level method will produce, at best, only approximate levelness aboard ships. The test bar method is the most accurate for shipboard use. The leveling of lathes actually refers to the removal of the twist in the bed. This twist results from setting the machine on an uneven foundation. The machine is leveled by adjusting one or more legs to remove the twist in the bed so that it is straight and parallel with the spindle.

The Spirit Level Method

The leveling, or untwisting, operation of lathes requires the use of a very accurate level. An ordinary carpenter's or machinist's level is not sufficiently accurate for leveling lathes. A sensitive, graduated-tube spirit level reading to 10 seconds of arc per graduation (0.0006 inch per foot) is required. The level should be adjustable and should have both a short base and a long tube. (Such a device is illustrated in fig. 4-1.)

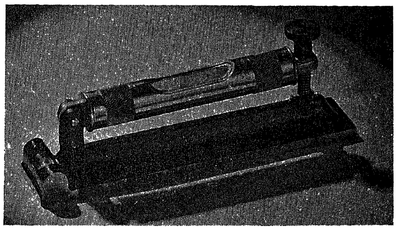

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Figure 4-1.—Proper type of device to use in leveling a turret or engine lathe.

The procedure for leveling engine and ram type turret lathes is as follows:

1. Loosen the lag screws that hold the right end legs to the deck. Do not loosen the lag screws on the left end (headstock) legs.
2. Place the level across the bed at a right angle to the center line of the bed near the headstock (as shown in view A, fig. 4-2). Adjust the level until the bubble is in the center, and allow at least 30 seconds for the bubble to come to rest.

3. Without changing its adjustment, move the level to the outer end of the ways and place it again at a right angle to the center line of the bed

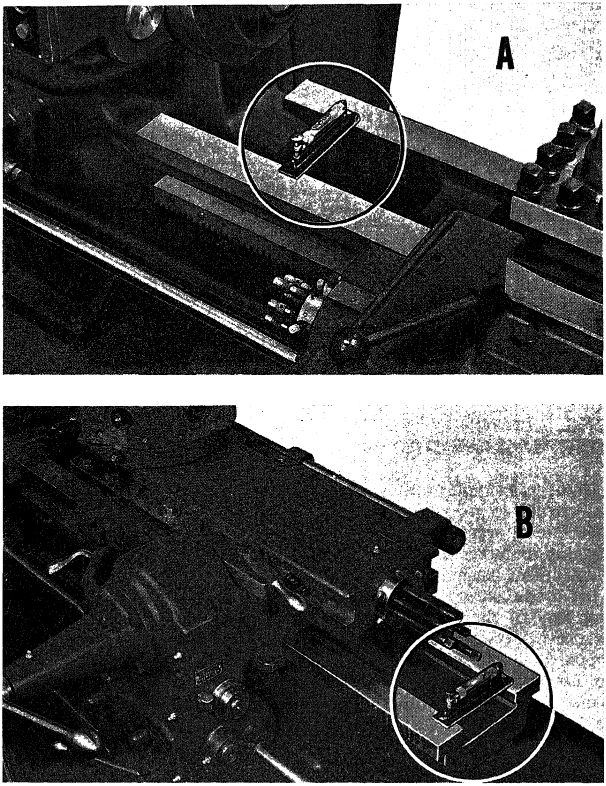

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Figure 4-2.—A. Placing the level at right angles to the center line of the back of the headstock. B. Placing the level at right

(as shown in view B, fig. 4-2). Then, by adjusting the leveling screws on the right-hand legs, bring the bubble to the center. (If the machine does not have leveling screws, use steel shims under the legs.)

4. Repeat steps 2 and 3 until the difference in the bubble readings at the two positions is less than one division.

5. Tighten the lag screws and repeat steps 2 and 3 as a final check.

The procedure for leveling a saddle-type turret lathe is as follows:

1. Loosen the lag screws holding the right end legs to the floor. Do not loosen the left end (headstock) legs.

2. Place the level across the turret (as shown in fig. 4-3). Use two small pieces of thin paper underneath the level to prevent it from slipping when the turret is moved. Also see that the level rests firmly and does not rock as the turret is moved.

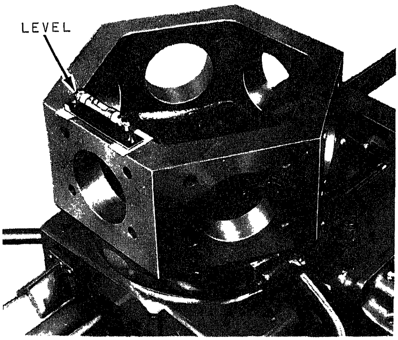

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Figure 4-3.—Placing the level across the turret with two small pieces of paper underneath the level.

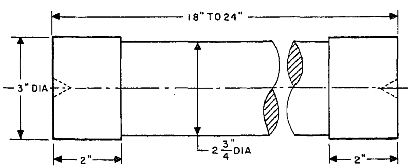

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Figure 4-4.—Lathe alignment test bar.

3. Move the saddle (by hand) to the extreme headstock end of the bed, bringing it as close to the spindle nose as it will go. Adjust the bubble to the center, and allow at least 30 seconds for the bubble to come to rest.

4. Move the saddle to the right end of the bed. Then, without adjusting the level, bring the bubble to the center (by adjusting the leveling screws in the right end legs).

5. Repeat steps 3 and 4 until the difference in the bubble readings at the two positions is less than one division.

6. Tighten the lag screws on the right end legs, and repeat steps 3 and 4 as a final check.

When you level a turret lathe, do not tamper with the bolts that hold the bed to the pan and the legs. These bolts have been carefully set at the factory and their settings should not be changed.

The Test Bar Method

The first step in the test bar method is to make the test bar. A test bar may be any metal bar, 3 inches in diameter and approximately 18 to 24 inches long. (See fig. 4-4 for a sample.) Next take a light cut on each of the two ends of the test bar WITHOUT CHANGING THE TOOL SETTING. Measure the diameter of each end. A difference in diameter indicates a misalignment. Adjust the machine leveling screws and repeat the procedure until a cut on both ends of the test bar results in the same diameter.

ALIGNMENT OF THE TAILSTOCK

The tailstock of a lathe, after long use, can become out of alignment with the headstock. This is primarily due to wearing down of the ways or the grooves in the bottom of the tailstock. To check this, clamp the tailstock close to the headstock and mount a dial indicator on the headstock spindle. Take indicator readings on the tailstock spindle. The reading on the dial indicator should be the same at the top and the bottom (fig. 4-5). If the tailstock and headstock are out of line in a horizontal plane, correct the alignment. If the tailstock is low, you must shim or build up the bottom surface of the tailstock. If the tailstock is high, its base must be either scraped or machined. Both scraping and machining should be done by a shipyard.

ALIGNMENT OF TURRET HOLES WITH THE SPINDLE

One of the causes of inaccuracies of turret lathes can be traced to poor turret hole alignment. In order to ensure the highest possible accuracy in making these machines, the turret holes and faces are often finished in the machine's own spindle after the machine has been carefully leveled. After the machine has been leveled according to manufacturer's instructions, the alignment between the spindle and the turret is automatically reestablished and requires no further attention.

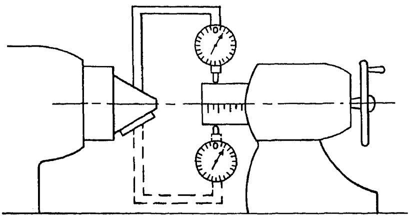

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Figure 4-5.—Checking tailstock alignment.

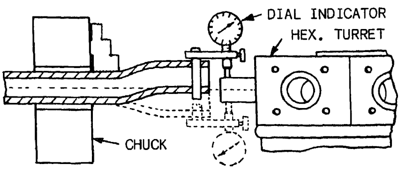

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Figure 4-6.—Alignment test for turret holes.

If you desire to check the turret hole alignment, use a dial indicator.

Figure 4-6 illustrates how to perform the alignment test for turret holes with a dial indicator. Secure a piece of tubing in the chuck, and mount the dial indicator at the end of the tube. Do not use solid bar stock, however, because its own weight makes it sag. The dial indicator rotates around a ground plug which, in turn, must have a good fit in the turret hole. The tubing, however, does not have to run true or straight. It has purposely been shown (fig. 4-6) with a bend, to illustrate that the dial indicator will still travel around the center of revolution of the spindle and will, therefore, give a true reading of the spindle's alignment.

ADJUSTING CLUTCHES

All clutches should be adjusted so that when they are engaged they are capable of pulling the heaviest load required, and when they are disengaged, they will be completely free. When clutches are allowed to slip, they wear quickly and have to be replaced. Clutches should be adjusted according to instructions in the manufacturer's technical manual. If the method of adjustment is not described in a manufacturer's technical manual, a careful study of the parts will usually show how an adjustment can be made.

ADJUSTING GIBS

All sliding units on engine and turret lathes are provided with gibs, so that as the bearing surfaces wear adjustments can be made to keep the machine tight and accurate. Most of the gibs are tapered and can be adjusted by means of screws, located at the end of individual gibs. If the gibs are not tapered, they can be adjusted by a series of screws along the sides of the machine.

Gibs should be adjusted so that the sliding units are sufficiently tight to obtain the accuracy required. If they are too tight, the slides will be hard to operate; and if they are too loose, the accuracy of the machine will be lost. When adjustment of the gibs causes the slide to bind in one position and to be free in another, the sliding units have worn and should be refitted according to manufacturer's instructions.

CHECKING THE ACCURACY AND ALIGNMENT OF MILLING MACHINES

As an MR1, you must know how to use a test bar and dial indicator to check the alignment and accuracy of milling machines. You can assure continuously accurate work by periodically checking the adjustment and the alignment of the milling machine.

You can detect end play of the spindle by placing a dial indicator against the spindle face and then moving the spindle back and forth along its axis while observing the indicator reading. If you find play, you can eliminate it by tightening the spindle thrust nut (as shown in fig. 4-7). You can check for looseness of the spindle bearing by chucking a rod in the milling machine spindle chuck and using the rod as a lever to move the spindle at 90° to its axis. Manufacturers have installed various devices such as tapered and split-shell bearings, which allow adjustment of bearing looseness.

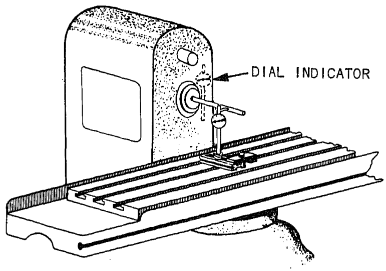

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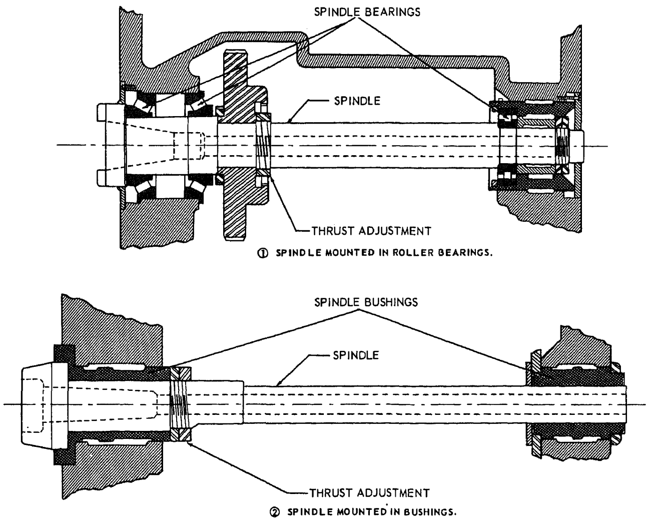
Figure 4-8.—Checking the accuracy of spindle rotation.

To check the accuracy of the spindle, use a setup similar to the one shown in figure 4-8. Place a test bar in the tapered spindle hole, and attach an indicator to the table of the milling machine with the indicator contact point touching the test



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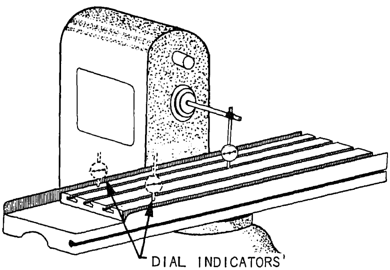
bar. Then rotate the spindle while you move the indicator along the axis of the test bar. If you observe any deviation from concentricity (runout), use a dial indicator to check the bore of the spindle for runout. If there is any evidence of runout, you may be able to correct the problem by adjusting the spindle bearings. Be sure to repair all small nicks and dents in the spindle bore before you use the spindle.

To check the accuracy and alignment of the table, knee, and column surfaces, place a test bar in the milling machine spindle and attach the dial indicator as shown in figure 4-9. With the dial indicator's contact point touching the table, move the table parallel and at 90° to the axis of the spindle, taking readings at various positions. Then adjust the table to various heights and take the readings again. Check the readings for variations that would indicate deviation of the column from the vertical. If the test indicates improper alignment, you may correct the problem by adjusting the gibs of the machine, rescraping the bearing surfaces of the table knee or column, or refinishing the worktable top.

LEVELING THE HORIZONTAL BORING, DRILLING, AND MILLING MACHINE

Although the horizontal boring machines, drilling machines, and milling machines are normally leveled during initial installation or after subsequent drydock repair, you should be familiar with the leveling procedures. Being aware of the steps involved will enable you to check the machines for trueness and to use the machines better.



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To level the machine, turn the leveling screws down against the leveling plates. Then raise the entire machine on the leveling screws. After you have leveled the machine through this procedure, secure it to the foundation by means of jam nuts on the foundation bolts. Then recheck the machine since levelness may have been disturbed when you set the foundation bolt nuts. Repeat the above operation until the machine is perfectly level and secured solidly to its foundation.

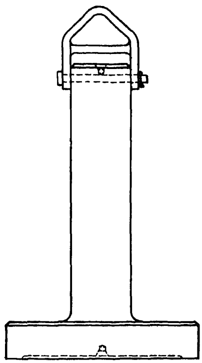
All modern boring machines have leveling pads provided on the rear and side of the column unit. After the machine has been properly leveled over the bedways, the column should be in an accurate vertical position when the level is placed over the leveling pads on the column, unless foreign matter has entered between the column and the bed unit during assembly.

ALIGNMENT

After the machine has been properly leveled, check it for alignment. To do this, you must have precision checking devices such as a cylindrical post, a square, and a sweep. Figure 4-10 shows the cylindrical post.

Cylindrical Posts

Cylindrical posts are used to check column and end support alignment. They are easier to



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handle and provide more reliable readings than the regular square.

Posts made from a close grain cast iron are quite satisfactory. However, the castings should be seasoned before the final finishing operations are performed. A cylindrical post should have the base cast as an integral part, and a lifting bail should be provided to facilitate handling.

When such a post is not available, you may use a standard precision square.

To check alignment with a cylindrical post, you must attach dial indicators to the sliding member of the unit to be checked and traverse them up and down the post.

It is always advisable to take two readings, the second reading with the post indexed to 180°. An average of the two gives the correct reading. If you use a standard square, follow the same procedure. Take one reading from the edge of the blade, then reverse the square and take a second reading from the same edge and average the results.

Sweeps

The sweep is used to check spindle alignment with the column runway or tables. It should have a balanced design and a means for fastening it rigidly to the spindle sleeve. There should also be a means for attaching the dial indicator to the sweep. Do not attach the sweep directly to the boring spindle because your readings will be unreliable.

Attach the indicators to the sweep as closely as possible, and use gauge dial blocks between the surfaces to be checked and the indicator. Reduce overhang to a minimum to avoid inaccurate readings.

Sweeps should be made of welded steel construction, if possible, to reduce weight and facilitate handling; figure 4-11 shows a sweep of approved design.

You can check the movement of the headstock on the column ways accurately by using a solid master square, set on the machine table. The method most commonly used is to attach an indicator directly to the machine spindle, with the indicator registering against the edge of the square. Disengage the spindle clutch so that the spindle does not turn while you perform the check. Then, by using feed or rapid traverse, move the headstock up and down on the column and take an accurate reading from the indicator.

Next, turn the square 180° and repeat the same procedure. If the indicator shows the identical

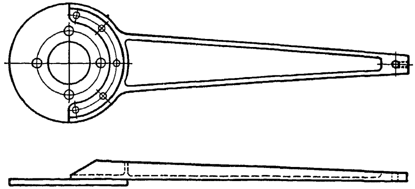

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Figure 4-11.—Drawing of a sweep.

reading within the required limits in both positions, you may assume that the face of the column is at 90° (right angle) in relation to the top of the table of the machine.

Now turn the square 90° and check the edge of the column for squareness.

If the face or edge of the column is not accurate with the edge of the square, you can make a correction by adjusting the leveling screw, which is located directly under the column. When you make the adjustment, take care not to disturb the levelness of the bed.

SPINDLE ALIGNMENT

The next step in setting up a machine is to check alignment of the main spindle to the top surface and to the edge of the bed ways. To do this, move the spindle out of the headstock, so it extends approximately 15 inches from the face of the spindle sleeve. Then revolve the spindle at low speed, and check it with an indicator to determine if it runs concentrically. Mark the mean point of eccentricity on the spindle. For instance, if the indicator is set at zero reading and, when the spindle is turned, the indicator shows a reading from zero to 0.001 inch plus, mark the point on the spindle indicating 0.005 inch with a pencil or crayon. Turn the spindle so that the point indicated is both toward you and centered between the top and bottom of the spindle. Place an indicator on a support similar to a surface gauge. Secure this support to the machine table at the right-hand edge, at a point nearest the headstock of the machine. Then move the headstock up and down on the column ways, until the indicator rests at a point on the center line of the spindle. Set the indicator at zero reading, and move the table and saddle unit in either feed or rapid traverse toward the column. Using this method, check the alignment of the spindle in relation to the edge of the bedways. The maximum tolerance for this alignment is 0.0002 inch in 12 inches.

If you need to make a correction because of a minor error in the above alignment, you can make the correction by changing the thickness of the steel liner at the tongue and groove on the right-hand side of the column. If you change this liner, you will also have to re-ream the dowel pin holes in the column unit.

Turn the spindle so that the mean point marked on the spindle is up, and move the table either right or left until the indicator rests on the center line of the spindle. Follow the procedure outlined above, and check the alignment of the top of the spindle to the top surface of the bedways. Do this by moving the table and saddle unit in either feed or rapid traverse, so that the indicator moves lengthwise over the top side of the spindle. The allowable error for this check is 0.001 inch in 12 inches. This error is largely due to the overhanging weight of the spindle, commonly called spindle sag.

Next, check the accuracy of the spindle to the edge of the column ways. Do this by securing some sort of solid bar or tube directly to the face of the spindle sleeve. Attach an indicator to the end of the bar so that unnecessary overhang of the indicator or bar is eliminated. Then turn the spindle by hand so the indicator is directly opposite the edge of the column ways below the headstock. Using an inside micrometer, height gauge, or Johansson blocks with the indicator set to register a zero reading, check the distance between the edge of the column ways and the indicator. Revolve the spindle by hand until the indicator is directly opposite the edge of the column ways above the headstock. Check the distance between the edge of the column ways and the indicator again. The allowable error between these two readings is 0.01 inch in 48 inches.

Now use the same method to check the accuracy of the main spindle in relation to the front edge of the machine table. Make the measurements in the same manner as described above. The allowable error for this checking is 0.01 inch in 12 inches.

CHECKING THE END SUPPORT AND END SUPPORT BLOCK

The next step in aligning the machine is setting and checking the end support block accurately with the machine spindle. It is best to place a large boring bar in the machine. The boring bar should be long enough to reach across the machine table with the spindle drawn fully back into the headstock. With the table and saddle unit moved to a point close to the column and the end support unit moved as near as possible to the machine table, check the alignment of the boring bar to the top crosswise surface of the machine table. Adjust the headstock with the hand crank so that it is stopped on the column in upward movement. Then clamp both the head and the end support block. Use an indicator mounted on a height gauge or a surface gauge, or an inside micrometer mounted on a base, to check the parallelism of the boring bar to the top surface of the table.

Corrections for slight errors in this alignment can be made very easily on a modern machine. For precision movement, the elevating screws for the headstock unit on the column and for the end support block on the end support column are suspended from precision bearings. However, the bearing support on the elevating screw for movement of the headstock unit on the column is accurate and fixed. The bearing support on the elevating screw for movement of the end support block is accurate and adjustable. The screw in its support bearings is carried in an adjustable sleeve with two round adjusting nuts provided on the adjusting sleeve. The sleeve is keyed in the end support column to keep it from turning. By loosening one nut and tightening the other, you may raise or lower the elevating screw and secure it in the desired position. You should anticipate wear on the elevating screws and nuts and should make periodic adjustments as necessary.

Before you adjust the headstock to a predetermined position on the column, be sure to stop the headstock in upward movement. This is necessary to align the end support block properly with the main spindle to compensate for any slight allowed backlash between gears, clutch, and other parts.

BALANCING

Mechanical unbalance is the uneven distribution of mass (weight) causing a displacement of the center of gravity of a workpiece from its rotation axis. This displacement causes the rotating workpiece to place unplanned and unnecessary forces on its supports. The purpose of balancing is to achieve a smooth running condition of a rotating machine element, consistent with the requirements of the particular machine.

The forces created by an unbalanced condition increase as the rotating speed increases. Since one of the characteristics of modern naval machinery is a high rotating speed, careful consideration must be given to the balanced condition of rotating parts. Balancing reduces vibration and noise, ensures greater operating efficiency, and results in longer bearing and machinery life. Some items that will require balancing are pump rotors, blower and ventilation fans, and shafts with gears or other parts of an assembly. In addition, armatures that have been rewound must be balanced before being returned to service.

All personnel must take great care to see that nothing is done to disturb the balance of repaired machinery or machinery parts.

When worn parts are replaced or when machining operations are performed on a part, the assembly must be balanced to eliminate potential vibrations. Since unbalance is the principal cause of vibration, this chapter will cover the balancing of rotating parts. Vibration, however, may result from causes other than unbalance. These other causes of vibration and how to determine them will also be discussed in this chapter. The terms used in balancing are listed at the end of this chapter.

CAUSES OF UNBALANCE

Some vibration exists in all machinery. Small vibrations are due to mechanical defects in the machinery or its parts. Since a perfect machine cannot be made, you must know how to eliminate vibration as much as possible. The defects causing unbalance are due to factors such as varying density of materials used in manufacture, tolerances of machining, inaccuracy and out-of-roundness of castings, blowholes, unsymmetrical or inaccurate armature windings, and many other causes. The most common causes are discussed in this section.

DAMAGE TO PARTS OR ASSEMBLIES

Shafts that are parts of an assembly, which may include impellers, fans, couplings, wheels, armature windings, and so forth, become unbalanced if they are bent or sprung out of alignment. The components of such an assembly may independently or altogether be a source of unbalance. Damage caused by erosion of a pump impeller will not be uniform; hence an unbalanced condition will occur. In addition, small amounts of metal broken loose from the impeller blading in one or more places will cause the rotor assembly to be out of balance.

DISTORTION DURING OPERATION

Distortion during operation which causes unbalance may occur in some types of fans other flexible workpieces. In squirrel cage fans, for example, the sheet metal blades under load at operating speeds may stretch or distort from their position when the blower is standing still or operating at reduced speeds. Because of initial stresses and variations in the thickness of the metal blading, such distortions may not be uniform throughout the fan, and an unbalanced condition may result.

The majority of rotors are designed as stiff rigid rotors. However, there are certain types of flexible rotors and these generally fall into the following categories:

1. Long, thin, high-speed rotors, such as special types of paper mill rolls, and automotive drive shafts

2. Large, exceptionally heavy generator units used in stationary power plants

3. Certain types of high-capacity steam turbines

CASTINGS

Balanced conditions cannot be ensured when castings are made. An impeller, for example, may have a blade on one side heavier than the blade on the opposite side, as a result of nonhomogeneity of the metal or improper dimensional tolerances.

A completely machined part such as a pulley or gear wheel appears to be in a balanced condition. Actually, an unbalanced condition may exist due to a blowhole underneath the machined surface. Unbalance may also result from slag inclusions in the metal used in the manufacture of the part. Unless blowholes and slag inclusions are indicated by surface defects of the metal, they cannot be detected except by special examination.

BALANCE TOLERANCES

Tolerances are allowed in the machining of most parts. Plans or blueprints specify the tolerances allowed in the manufacture of replacement parts. When parts such as pulleys and gear wheels are machined, they may be within the allowable tolerance requirements; however, this will not necessarily mean that the mass center of the piece coincides with the rotational axis of the bore. One side of a pulley may be heavier than the other side, resulting in a certain amount of unbalance. When machine parts are designed, the tolerances that permit eccentricity or lack of squareness of machined surfaces, with respect to the rotational axis, are taken into consideration. When you machine high-speed rotating parts, you must ensure that the parts are carefully balanced, as well as manufactured within dimensional tolerances.

One of your responsibilities in balancing equipment is to set up unbalance tolerances. You must consider the weight and operating speed of the workpiece, as well as its design. For instance, a squirrel cage fan distorts as its speed increases.

There are several methods that you can use to determine the proper tolerance for balancing. The first method uses the guidelines outlined in the *U.S. Military Standards 167-1*. The tolerances are based on three rpm ranges and can be determined by the use of the formulas listed below. The appropri formula is dictated by the speed at wh the machine will operate.

$U = 0.177\ W$ (Operating speed is from 0 to 149 rpm

$U = \frac{4000\ W}{N^2}$ (Operating speed is from 150 to 1,000 r

$U = \frac{4W}{N}$ (Operating speed is <u>above</u> 1,000 r

Where:

U = Permissible residual unbalance for each two planes, measured in ounce-inches

W = Weight of workpiece in pounds

N = Operating speed of workpiece (not the balan speed)

A second but somewhat less accurate meth of determining the tolerance of balanc involves the use of nomograms. This meth uses two charts, one precision balance (table 4 and one commercial balance (table 4-2). To this method, use the following procedure:

1. Find the operating speed of the workpi in the left column.
2. Find the weight of the workpiece in right column.
3. Draw a line from the speed in the left c umn to the weight in the right column.
4. Find the maximum permissible unbala in each of two planes at the point where the l crosses the center column.

Two other methods for determining unbala tolerance are the dynamic bearing load meth and the test method. The dynamic bearing l method is based on the unbalance tolera being a small percentage of the static bearing lo The test method involves the balancing o workpiece to as close to zero balance as possi and then adding weight to determine the poin which objectionable vibration starts. The ad amount of weight is then divided by two to g the permissible level of unbalance in each of t planes.

THEORY OF BALANCING

As a rotor revolves on its rotational a centrifugal force acts upon the entire mass of

Table 4-1.—Example of Precision Balance

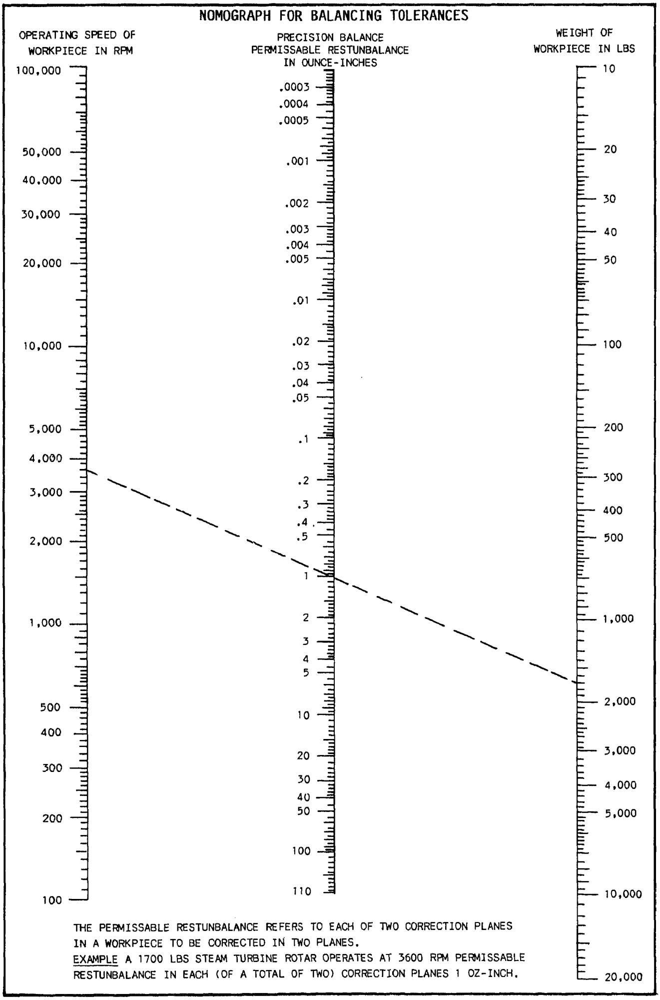

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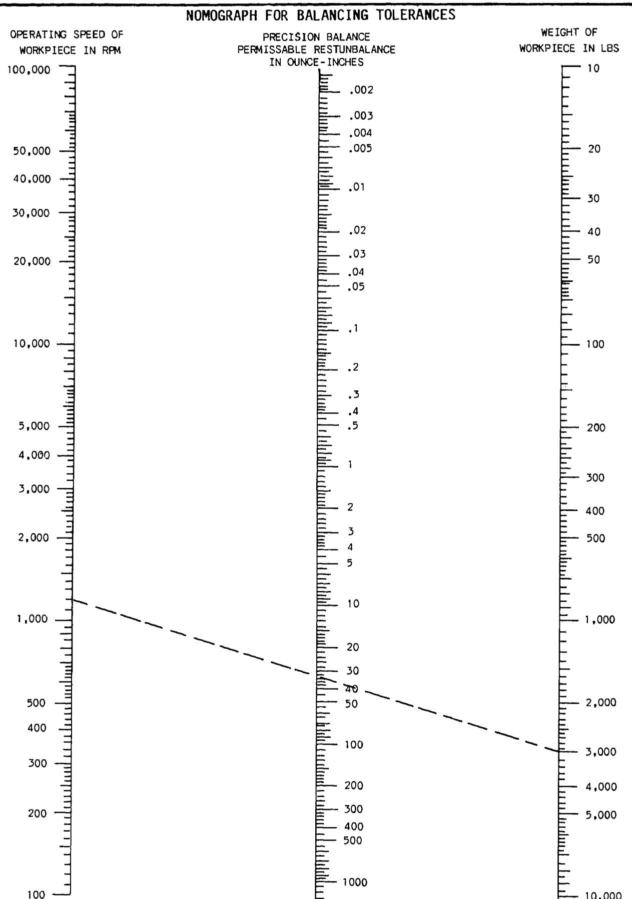
Table 4-2.—Example of Commercial Balance



THE PERMISSABLE RESTUNBALANCE REFERS TO EACH OF TWO CORRECTION PLANES IN A WORKPIECE TO BE CORRECTED IN TWO PLANES.

EXAMPLE A 3000 LBS ARMATURE OPERATES AT 1200 RPM PERMISSABLE RESTUNBALANCE IN EACH PLANE OF CORRECTION 34 OZ-INCH.

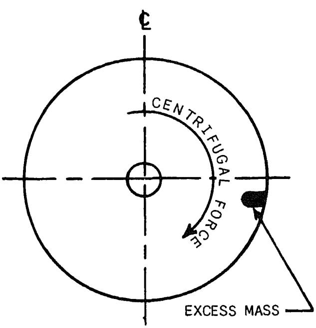
part, impelling each particle away from the rotational axis in a perpendicular direction. All forces will balance, providing the mass is evenly distributed about the rotational axis. In other words, if the part is in balance, it will rotate without vibration. However, if the mass on one side of the rotor exceeds the mass on the exact opposite side of the rotor, the centrifugal force on the heavy side will exceed the force on the light side and will pull the entire rotor in the direction of the heavy side. Figure 4-12 shows an excess of mass on one side. The centrifugal force caused by this excess mass pulls the rotor in the direction of the arrow.

An excess of mass on one side is called unbalance. As the rotor revolves, the unbalance will exert pull to the right, then down, then to the left, and then up in each revolution. This pull causes the rotor and its shaft to attempt to rotate in a circular motion or to vibrate.

EFFECTS OF CENTRIFUGAL FORCE

As we have seen, an uneven mass distribution (unbalance) will cause a rotating part to vibrate due to the centrifugal force exerted by the heavy side of the part. When the part is stationary, the heavy side exerts no force; consequently, there is no vibration. Yet the unbalance is the same. We may safely say, then, that the amount of unbalance is independent of the rotational speed. It remains the same whether the part is stationary or is in rotation. However, as soon as rotation starts, the unbalance will exert centrifugal force. This force sets up vibration, and as the speed is increased the force will increase, which increases the vibration. Figure 4-13 illustrates that 1 ounce of unbalance at 500 rpm produces 0.443 pound of centrifugal force, and that at 5,000 rpm (a speed 10 times greater) the centrifugal force has increased to 44.3 pounds (centrifugal force 100 times greater). The centrifugal force has increased as the square of the number of times the speed increased. Remember though, the amount of unbalance depends only on the uneven distribution of weight and is completely independent of the operating speed. Therefore, it is not necessary to balance a workpiece at its operating speed.

Another factor affecting centrifugal force is the distance of the excess mass from the axis of



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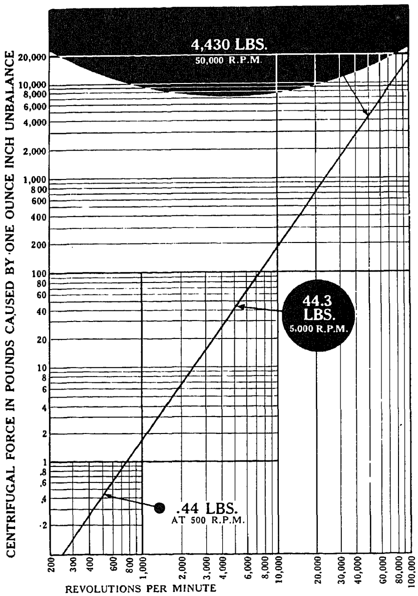

CENTRIFUGAL FORCE EXERTED BY UNIT UNBALANCE AT VARIOUS SPEEDS (Plotted on logarithmic paper)

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rotation. If you swing a weight around your head, you will immediately notice that centrifugal force, exerted by the weight, increases as the length of the string increases. Therefore, the effect depends on the weight and the distance of the weight from the axis of rotation. This product of weight times distance is considered a measure of unbalance and is expressed as ounce-inches, gram-inches, and so forth. This measurement of unbalance will be discussed in more detail later.

TYPES OF UNBALANCE

Unbalance may be divided into two distinct types; STATIC (or force) unbalance and DYNAMIC (or moment) unbalance. Static unbalance is present if the workpiece rotates when it is placed on two parallel knife edges. The workpiece rotates because the center of gravity lies on a point off at the workpiece's rotational axis. Dynamic unbalance is present if the workpiece vibrates as it rotates. Dynamic unbalance is caused by an improper distribution of weight in two or more transverse (perpendicular to the rotational axis) planes.

Static (or Force) Unbalance

Static unbalance is primarily thought of as it exists in disk-shaped bodies such as grinding wheels, flywheels, brake disks, fans, and so on. Such a body has its principal axis of inertia displaced parallel to the axis of rotation (fig. 4-14). The unbalance can be corrected by applying a correction weight in a single plane passing through the center of gravity of the workpiece.

As an example of static unbalance, assume that a grinding wheel (fig. 4-15) has a heavy point of 5 ounces located 2 inches from the rotational axis. In this example, there is an unbalance of 10 ounce-inches. This unbalance may be corrected by applying an equal weight (5 ounces) an equal and opposite distance (2 inches) from the rotational axis. However, the correction weight does not have to be the same weight or placed the same distance from the rotational axis as the weight of unbalance. The unbalance could also be corrected by applying a 2 1/2-ounce weight 4 inches from the rotational axis on the light side of the wheel. In both cases, the unbalance of 10 ounce-inches has been corrected.

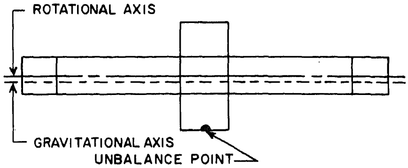

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Figure 4-14.—Parallel displacement.

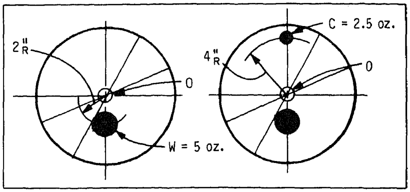

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Figure 4-15.—Correcting static (force) unbalance.

Now let's review the method of expressing static unbalance. If a part has an unbalance of 10 ounces, and this heavy point is at a distance of 5 inches from the rotational axis, we simply multiply the weight of unbalance (W) by the distance from the rotational axis (R) to determine that the static unbalance is 50 ounce-inches. We previously mentioned that the distance from the rotational axis affects the amount of unbalance. Now assume that a similar part has an unbalance of 5 ounces located 10 inches from the rotational axis. Multiplying $W \times R$, we find that the second part has the same amount of static unbalance as the first, even though the unbalance weight is halved and the distance is doubled. That is, 10 ounces × 5 inches = 50 ounce-inches and 5 ounces × 10 inches = 50 ounce-inches. Both of these parts can be statically balanced by using any reasonable combination of weight and distance that equals 50 ounce-inches. This principle can be expressed by the formula $W \times R = W_c \times R_c$, where $W \times R$ is the amount of unbalance and $W_c \times R_c$ is the correction.

Since the amount of static unbalance weight and its distance from the rotational axis are unknown, using the static unbalance correction procedure would consume an excessive amount of time. It is practical only for balancing a rotating part with a large diameter and a relatively short axis, such as a wheel used on a grinding machine. Although we have no way of knowing exactly how much the static unbalance weight is or how far it is from the rotational axis, we do know which side is heavy. So we can add weight to the light side until the part no longer rotates when placed on knife edges.

Dynamic (or Moment) Unbalance

A rotating part may be corrected for static unbalance and yet be dynamically unbalanced. The rotor in figure 4-16 had a static unbalance at point A. This unbalance was corrected by adding the weight, B. The rotor is now in static balance while at rest; but when it begins rotating, the two weights will produce opposite forces, and the part will display dynamic unbalance.

The gravitational axis of this rotor and of all other dynamically unbalanced parts is located at an angle to the rotational axis. This is because the two unbalances are offset on opposite sides of the rotational axis. This type of unbalance will be present as long as the uneven mass distribution is on opposite sides and not in the same transverse plane. When the rotor is rotating, each end will try to vibrate independently and thereby give an indication of the uneven mass distribution.

Dynamic unbalance is sometimes expressed in terms of ounce-inch-inches. The second "inch" dimension refers to the distance between the two planes of unbalance. For the purpose of illustrating corrections, we will use this term. The amount of unbalance is determined by multiplying the value of weight (W) × the distance from the rotational axis (r) × the distance between planes (L); or, W × r × L.

A pure dynamic unbalance is illustrated in figure 4-17. Each of the planes, L and R, has an unbalance of 5 ounces at a radius of 6 inches. The planes are 30 inches apart. Although this rotor is badly out of balance dynamically, it would not rotate on a pair of knife edges. This rotor has an unbalance of W × r × L or 5 × 6 × 30 = 900 ounce-inch-inches. The unbalance can be compensated for by a correction of the same amount. Figure 4-18 shows that our correction weights of 1.5 ounces were placed at a radius of 10 inches

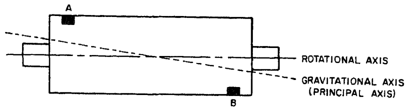

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Figure 4-16.—Gravitational axis at an angle to the rotational axis in a rotor with dynamic unbalance.

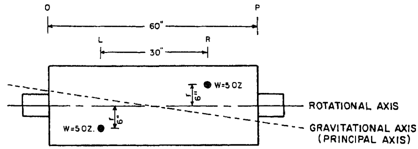

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Figure 4-17.—A pure dynamic unbalance of 900 ounce-inch-inches.

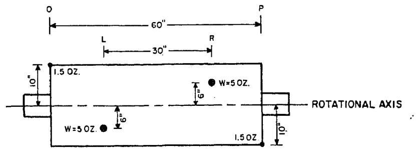

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Figure 4-18.—A pure dynamic unbalance of 900 ounce-inch-inches corrected.

on correction planes 60 inches apart. This combination of weights and distances was determined by using the formula for dynamic unbalance. The correction, 900 ounce-inch-inches, will completely correct the original unbalance.

Rotating parts, if unbalanced, generally have both static and dynamic unbalance. In fact, there may be many points of unbalance throughout the entire mass of the rotor. To locate and correct each one independently would be impossible. When a large number of unbalance points exists, many of them will partially counteract each other. In practice, as few corrections as possible are made. To accomplish this, all the static and all the dynamic unbalances are combined and a single correction weight is added in each of two planes at the correct angular location (explained later on in the chapter). Generally this is all that is necessary to eliminate the effects of the total unbalance.

Figure 4-19 shows a static unbalance in plane S of 1.5 ounces at a radius of 10 inches. The value of this static unbalance is 15 ounce-inches. The rotor also has a dynamic unbalance of 5 ounces in planes L and R, at a radius of 6 inches. The distance between these planes is 30 inches. Therefore, the dynamic unbalance (W × r × L) is 900 ounce-inch-inches. Each type of unbalance could be corrected independently using the previously described methods. However, since a rotor in an unbalanced condition may have an almost infinite number of unbalance points, the number of correction planes is also nearly infinite. Therefore, we simplify the process by determining the resultant unbalance and compensating for it in only two planes of correction, simultaneously eliminating both static and dynamic unbalance. Figure 4-20 shows the corrections to the unbalances shown in figure 4-19. The 1-ounce weight on the right end of the rotor and the 2.5-ounce weight on the left end provide appropriate forces to counteract both the static and dynamic unbalances.

To simplify understanding the correction of unbalance, we have assumed that the unbalances present in a rotor are at the same location or exactly opposite angular locations. Actually, it would be an extremely rare case if this were to happen. Since the unbalances may be at many points throughout the workpiece, determination of the total amount of correction weight, in each plane, and the angular locations of these weights, must be determined by using the balancing machine.

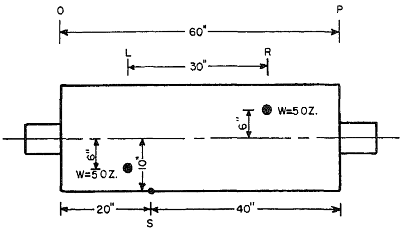

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Figure 4-19.—Combined static and dynamic unbalance.

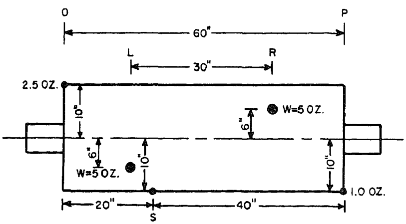

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Figure 4-20.—Combined static and dynamic unbalance corrected.

BALANCING MACHINES AND THEIR FUNCTIONS

We have seen that balancing is a process whereby the distribution of mass in a rotating part is altered by either adding or removing correction weights to eliminate vibration. There are currently two general steps to the process; first, locating and measuring the corrections required to eliminate unbalance, and second, applying the corrections at the proper angular locations.

For correcting unbalance, we depend largely upon the balancing machine to give accurate as well as understandable information on the amount of correction weight required and where it should be placed (or removed). A good balancing machine must enable you, the operator, to select correction planes for the unbalance, and then to determine the amount of correction weight and the angular location of the correction. Since the Navy has many different balancing machines, we will only cover basic general operating characteristics. To learn how to operate a specific machine, you will have to consult the operator's manual for that particular machine.

BASIC OPERATING PRINCIPLES

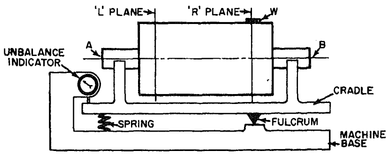
A good balancing machine indicates directly the amount and the angular location of correction weight to be added or removed in each correction plane you select. Your selection of correction planes should be based on a careful consideration of both the design and the function of the workpiece.

The balancing machine you use may operate on any one of three basic operating principles—pivoted cradle, nodal bar, or electrical network.

The PIVOTED CRADLE method was originated about 30 years ago. This setup is shown in figure 4-21. The part to be balanced is supported at A and B on the cradle. The cradle is supported by a fulcrum on one end and by a spring on the other. As the workpiece is rotated, the amount of vibratory motion between the cradle and the machine base away from the fulcrum is registered on the unbalance indicator. After the unbalance is measured on this correction plane, the workpiece is turned around to check the unbalance on the other correction plane. In figure 4-21, an ideal situation, an unbalance (W) happens to exist in a plane (R) located at the fulcrum point. When the workpiece is rotating, the unbalance indicator will register zero, since the centrifugal force is confined to plane R. When the fulcrum is placed in plane L or the workpiece is turned end-for-end, and the piece is again rotating, the unbalance indicator will register a reading for plane R. Therefore, unbalance on the correction plane in which the fulcrum is placed does not affect the reading of the unbalance in the plane being measured.

The pivoted cradle allows you to separate unbalance into two planes. But unfortunately, the dampening effect of the mass of the cradle reduces the vibration produced by a given unbalance and therefore reduces the accuracy of measurement.

The second method of plane separation, more recent than the pivoted cradle, is shown in figure 4-22. It uses a NODAL BAR, and has the workpiece flexibly supported by bearings located at points A and B. These bearings are attached to the nodal bar, giving it the same motion as the workpiece.



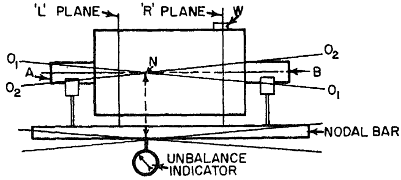


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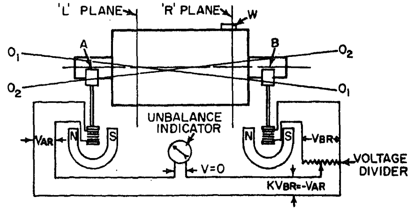
Figure 4-22.—The nodal bar.

In figure 4-22, an unbalance W exists in plane R. As the workpiece is rotating, the axis will vibrate between lines $O_1 - O_1$ and $O_2 - O_2$. Since the excess weight is located closer to bearing B than to bearing A, the vibratory motion of bearing B will be greater than that of bearing A. At some point (N) along the axis of rotation and at the corresponding point on the nodal bar, there is no vibratory motion. This point, called the nodal point, is the pivot point of the vibration. An unbalance indicator placed at this point will give a zero reading. If you place an indicator at the nodal point and then clamp the left end of the workpiece to stop left end vibration, the indicator will show a reading of unbalance in the right-side correction plane. Likewise, if you clamp the right side of the workpiece, you can read from the indicator the unbalance of the left-side correction plane. This method provides more accurate correction plane location than the cradle method. However, the mass of the nodal bar and the connecting pieces still reduces the accuracy of measurement.

The third, and most accurate method for locating correction planes uses ELECTRICAL NETWORKS (fig. 4-23). In this method, the



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workpiece is supported by bearings A and B. Each bearing is connected by a rod to a coil suspended in the magnetic field of a permanent magnet. Both coils are connected to an electrical network that includes a meter used as the unbalance indicator. When the bearings move in response to an unbalance, the coils move within their magnetic fields. As the coils move, a voltage proportional to the amount of bearing displacement is generated in each of the coils.

Figure 4-23 shows an unbalance W in plane R. As the workpiece is rotated, its axis of rotation will vibrate between lines $O_1 - O_1$ and $O_2 - O_2$. The directions of travel of the two coils, and the generated voltages, V_{AR} and V_{BR}, are opposite each other. Since the motion of bearing B is greater than the motion of bearing A, voltage V_{BR} will be greater than voltage V_{AR}.

With a voltage divider, voltage V_{BR} can be reduced until it is equal in magnitude to voltage V_{AR}. At this point, reduced voltage V_{BR} (KV_{BR}) is equal but opposite to voltage V_{AR}. The unbalance indicator will read zero because the voltages cancel one another in the electrical circuit. To determine the unbalance of plane R, we simply use a left-right switch to read the excess voltage in the right side of the circuit. The excess voltage, the difference between V_{BR} and V_{AR}, will appear on the meter as an unbalance in the right-side correction plane. Turning the left-right switch to the left position will reveal any unbalance in the left-side correction plane (fig. 4-24). Turning the left-right switch in the electrical network method serves the same purpose as turning the workpiece end-for-end in the pivoted cradle method.

MASS OF WORK-SUPPORTING STRUCTURES

In any balancing machine, the amount of vibratory motion of the rotating piece is the basis for determining the amount of unbalance. Therefore, the work supports of the machine must be lightweight for maximum vibratory motion to result from any given unbalance.

An unbalanced part would have maximum vibratory motion if it could rotate freely in space. But parts must be supported while they are in a balancing machine, and the mass of the support, in addition to the mass of the piece, must be moved by the forces of unbalance. This added mass of the supports reduces the amplitude of the vibratory motion. For example, vibrations due to unbalance in the small electric motor shown in figure 4-25 are definitely felt, but when the motor is fixed to a block nine times its own mass, as shown in figure 4-26, the vibration is hardly noticeable. Although in each case the centrifugal forces of unbalance are the same, the amplitude of vibration in the motor shown in figure 4-26 is only one-tenth of that in the motor shown in

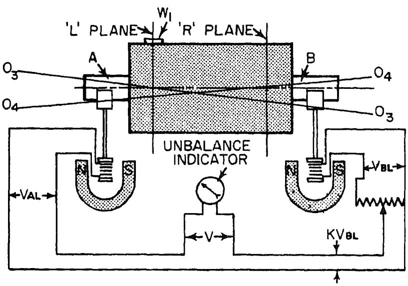

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Figure 4-24.—Checking both planes by the electrical-network device.

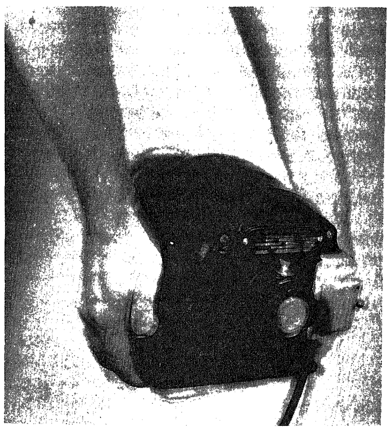

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Figure 4-25.—Vibration of an unattached electric motor.

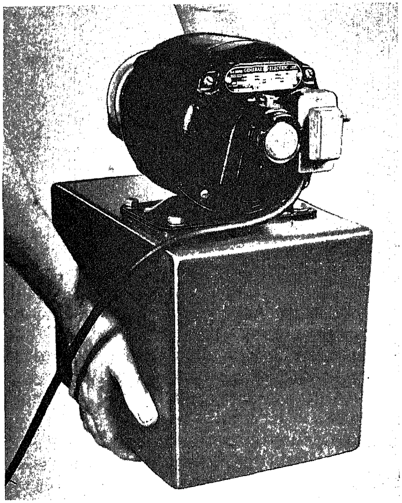

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Figure 4-26.—Vibration is decreased when the motor is bolted to a heavy block.

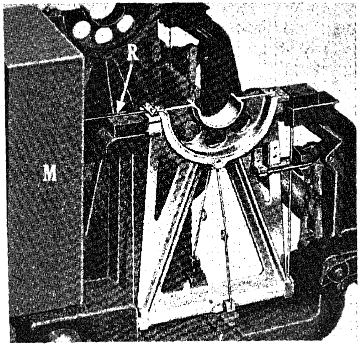

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Figure 4-27.—Work-support member of a balancing machine.

figure 4-25—the total mass in figure 4-26 being 10 times the mass in figure 4-25. There is a similar effect when the work supports of a balancing machine are too heavy.

In general, modern balancing machines use extremely lightweight members to support the workpiece. This results in a negligible reduction of the vibratory motion of an unbalanced rotating piece. The work supports of some machines seldom weigh as much as the smallest workpieces the machines balance. When large workpieces are balanced on these machines, the weight of the work supports has no effect on the balancing operation. Figure 4-27 shows work support suspended on steel wires offering minimum restraint to the vibratory motion, which is transmitted to a coil within a magnet under cover M, through rod R.

MEASUREMENT OF AMOUNT OF UNBALANCE

Since the vibratory motion of an unbalanced piece is small, and since measurement of such motion is the only means of determining the amount of required correction, it follows that some method must be used to amplify this motion to ensure precise measurement. (Note that this section stresses the amount of corrections. The question of proper angular location of correction will be discussed later in the chapter.) Three types of methods are used to measure the amount of unbalance. They are mechanical, optical, and electrical.

A mechanical device for determining the amount of unbalance is illustrated in figure 4-28. This illustration shows that the vibratory effects of unbalance are amplified by single or compound levers, so they can be read more precisely on a large scale. A standard dial indicator may also be

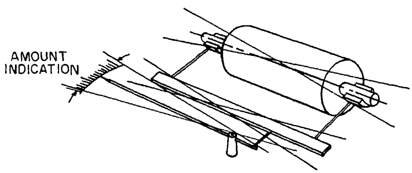

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Figure 4-28.—A mechanical method for measurement of unbalance.

used for this purpose. Because of the inertia of their members, these devices can follow only low-frequency vibrations; and at low frequencies, centrifugal forces are so small that they are seriously affected by the friction of the device's pin joints. In addition, the members of this amplifying device reduce the amplitude of the vibratory motion, further decreasing the device's accuracy. The unbalance that will produce a force sufficient to overcome these problems is the minimum unbalance that such a device is capable of measuring.

A method that avoids the inertia and friction problems mentioned uses an optical method, as illustrated in figure 4-29. This method uses a mirror connected to the vibratory work support to reflect a beam of concentrated light from a fixed source onto a scale on a screen. As the mirror's inclination is changed by the vibratory motion of the work support, the reflected beam makes a streak of light on the scale. The length of this line is a measure of vibration amplitude and an indication of the amount of correction needed. Amplification can be varied by changing the length of the beam between the rotating mirror and the scale. One of the limitations of this device is that as the beam's length is increased for greater amplification, the beam will appear on the screen as a spot instead of a point. The length of the streak of light on the screen created by the moving spot will become one spot diameter too long. Determination of the amount of unbalance then becomes a matter of operator skill in estimating the true length of the streak.

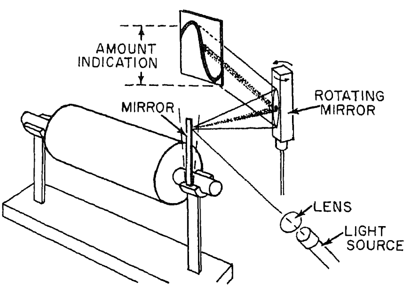

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Figure 4-29.—An optical method for measurement of unbalance.

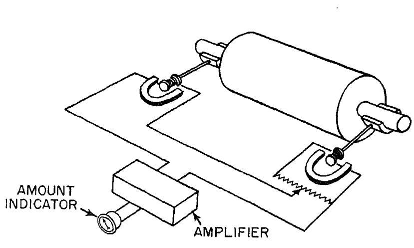

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Figure 4-30.—An electrical method of measurement of unbalance.

An electrical method of measuring the amount of unbalance and the amount of correction required is shown schematically in figure 4-30. In this method, there is no lost motion between the vibratory support and the amount indicator.

The output of the electrical network is fed into an amplifier before reaching the amount indicator; this amplification can be of any desired order—1,600,000 times or more—and is easily varied to suit particular jobs. The result is a stable meter indication large enough to determine precisely the amount of unbalance.

ANGULAR LOCATION OF CORRECTION

In addition to indicating the amount of correction required in each of the selected planes, a balancing machine must indicate the specific point on the periphery of the piece where the correction must be applied to balance the piece. If the precise location of the correction weight is not (or cannot) be determined, the piece cannot be balanced. The time taken to determine the precise weight of corrections will have been wasted. It is also essential that the accuracy of the means used to determine angular location be independent of the amount of unbalance in the piece for balancing to be possible.

Electrical-network balancing machines use electrical devices to indicate the angular location where the correction should be made. One of these

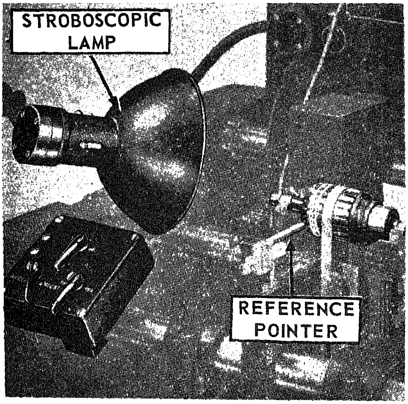

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Figure 4-31.—Lamp method for indicating location for correction.

devices is an electron tube functioning as a stroboscopic lamp (fig. 4-31).

The stroboscopic lamp will flash each time the voltage in the electrical network changes from negative to positive. Even the minute vibratory effects of the smallest unbalances can be detected and measured with this type of balancing machine. The stroboscopic lamp is triggered repeatedly at the same point, in the rotation of the workpiece, whether the unbalance is large or small. The amplified triggering voltage for the lamp is more than 15 times the voltage supplied to the amount of unbalance meter. Indications of the locations for correction are shown with an order of accuracy greater than that for the indication of the amount. The same stroboscopic lamp, reference pointer, and angle band on the piece are used to locate the unbalance in each of the two correction planes.

Another method for determining angular locations for corrections uses a wattmeter to measure the average value of the product of an instantaneous voltage and an instantaneous current—that is, it measures the average power. The instantaneous voltage is the amplified output of the network; the instantaneous current is supplied either by a sine-wave generator coupled to the end of the workpiece, or by the amplified output of a photoelectric tube actuated by a reference spot of contrasting color on the workpiece.

With the wattmeter method, the turning of the handwheel or knob brings the pointer of the wattmeter to a zero reading. An indicating device associated with the handwheel or knob will, when the wattmeter reads zero, point to the angular location at which the corrections are to be made.

ELIMINATION OF UNWANTED VIBRATIONS

In all balancing machines, the piece to be balanced is supported in a flexible structure that offers minimum restraint to the vibratory motion produced by unbalance. This structure is sensitive to vibrations produced by other means as well as to those produced by unbalance. Unless you understand the characteristics of these flexible structures and use them properly, you may very well amplify and measure, as unbalance, vibrations transmitted through a common floor from such machinery as punch presses and lathes under intermittent cut. During balancing operations, you should exercise care to minimize the excitation of flexible structures of balancing machines by external sources.

DRIVES FOR THE WORKPIECE

The workpiece in any balancing machine is rotated by a driving device at one end or by a belt over the periphery of the piece. With smaller pieces, the latter means is more advantageous; the use of an end drive for rotating the piece presents certain difficulties, especially when small parts are being balanced to a high order of accuracy.

MEASUREMENT IN UNITS OF CORRECTION

Balancing machines ordinarily indicate the amount of unbalance in ounce-inches. You, as the operator, must convert this measurement into a correction you can use on the job—such as depth of drilling, or of the length of wire solder to be applied, the number of washers to be attached, or similar methods of adding weights.

Some types of balancing machines are designed to allow you to convert machine measurements to practical correction units by using a calibration constant. A calibration constant is a number by which you multiply the machine indication to determine the amount of balancing machines are designed to eliminate any trial-and-error methods in making corrections. The amount of corrections required may be shown directly on an amount indicator.

CORRECTING UNBALANCE BY ADDING WEIGHT

The common means for adding balancing weight are (1) the addition of a measured length of wire solder of a given diameter, (2) the addition of a measured length of strip metal of a given cross section, and (3) the addition of a selected size or a given number of one size of a known weight generally made up as washers, lead slugs, or cast weights.

To balance squirrel cage fans, for example, you can attach measured lengths of wire solder to the shroud rings. To balance armatures for direct-current motors and generators, you can attach the solder to the banding wires.

Figure 4-32 shows a device you can use to meter lengths of correction solder by turning the handwheel to a number corresponding with the unbalance indication of the balancing machine; you then cut off the solder into the tray by applying a light blow on the punch knob. You may also use strip material of a given cross section on squirrel cage fans and on other parts built up or formed out of sheet material. In all cases, however, you should consult the manufacturer's technical manual for the specific equipment to determine the type of correction required.

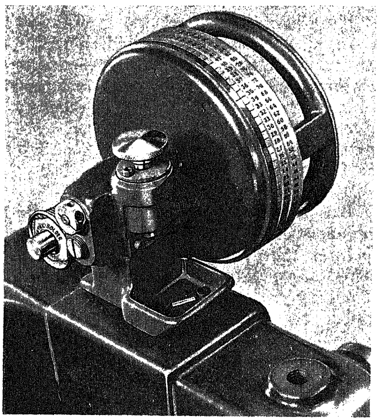

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Figure 4-32.—Metering device for adding correction weight.

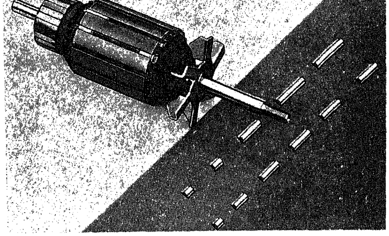

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Figure 4-33.—A method of using correction weights for electrical armatures.

Figure 4-33 shows how strips of brass or aluminum may be used on small universal motor armatures. The extended material is precut to various lengths, which are multiples of the base unit of correction as indicated by the balancing machine; the lengths are inserted in the slots of the armature's cone. This is a very accurate method, providing the lengths are accurately controlled. For some components, corrections are applied in the form of washers, lead slugs, or cast weights. These various weights may be in multiples of the base unit of correction or, when all are of the same size and weight, may be attached in the proper numbers as indicated by the balancing machine.

CORRECTING UNBALANCE BY REMOVING WEIGHT

The common means of removing weight are milling, grinding, shaping, and drilling. Milling or shaping often do not produce an accurate job because of variations in surface, especially with forged or cast pieces. The effectiveness of snag grinding is limited by the operator's skill, and there is the possibility of burning the metal and destroying its quality. Drilling is usually the best means of removing metal for balance. The machine tool, suitable work-holding fixtures, and any needed guide bushings are comparatively inexpensive. A given diameter of drill sunk to a measured depth will remove an intended weight of metal with a high degree of accuracy. Be sure to use charts that are provided by the manufacturer and take precautionary measures in the location where metal is to be removed. Otherwise, you may impair the strength of the rotating part or piece.

TERMS USED IN BALANCING

The following list contains some of the terms used in balancing:

1. Center of gravity—The point in a body at which all of the gravitational forces in the body are equal.
2. Center of mass—The point in a rotating body at which the sum of all movement is equal.
3. Gravitational axis—The axis in a rotating body about which the gravitational forces in the body are equal.
4. Rotational axis—The axis in a rotating body about which the body is forced to rotate due to support bearings.
5. Dynamic bearing load—The weight supported by each of the several bearings supporting a workpiece.
6. Correctional plane—A plane perpendicular to the rotational axis of a part on which weight corrections for unbalance are made.
7. Centrifugal force—A force exerted away from the axis of rotation by all particles of a rotating body.
8. Unbalance—A condition under which the mass weight of a rotating part is unevenly distributed about its rotational axis, causing the gravitational axis to be displaced either parallel or at an angle to the rotational axis.

CHAPTER 5

METALLURGY AND HEAT TREATMENT

As a Machinery Repairman, you work with many different types of metals and alloys. The more knowledge you have of metals and alloys, the better you will be able to perform your repair and maintenance duties. The information you have already learned about the characteristics of metals and alloys from your *Machinery Repairman 3 & 2* book will help you better understand the theory of metallurgy and heat treatment.

The information given in this chapter includes only the minimum amount of theoretical background information you will need in order to give directions to subordinates and to understand the terminology used in this chapter. If you find that you need a more extensive knowledge of the theory and understanding of metallurgy and heat treatment, consult a machinist handbook or any textbook on physical metallurgy.

Metallurgy is the art or science of separating metals from their ores, making and compounding alloys, and working or heat-treating metals to give them certain desired shapes or properties. Metallurgy has been broken down into three branches—chemical metallurgy, physical metallurgy, and mechanical metallurgy.

CHEMICAL METALLURGY deals with the reduction of metals from their ores and the creation of alloys by changing the chemical structure of the base metals. For example, steel is made from iron, which is produced from iron ore. During this process, coke is used as a fuel, and limestone is used as a fluxing agent.

PHYSICAL METALLURGY deals with the nature, structure, and physical properties of metals and alloys. The subject of physical metallurgy includes metallography (study of metals with a microscope), mechanical testing, and heat treatment, which we will discuss later in this chapter.

MECHANICAL METALLURGY deals with the working and shaping of metals through operations such as machining, casting, and forging.

STRUCTURE OF METAL

Throughout your career as a Machinery Repairman, you have become familiar with the physical properties, such as hardness, brittleness, malleability, and ductility, associated with various metals. These properties of metal are directly related to the internal, or atomic, structure of the metals. This section will explain to you how various arrangements of atoms result in these and other properties.

Metals in liquid state have a noncrystalline structural form. The crystals in metal are called GRAINS (irregularly shaped crystals developed from the converging lattices). These irregularly shaped crystals are formed as the metal cools and changes from a liquid state to a solid state. This change of state is called FREEZING. As the metal freezes, its atoms lose the energy of motion they had in the metal's liquid state. The slow-moving atoms become attached to one another, usually in one of four predictable patterns, depending on the type and composition of the metal. These patterns are shown in figure 5-1 and will be discussed in greater detail later in this chapter.

CRYSTALS AND GRAINS

The first group of atoms to form a pattern creates what is called a UNIT CELL, or GRAIN NUCLEUS. The unit cell is the basic building block of the metal. Many unit cells connect in the same pattern that makes up the unit cell and form a CRYSTAL. Crystals then connect to form the metal's CRYSTALLINE STRUCTURE.

Under ideal conditions, crystals will be perfectly shaped. Under real world conditions, however, crystal shapes are usually distorted. These typically distorted crystals, or grains,

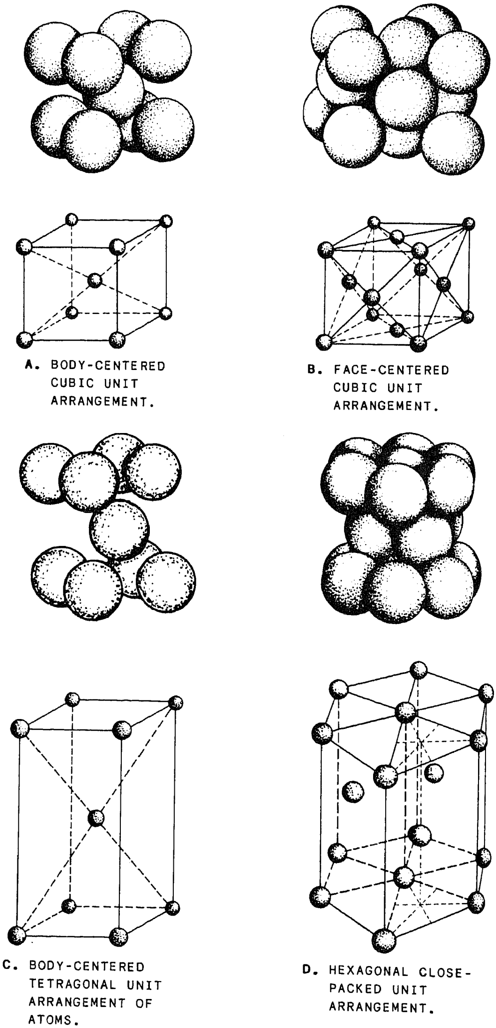

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Figure 5-1.—Atom arrangement in a space lattice system.

form what is known as the GRAIN STRUCTURE of the metal.

The surface of a metal does not indicate its internal grain structure. However, when the metal is fractured, structure will show on the fractured surface. The size of the grains depends upon a number of factors, including the nature of the metal, the temperature to which it is heated, the length of time it is held at a specific temperature, and the rate at which it is cooled from a liquid to a solid. In general, the quicker a metal solidifies, the smaller the grains will be.

Some grains may be seen with the naked eye. Others can only be seen under magnification. The studyof the microscopic structure of metals is called metallography. Instruments used to magnify grains are called METALLURGICAL MICROSCOPES. These microscopes can magnify grains several hundred times their actual size. Additional magnification can be gained through the use of an ELECTRON MICROSCOPE, which can magnify up to many thousand times actual size.

Metallurgical microscopes equipped with devices for photographing the microstructure of metals are known as METALLOGRAPHIC MICROSCOPES.

SPACE LATTICES

The arrangement of atoms (the most basic unit of matter) in a crystal can be shown by a graphic illustration called a SPACE LATTICE. Each of the four line-dot drawings in figure 5-1 is a space lattice. The dots represent atoms, while the lines make the shape easier to visualize.

The space lattices of most metals can be identified as one of the following four types:

1. Body-centered cubic
2. Face-centered cubic
3. Body-centered tetragonal
4. Hexagonal close-packed

Body-Centered Cubic Lattice

The body-centered cubic lattice (fig. 5-1, view A) contains nine atoms, one at each corner of the cube and one at the center of the cube. In this arrangement, each atom is held in position by the force of the remaining eight atoms.

Metals that have the body-centered cubic arrangement are usually stronger, but harder to work cold, than metals that have a face-centered cubic arrangement (discussed next). Some of the body-centered metals are tungsten, molybdenum (MO), vanadium (V), wolfran (W), columbium, and ferrite (or alpha iron) below its hardening temperature.

Face-Centered Cubic Lattice

The face-centered cubic lattice (fig. 5-1, view B) contains 14 atoms, one at each corner of the cube and one at the center of each face of the cube. In this arrangement, the atoms are more closely packed, making the face-centered cubic metals softer than body-centered cubic metals and relatively easy to work cold. Representative metals in this group are nickel (Ni), copper (Cu), lead (Pb), aluminum (Al), gold (Au), silver (Ag), and calcium (Ca).

If ferrite is heated to its hardening temperature, its grain structure changes from body-centered cubic to face-centered cubic. At this point, the metal becomes AUSTENITE, or gamma iron (fig. 5-2). During the hardening process, carbon is freed from a high-carbon metal between the grains called cementite, or iron-carbide, and is uniformly dispersed into the solid hot iron. In this manner, austenite can be given a carbon content as high as 2.00 percent; whereas the body-centered cubic metal ferrite, containing fewer atoms per grain, can only have up to a 0.05 percent carbon content.

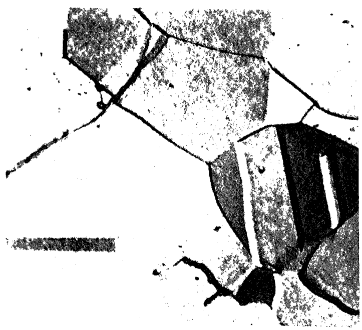

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Figure 5-2.—Microscopic structure called austenite magnified 500 times.

Body-Centered Tetragonal Lattice

The body-centered tetragonal lattice (fig. 5-1, view C) contains nine atoms and looks like a body-centered cubic lattice stretched in one dimension.

Recall that steel heated to its hardening temperature becomes a face-centered cubic material called austenite. If austenite is quenched at its hardening temperature and cooled rapidly to a temperature of less than 400°F, it will change into MARTENSITE (fig. 5-3). During the transformation from austenite to martensite, the steel becomes supersaturated with carbon. Because of its extremely high carbon content and the distortion of its structure, martensite is the hardest and most brittle form of steel.

Hexagonal Close-Packed Lattice

The hexagonal close-packed lattice (fig. 5-1, view D) contains 17 atoms. This structure does not have the high degree of symmetry evident in the cubic structure, and as a result this type of structure is every difficult to deform. Metals that have this structure have little plasticity and are very difficult to work cold. Some examples of this type of metal are cadmium (Cd), cobalt (Co), magnesium (Mg), titanium (Ti), zinc (Zn), and beryllium (Be).

Of the four lattices mentioned above, the cubic types are the most important. If you understand the role these structures play in the heat-treating process, you will be able to understand better how desired characteristics are given to various forms of steel. The relationship between atomic structure, carbon content, and characteristics of the metal will be discussed later in this chapter.

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Figure 5-3.—Microscopic structure called martensite magnified 2500 times.

Some metals may exist in more than one lattice form at a particular temperature. When a metal exists in more than one lattice form it is said to be ALLOTROPIC in nature. A change from one lattice structure to another is called an allotropic change. The temperature at which allotrophic changes take place is called the TRANSFORMATION TEMPERATURE. The changes from one form of iron to another are not often instantaneous at a specific temperature. Rather, they generally take place within a range of temperatures called the TRANSFORMATION TEMPERATURE RANGE. The temperature of the lower end is called the lower transformation temperature and the temperature of the upper end is called the upper transformation temperature.

Recall that when a metal crystallizes in such a way that the crystals are not perfectly formed the crystals are called grains. The line-shaped areas between adjacent grains are known as GRAIN BOUNDARIES. A high state of stress exists at the grain boundaries, due to a mismatch of each lattice. When a metal is deformed, the atoms in the structure slide over one another along certain planes called SLIP PLANES. Slip planes are the planes of least resistance to an applied force. Metals with large grains have long slip planes, allowing deformation to occur easily. On the other hand, metals with small grains have short slip planes, making deformation difficult. The plane along which a metal separates when subjected to an applied force is called a CLEAVAGE PLANE.

In alloys (substances composed of two or more metals or of a metal and a nonmetal), the internal structure may be in the form of crystals of pure metals, a solid solution, intermetallic compounds, mechanical mixtures, or some combination of these structures.

In a solid solution, the elements are completely dissolved in each other, with the atoms of one element fitting into and forming parts of the space lattice of the other element. Figure 5-4 illustrates two ways in which solid solutions may exist. The atoms of one element may fit into the spaces between the atoms of another element, as indicated in figure 5-4, view A; or the atoms of one element may replace the atoms of another element in the space lattice, as indicated in figure 5-4, view B.

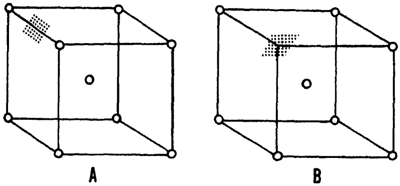

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Figure 5-4.—Space lattices of two forms of solid solution. A. Atoms of one element fit between atoms of another element. B. Atoms of one element replace atoms of another element.

A solid solution in a metal is similar to many solutions you are familiar with. For example: water dissolves salt. The result is a wet salty liquid. The taste of the salt and the wetness of the water have not changed. As you see, there has been no change of individual properties. However, you cannot see or distinguish which is water and which is salt. The loss of individual identity is apparent. An example of a familiar solid solution is Monel metal. You know from experience that Monel is tough, and yet soft and plastic; the toughness of nickel and the plasticity of copper have been combined in the form of a metallic solid solution.

The individual elements lose their identity in a solid solution. A polished cross section of a material that consists of only one solid solution shows all grains to be of the same nominal composition.

Ferrite and austentite are two solid solutions that are important constituents of steel. FERRITE is the name given to a solid solution of alpha iron and carbon. AUSTENITE is the term for a solid solution of gamma iron and carbon. Carbon is only slightly soluble in alpha iron but is quite soluble in gamma iron. Alpha iron at room temperature can hold only about 0.007 percent carbon in solid solution. At a temperature of 2065 °F, gamma iron can hold up to about 2.0 percent carbon in solid solution.

As an introduction to compounds, consider ordinary table salt. The two poisonous elements, sodium and chlorine, are combined chemically to create a new and different substance, sodium chloride, or table salt. Salt, with its own identity and properties, does not resemble either sodium or chlorine.

Similarly, INTERMETALLIC COMPOUNDS are combinations of a metal and some other substance such as carbon or sulfur. Under certain conditions, intermetallic compounds form and a new substance with new properties is created in very much the same manner but on a more complicated basis. Perhaps the most important thing to remember about the intermetallic compounds is the loss of identity and the change in properties of the combining elements. The heat treater quite often uses the change in properties offered by compound formations in metals to create compounds with certain desired properties.

One intermetallic compound of great importance in ferrous alloys is known as IRON CARBIDE or CEMENTITE. This is an extremely hard and brittle compound which is formed by the combination of iron (a metal) and carbon (a metalloid). The formula for iron carbide, or cementite, is Fe_3C. This formula shows that three atoms of iron combine with one atom of carbon to produce one molecule of iron carbide, or cementite.

The structure of an alloy is described as being a MECHANICAL MIXTURE when two or more structural forms are mixed together but are still separately distinguishable. A mechanical mixture of an alloy is comparable—though on a smaller scale—to the mixture of sand and gravel in concrete.

One of the most important mechanical mixtures that occurs in many steels is known as PEARLITE, where hypoeutectoid steel changes into hypereutectoid steel. Pearlite, so called because it has a pearly luster when seen under a microscope, is an intimate mechanical mixture of ferrite and cementite in alternate plates or layers. Ferrite is a solid solution, and cementite or iron carbide is an intermetallic compound; in pearlite, the two are closely mixed to form a characteristically layered structure.

Pearlite is formed when steel that contains approximately 0.83 percent carbon (plain carbon steel) is heated to a certain temperature and then cooled slowly. When the entire structure of the alloy is in the form of pearlite, the composition is referred to as the EUTECTOID COMPOSITION. The pearlitic structure is called the EUTECTOID or the EUTECTOID STRUCTURE.

The internal structure of an alloy may show various combinations of pure metals, solid solutions, intermetallic compounds, and mechanical mixtures. Many of the combinations that are important in steels and other alloys are

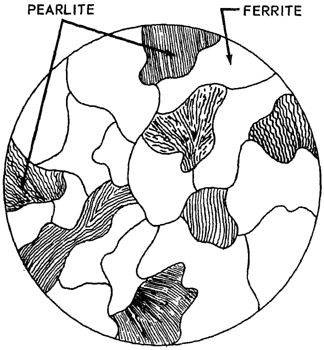

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Figure 5-5.—Typical structure of low carbon steel (carbon less than 0.83 percent).

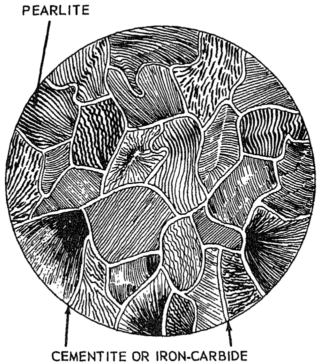

Figure 5-6.—Typical structure of steel containing more 0.83 percent carbon.

the result of controlled heating and cooling of the alloy. In other words, they are the result of heat treatment. Figure 5-5 shows, very much enlarged, a typical combination that occurs when plain carbon steel containing less than 0.83 percent carbon is heated to a certain temperature and then cooled slowly. This combination consists of the solid solution ferrite and the mechanical mixture pearlite, each in crystal form, distributed throughout the alloy. The relative proportions of ferrite and pearlite in this combination depend largely upon the carbon content of the alloy.

Figure 5-6 shows the combination that occurs when plain carbon steel containing more than 0.83 percent carbon is heated to a certain temperature and then cooled slowly. This combination contains no free crystals of ferrite; instead, it consists of crystals of pearlite surrounded by cementite at the grain boundaries.

GRAIN SIZE is determined by the number of grains per square inch in a metal magnified 100 times normal size. The number of grains that form depends upon the rate of cooling from a molten state to a solid state. If a metal cools rapidly, many grains will form, and the size of the grain will be smaller. The smaller the grain, the shorter the slip planes, and the harder and stronger the metal will be. The opposite will occur if the metal is cooled slowly. Grain size, therefore, directly affects the physical and the mechanical properties of metal and can be changed by various heat treatment methods.

HEAT TREATMENT

Heat treatment may be defined as operation or combination of operations involves the heating and cooling of a solid m or alloy to obtain certain desirable propertie conditions. The basic purpose of all treatment is to change the properties of the m in some particular way. The change may required in order to improve the metal fo intended service, to support some subseq operation such as machining, or to relieve str in the material. Heat treatment is comm used to develop or change such propertie hardness, ductility, toughness, machinabilty, resistance, brittleness, magnetism, and elect conductivity.

No single heat-treating operation coul used to produce all of these changes. In improving a metal in one way often chang undesirably in some other way. For exam hardening and tempering carbon steel will inc the tensile strength and yield strength; at the s time, however, this treatment may reduce metal's ductility, as measured by per of elongation. Therefore, heat treating not be successful unless you know exa what properties you can afford to sacr and exactly how to produce the requ properties in the particular metal with w you are working.

As a First Class or Chief Machinery Repairman, you will need to have certain machine parts or tools heat treated before and after machining operations.

HEAT-TREATING EQUIPMENT

The equipment required for heat-treating consists of furnaces or other heating devices, quenching baths or other cooling devices, temperature controls and indicators, and other controls and indicators required for the proper operation of the equipment or for the control of the process. In addition, heat-treating equipment includes tongs and other devices for handling and holding the work while it is being heated or cooled.

The type of heat-treating equipment you are required to use depends upon where you are stationed. On board ship, of course, heat-treating equipment is less elaborate than at many shore stations. Repair ships have fairly complete equipment for heat-treating, but most other ships do not. On ships that have no real heat-treating equipment, the occasional heat-treating that must be done is accomplished with improvised ovens and improvised quenching baths. Obviously, heat treatment is something less than an exact science when such improvised equipment is used. Even with improvised equipment, however, you can do a good job if you understand the principles of heat treatment, know exactly what you want to do to the structure of the metal, and understand the limitations of the equipment.

Because heat-treating equipment varies so widely, it is not practical to describe or to give operating instructions for different types in this course. The equipment described here is typical of heat-treating equipment you may be required to use, but it does not include all possible types of equipment. If you are required to heat-treat metals, find out all you can about the equipment that is available before you begin to use it. The instructions furnished by the manufacturer are usually your best—and sometimes only—source of authoritative information on a specific item of heat-treating equipment.

HEATING EQUIPMENT

Equipment designed for the heating of metals includes electric furnaces, fuel-fired furnaces, bath furnaces, and devices for the measurement and control of temperature. Improvised heating devices may include oxyacetylene torches, Hauck burners, forges, and temporary ovens constructed of firebrick and sheet asbestos.

The gases that circulate through the furnace heating chamber and surround the metal as it is being heated make up the FURNACE ATMOSPHERE. By controlling the composition of the furnace atmosphere, you can produce the type of atmosphere best suited for the heating of a particular type of metal. Furnace atmospheres are generally classified as being oxidizing, reducing, or neutral.

An OXIDIZING ATMOSPHERE exists when excess air is circulated through the furnace. Some electric furnaces are designed to operate with an oxidizing atmosphere at all times. In a fuel-fired furnace (gas or oil), an oxidizing atmosphere may be produced by introducing more air into the heating chamber than is required for the combustion of the fuel. An oxidizing atmosphere is indicated by bright, clean walls and a clear, transparent atmosphere in the furnace. Metals heated in an oxidizing atmosphere occasionally develop films of metal oxides on their surfaces. In some cases, this is undesirable; but in other cases, it is desirable because it tends to prevent further decarburization of the metal. Decarburization is a term used to describe the loss of carbon from the surface of ferrous metals with consequent softening of the material.

A REDUCING ATMOSPHERE tends to remove oxygen from the surface of the metal. A reducing atmosphere is often desirable in heat treatment since it tends to prevent oxide formation and other surface deterioration. If decarburization of steel is to be avoided, however, a neutral atmosphere rather than a reducing or oxidizing atmosphere is used.

A NEUTRAL ATMOSPHERE is neither oxidizing nor reducing because it contains no oxygen (oxidizing agent) and no carbon monoxide (reducing agent). In reality, other factors often tend to produce either oxidation or decarburization; therefore, an atmosphere that is described as neutral may not always be totally neutral.

The furnace atmosphere may be the natural result of the combustion of the fuel (gas or oil) that heats the furnace, or it may be the result of the deliberate introduction of a gas or a mixture of gases into the heating chamber. When gases are deliberately introduced into the heating chamber for the purpose of controlling the atmosphere, the furnace is said to have a CONTROLLED or PROTECTIVE ATMOSPHERE.

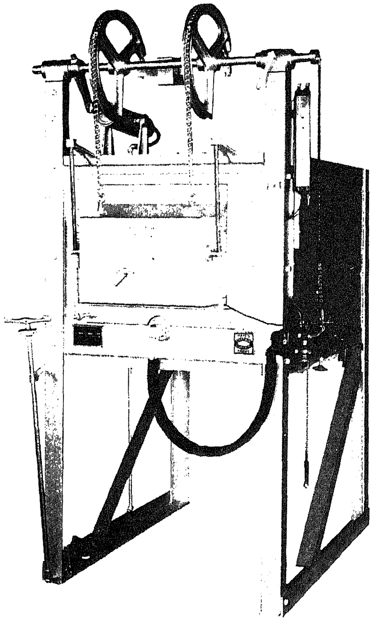

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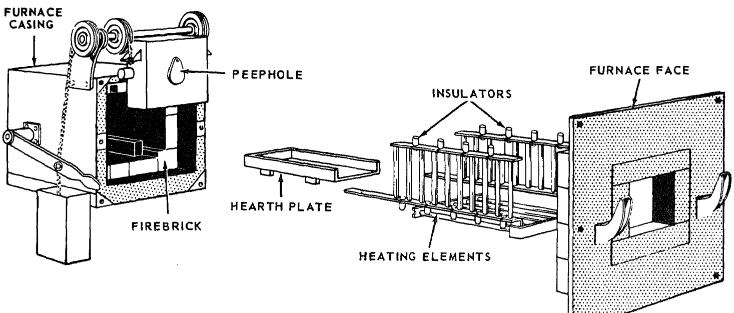
Figure 5-7.—Controlled atmosphere electric furnace for heat-treating.

Electric Furnaces

Electric furnaces with a controlled atmosphere are frequently used for heat-treating on repair ships and tenders. Quite often two such units are used on the same ship. One is a relatively low-temperature furnace used for preheating or annealing, and the other is a higher temperature furnace used for hardening. Both types are equipped with control devices for regulating temperature. The high-temperature furnace may also be equipped with rheostats used to increase the rate of heating. A typical electric furnace for shipboard use is shown in figure 5-7. An exploded view of a slightly different type of electric furnace is shown in figure 5-8.

The outer casing of the furnace is usually made of sheet steel. Just inside the casing is a layer of insulating material, such as mica, spun glass, or asbestos. Inside this insulating material is a lining of refractory material, such as firebrick and insulating brick. The refractory lining insulates the furnace, helps maintain the required high temperatures, and supports the heating elements and the hearth plate.

The heating elements of an electric furnace are metal or silicon carbide resistors in the form of bars or tubes. Metallic resistors made of nickel-iron-chromium are used for temperatures up to about 2000 °F. Molybdenum or tungsten resistors are used for temperatures up to 3100 °F if a



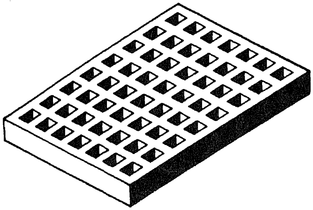


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Figure 5-9.—Grid for heat-treating furnace.

hydrogen atmosphere is provided in the furnace. As a rule, silicon carbide resistors are used for temperatures over 2000 °F.

Hearth plates are placed on the bottom of the heating chamber to support the pieces being heated. Hearth plates must withstand high temperatures without sagging or scaling. They are often made of a special nickel-chromium heat-resistant alloy. If the furnace is designed for the heat treatment of high-speed steels, the hearth plate maybe made of a carbon and silicon.

Grids, usually made of iron-chromium-nickel alloy, keep heavy or long sections of material off the hearth plate. The use of grids ensures more uniform heating of the material and tends to prevent warping. A grid for an electric furnace is shown in figure 5-9.

A special type of electric furnace known as an AIR-CIRCULATING FURNACE is sometimes used for stress-relieving and for heat-treating nonferrous metals. This type of furnace contains no heating elements in the chamber where the material is heated. Instead, air is heated in an adjacent chamber and is then passed through ducts into the chamber in which the material is placed. The circulation of air to this type of furnace is usually sufficient to provide between 350 and 600 complete changes of air per minute. The heated air usually passes vertically through the furnace load. Air-circulating furnaces are relatively low-temperature units, usually designed to operate at temperatures ranging from 275 ° to 1250 °F. Temperature control is both accurate and rapid. The maximum temperature variation is seldom more than plus or minus 5 °F, and very rapid changes to a higher or lower temperature are possible.

In operating and maintaining an electric heat-treating furnace, observe the following precautions:

1. Do not allow a conductor (a piece of metal, for example) to short-circuit the heating elements.
2. Do not try to heat the furnace to a temperature higher than the temperature specified by the manufacturer. Do not overload the furnace.
3. Keep the interior of the furnace clean.
4. Inspect the entire unit at frequent intervals. Replace defective parts immediately.
5. Open and close the furnace door carefully to avoid damaging the insulation or other parts of the furnace.
6. Observe all safety precautions appropriate to electrical equipment in general and all special instructions given by the manufacturer. Electric furnaces carry heavy amperage and high voltage. They can be dangerous if operating instructions and maintenance procedures are not followed correctly.

Fuel-Fired Furnaces

Furnaces that are heated by the combustion of fuel gas or fuel oil are referred to as FUEL-FIRED FURNACES. Although fuel-fired furnaces may be found on board ship, they are primarily located in heat-treating shops at shore stations.

In design and construction, fuel-fired furnaces are generally quite similar to electric furnaces. The actual heating equipment, of course, is different. Burners are used in fuel-fired furnaces instead of the heating elements. Another difference is that special containers called MUFFLES, are used in fuel-fired furnaces to protect the work from direct exposure to flames or excessively hot combustion gases.

Always follow the manufacturer's instructions in operating and maintaining a fuel-fired furnace. Also, observe the following general precautions when you use fuel-fired furnaces:

1. Open all doors before you light the burners.
2. Purge the furnace with air from the blower before you light the burners. Be sure the fuel oil or gas valves are closed while you purge the furnace.
3. When you shut off any type of oil or gas burner, shut off the fuel supply before you shut off the air supply.

4. Inspect burners frequently and remove any scale or other material that may be clogging the burners.

5. Inspect the entire unit at frequent intervals. Replace defective parts immediately.

6. Inspect all pipes and joints at regular intervals. Keep them in good repair.

7. Do not overload the furnace. Consult the manufacturer's instructions concerning proper loading.

8. Observe all appropriate safety precautions in connection with the use, handling, transfer, and stowage of the fuel.

Bath Furnaces

Various types of liquid baths may be used for heating materials. A BATH FURNACE is merely a melting pot or crucible filled with salt, lead, or oil. The bath material is melted and maintained at a constant temperature by electric resistors. Figure 5-10 shows the general arrangement of a bath furnace. Various salts are used in furnaces of this type. The particular salt selected for any application depends upon the melting point of the salt and the practical range through which the liquid salt can be heated.

Observe the following instructions and precautions in connection with the use of bath furnaces:

1. Before melting solid salts, remove the steel wedge from the center of the frozen salt cake. If the wedge is stuck to the cake, loosen it by tapping it on each side.

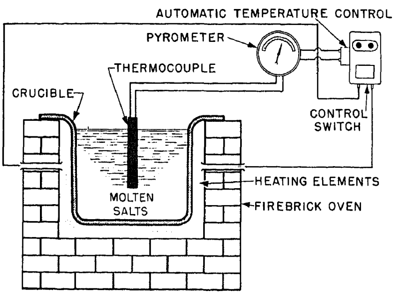

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Figure 5-10.—General arrangement of bath furnace used for heat-treating.

2. Heat solid salts slowly. They melt slowly, and if you try to make them melt rapidly, you will merely overheat the crucible and the salt nearest the crucible.

3. If possible, add new salts before the melting starts. If you must add new salts after some of the bath material has already melted, preheat and dry the new salts before adding them.

4. Before placing metal parts or tools into a molten bath, preheat the metal to at least 250 °F. Undetected moisture on any metal part will cause violent popping and sputtering of the molten salts when the metal is immersed. As a result of this popping and sputtering, you may be severely burned by the molten salts.

5. Use only the correct kind of salts of the required purity in bath furnaces. DO NOT MIX DIFFERENT KINDS OF SALTS! Violent explosions have resulted from the accidental mixing of different kinds of salts. Tools and parts must be completely cleaned of all traces of salts before they are allowed to come in contact with any other kind of salts.

6. If thermocouples extend into the molten material of the bath, be sure to remove them before the material solidifies.

7. Be sure there is adequate ventilation when you use a bath furnace. A suitable exhaust system MUST be provided to remove fumes from the space.

8. Do not allow lead or salts to accumulate around bath furnaces.

9. Be sure the quenching tanks are placed at a safe distance from the bath furnaces.

10. After using a salt bath, place a steel freeze wedge in the center of the molten salts before allowing the salts to cool. Before the salts are used again, remove the wedge. The opening formed in the frozen salt cake provides a space for expansion of the salts as they heat. This allows more rapid melting of the salt cake than would be possible without the opening.

11. Use appropriate safety equipment—gloves, goggles, and masks, as necessary.

12. Observe all safety precautions that apply to the materials used in the bath furnaces. SOME OF THE SALTS USED IN BATH FURNACES ARE DEADLY POISONS. Do not swallow these substances. Do not breathe the fumes. Do not allow the salts to come in contact with cuts or scratches on your skin.

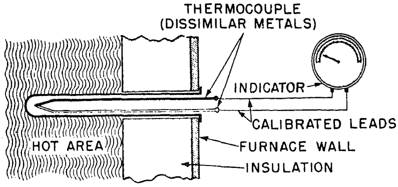

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Figure 5-11.—Thermoelectric pyrometer used in heat-treating furnace.

Temperature Measurement and Control

The measurement and control of temperature are extremely important in all heat-treating processes. Modern heat-treating furnaces are equipped with various devices for indicating (and in some cases recording) temperatures. Some furnaces are also equipped with temperature controllers.

The most commonly used device for measuring the temperature in a heat-treating furnace is the THERMOELECTRIC PYROMETER. This instrument (fig. 5-11) consists of a thermocouple, an extension lead, and an indicating unit. The thermocouple consists of two wires or strips of dissimilar metals twisted or welded together at the tip. An extension lead from each wire or strip leads to the indicating unit. When the thermocouple is heated, an electromotive force of voltage is generated. The indicating unit is an extremely sensitive galvanometer capable of registering voltage in thousandths of a volt. Since the voltage generated by the heating of the two dissimilar metals is proportional to the temperature, the indication of voltage is actually also an indication of temperature. The indicating unit is calibrated in degrees Fahrenheit.

The thermocouple is inserted into the working chamber of the furnace or into the solid material in a bath furnace. Iron, copper, nickel, and chromium are among the metals used in thermocouples for temperatures up to 2000°F. For higher temperatures a platinum and rare metal combination is often used. The extension leads are made of the same materials as the thermocouple itself.

The indicating unit of the pyrometer shows the difference between the temperature at the hot end of the wires or strips and the temperature at the cool end. This means that the temperature at the cool end must be known and must be either held constant or compensated for if the temperature indication is to have any meaning. Some pyrometers are equipped with a thermostatically operated control spring that makes the required temperature correction automatically. Other pyrometers have a zero adjuster that must be operated by hand.

Some pyrometers merely indicate the temperature; others indicate it and record it. Most electric furnaces and many fuel-fired furnaces are equipped with pyrometers that are controllers as well as measuring devices. This type of instrument can be set to develop and maintain any desired temperature within the limits of the furnace design.

If you are using improvised heat-treating equipment, you will probably not have any accurate way of measuring temperature and will have to improvise methods for determining temperature.

It is possible to estimate the temperature of ferrous metals by noting the color changes that occur when the material is heated. This method is not practical for nonferrous metals since most nonferrous metals melt before they show a color change. At best, the color method of judging temperatures is guesswork. Nonetheless, you should develop some skill in using this technique. It may be the only method you have to estimate temperature when you do not have adequate heat-treating equipment.

The best way to learn to judge the temperature of ferrous metal by color is by heating small samples of clean, polished steel under controlled conditions. This way you can check the color of the sample against the actual temperature. Also, study the color charts that relate color and temperature. Your perception of the colors will be affected by the color and intensity of the light in the furnace or in the room where you are working. Use standard lighting conditions, if possible, when you must estimate the temperature of a metal by observing the color. Charts are available in various handbooks and textbooks on metals.

Color	Approximate Temperature (°F)
Faint red, visible in darkness	750
Faint red, visible in daylight	900
Blood red	1050
Dark cherry	1075
Medium cherry	1250
Cherry or full red	1375
Bright red	1550
Salmon	1650
Orange	1725
Lemon	1825
Light yellow	1975
White	2200
Dazzling white	2350

Table 5-1 is a rough guide to the color-temperature relationships of steel.

At temperatures below those given in table 5-1, another type of color determination can be made. If steel is thoroughly cleaned and polished, the surface will appear to change color as the material is heated. An oxide film forms on the polished surface as the steel is heated, and the oxide color corresponds to a certain temperature. Some oxide colors for steel are given in table 5-2.

Special temperature-indicating crayons or other materials may be available for use in connection with heat treatment. These materials give a much more accurate indication of temperature than can be obtained by merely observing the color of the metal. Temperature-indicating crayons are made of materials that melt rapidly and clearly at specified temperatures. A series of crayons is supplied to cover a wide range of temperatures.

The crayons are easy to use. You select the crayon that is labeled with the temperature you want. As the metal is being heated, stroke the work with the crayon. When the metal is below the temperature rating of the crayon, the crayon will leave a dry or chalky mark on the surface. When the proper temperature is reached or exceeded, the crayon will melt quickly, leaving a liquid smear on the metal. Do not forget that the crayons indicate only the skin or surface temperature of the metal. The interior of the piece may be at quite a different temperature unless the piece has been soaking for some time.

Color	Approxi Temper (°F
Pale yellow	428
Straw	44
Golden yellow	46
Brown	49
Brown dappled with purple	50
Purple	53
Dark blue	55
Bright blue	56
Pale blue	61

COOLING EQUIPMENT

The rate of cooling is controlled by sele an appropriate cooling medium and co procedure. The equipment required for co includes the substances used for cooling, a or other container to hold the cooling med and various kinds of tongs, baskets, and devices for handling and holding the work

The rate at which a metal cools depends a number of factors. The size, shape, tempera and composition of the material and temperature and composition of the co medium are the major factors involved. Th at which a cooling medium can absorb heat i greatly influenced by circulation. When cooling medium is agitated, the rate of co is much faster than when the cooling medi not in motion. The volume of the cooling me is also important. As the metal cools, cooling medium absorbs heat. If the volu insufficient, the cooling medium will becom hot to cool the work at the required rat regular heat-treating shops where the co mediums must be used continuously, mecha cooling systems are used to maintain the co medium at the correct temperature.

Liquids, gases, and solids are all use cooling mediums for heat-treating operat Table 5-3 shows the relative cooling rates of commonly used liquids and gases. Solid mat such as lime, sand, ashes, and cast-iron chip sometimes used when the rate of cooling mu slower than that produced by liquids or g

Liquid quenching is accomplished eith STILL-BATH QUENCHING or by FL

Table 5-3.—Average Cooling Rates of Some Liquids and Gases Used for Cooling, as Compared with Cooling Rate of Water at 65 °F

Cooling Medium	Cooling Rate, as Compared to Water at 65° F
10-percent brine solution at 65° F	1.96
10-percent caustic soda solution	1.38
Water at 65° F	1.00
Prepared oil	0.44
Fuel oil	0.36
Cottonseed oil	0.36
Neatsfoot oil	0.33
Sperm oil	0.33
Fish oil	0.31
Castor oil	0.29
Machine oil	0.22
Lard oil	0.19
Circulated air	0.032
Still air	0.015

18.122

QUENCHING. In still-bath quenching the metal is cooled in a tank of still liquid. The only movement of the liquid is that caused by the movement of the hot metal. Flush quenching is used for parts that have recesses or cavities that would not be properly quenched by the still-bath method. In flush quenching, the liquid is sprayed under pressure onto the surface of the piece and into every cavity or recess. This procedure is often used to minimize distortion by providing a relatively uniform quench to all parts of the piece.

Portable quenching tanks of the type shown in figure 5-12 are sometimes used in small shops that do not have permanent, built-in equipment. They may also be used in larger shops where tanks that may be moved from one place to another are needed. Portable quenching tanks may have one compartment or several. When more than one quenching medium is to be used, the seal between the compartments must be absolutely tight in order to prevent mixing of the mediums. Each compartment is equipped with a drain plug, a screen in the bottom to catch scale and other foreign matter, and a mesh basket to hold the parts being quenched. The mesh basket and the wire screen are suspended in the tank and held in position by clips that fit over the rim of the tank. A portable electric pump may be attached to the rim of the tank to circulate the liquid.

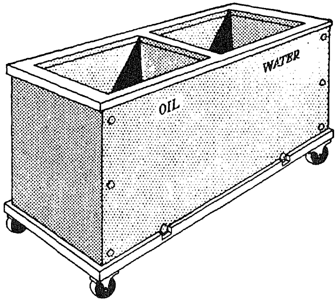

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Figure 5-12.—Portable quenching tank for use in heat-treating.

Stationary quenching tanks are usually designed to contain only one liquid. In a stationary quenching tank, the mesh basket that holds the work is usually raised and lowered by air pressure and is controlled by a three-way air valve. The basket can usually be positioned at any level and can be raised above the level of the liquid so that the parts can be drained after they have been cooled. Stationary quenching tanks usually have built-in electric pumps to circulate the liquid. WATER is often used as a quenching medium for plain carbon steels and for aluminum and other nonferrous metals. The water must be kept clean by frequent changing. The temperature most often used for water quenching is about 65 °F. Normally, the volume of water in the tank should prevent a temperature rise of more than 20 °F. When very heavy pieces are being quenched, the temperature rise may exceed 20 °F, but it should always be kept as low as possible.

BRINE is used for many quenching operations. At any given temperature, brine cannot hold as much dissolved air as fresh water can hold. With brine, therefore, there are fewer air bubbles or gas pockets on the surface of the work. Brine wets the surface more thoroughly and cools the work more rapidly and more uniformly than plain water.

Brine solutions usually contain from 7 to 10 percent salt by weight or 3/4 of a pound of salt for each gallon of water. The correct temperature for a brine quench ranges from 65° to 100 °F.

Plain carbon steels and low-alloy steels are often quenched in brine. High-carbon steels and all alloy steels that are uneven in cross section must be quenched very carefully if brine is the cooling medium. Brine cools the material so rapidly that great internal stresses may develop and crack the work. Brine is not used as a quenching medium for nonferrous metals because of its high corrosive effect on these metals.

OIL is used to quench high-speed steels and oil-hardened steels. It is also the preferred quenching medium for almost all other steels except where the necessary hardness cannot be obtained by such a relatively slow quench. Although nonferrous metals are not normally quenched in oil, they may be in special cases. A wide variety of quenching oils may be used, including animal oils, fish oils, vegetable oils, and mineral oils. Oils have a slower cooling rate than brine or water but a faster cooling rate than air or solid materials. Quenching oils are usually used in the temperature range of 80° to 150°F.

The chief danger involved in quenching with oil is that a hot metal piece may raise the temperature of the oil to the flash point and cause it to burst into flames. A cover should always be kept near a quenching tank that is used for oil. If the oil flashes into flames, put the cover over the tank immediately to smother the fire.

Some water usually collects in the bottom of the oil tank. The water does no harm if only a small amount is present. If enough water is present that the work extends into the water, the rapid quenching action of the water may cause the piece to crack.

CAUSTIC SODA in water is used for some steels that require rapid quenching. A 10-percent caustic soda solution quenches faster than water, but slower than brine. Nonferrous metals are not quenched in caustic soda solutions.

AIR is used for cooling some high-alloy steels and some nonferrous metals. Both still air and circulating air are used. For either method the work pieces are placed on racks or other suitable containers so that all parts are uniformly exposed. Air is often circulated by electric fans arranged to provide uniform cooling. Compressed air is sometimes used to concentrate the cooling on particular areas. Compressed air used for this purpose must be entirely free of moisture. Any moisture in the air produces rapid quenching wherever it touches the metal and may cause cracking or hard spots.

MOLTEN LEAD at temperatures ranging from 650° to 1100°F is often used as a first-stage quench for high-speed steels. A common practice is to quench high-speed steel in molten lead as soon as the work is removed from the furnace and to follow this quench by cooling the part in still air to about 200°F before tempering. Molten lead is not used as a quenching medium for nonferrous metals.

MOLTEN SALT at temperatures ranging from 300° to 1000°F is sometimes used as a quenching medium for steels that tend to crack or distort from more sudden quenches. The final cooling for the temperature of the molten salt bath is accomplished in still air. All traces of the salt must be washed from the steel to prevent corrosion. Molten salt is never used as a quench for nonferrous materials.

SPECIAL PROTECTIVE ATMOSPHERES are used for the first-stage cooling of some steels. The protective atmosphere almost entirely eliminates air from around the metal and thus prevents scaling. When the steel has cooled enough so there is no further danger of scaling, the remainder of the cooling is done in still air.

PRINCIPLES OF HEAT-TREATING

As we have seen, the properties of a metal or an alloy are directly related to the metallurgical structure of the material. Since we know that the basic purpose of heat treatment is to CHANGE the properties of the materials, let's see how this is done. The following sections deal with basic considerations in heat treatment—equilibrium diagrams, transformation temperatures, and the effects of heating, holding at temperature, and cooling.

EQUILIBRIUM DIAGRAMS

The relationships among the various metallurgical structures that compose alloys and the temperatures at which these structures exist are shown on existing equilibrium diagrams for all major alloy systems. Figure 5-13 shows a simplified equilibrium diagram (also called a phase diagram) for iron-carbon alloys. This type

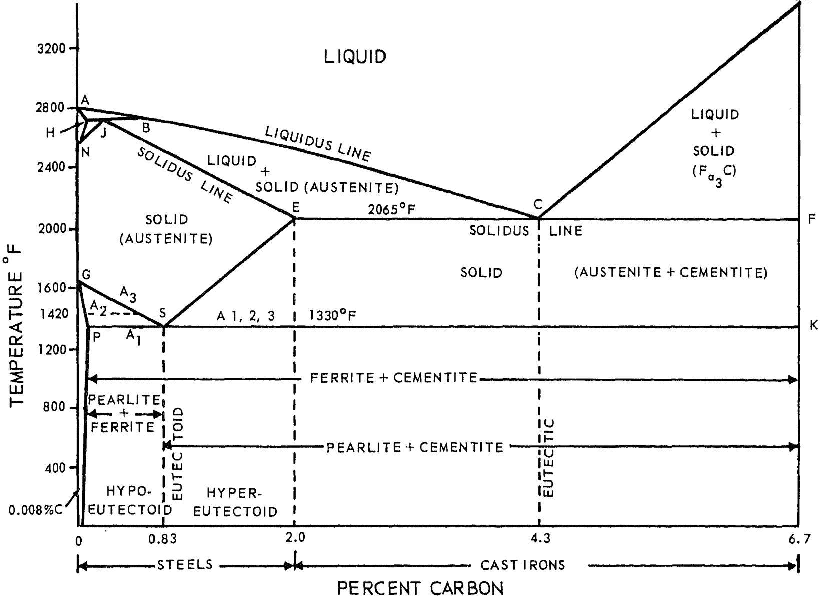

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Figure 5-13.—Iron-carbon phase diagram.

of diagram gives a good overall view of the effects of temperature on the structures of various alloys. However, you should note that an equilibrium diagram indicates equilibrium conditions—you might say, ideal conditions of very slow and very uniform heating and cooling. The rate and uniformity of heating and cooling affect the internal structure of alloys and alter the relationship between temperature and internal structure. Therefore, equilibrium diagrams represent theoretical rather than actual conditions.

TRANSFORMATION TEMPERATURES

If you allow a molten sample of pure iron to cool slowly and measure the temperature of the iron at regular intervals, an idealized (equilibrium) time-temperature plot of the data will appear as shown in figure 5-14. The

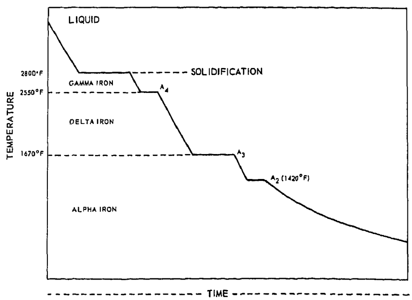

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Figure 5-14.—Idealized cooling curve for pure iron.

horizontal discontinuities (temperature arrests) in this curve are caused by physical changes in the iron.

The first arrest at 2800 °F marks the temperature at which the iron freezes. The other arrests (known as transformation temperatures or critical points) mark temperatures at which certain internal changes take place in the solid iron. Some of these temperatures are very important in the heat treatment of steel.

As was mentioned before, the atoms in all solid metals are arranged in a definite geometric pattern. The atoms in iron immediately after freezing are arranged in the body-centered cubic structure. In this crystal structure the unit cell consists of a cube with an iron atom at each of the eight corners and another in the center. Each of the many individual grains (crystals) of which the solid metal is composed is built up of a very large number of these unit cells, all oriented alike in the same grain. This high-temperature iron is known as delta (δ) iron.

At 2550 °F (the A_4 point, fig. 5-14), iron undergoes an allotropic transformation; that is, the arrangement of the atoms in the crystal changes. The new crystal structure is face-centered cubic, and the unit cell again consists of a cube with an iron atom at each of the eight corners, but with an iron atom in the center of each of the six faces instead on one in the center of the cube. This form is known as gamma (γ) iron. At 1670 °F (the A_3 point), iron undergoes another allotropic transformation and reverts to the body-centered cubic system. This structure, which is basically the same as the structure of delta iron, is stable at all temperatures below the A_3 point and is known as alpha (α) iron. The arrest at 1420 °F (the A_2 point), is not caused by an allotropic change. It marks the temperature at which iron becomes ferromagnetic and is therefore termed the magnetic transition. Above this temperature iron is nonmagnetic.

These various temperature arrests on cooling are caused by evolutions of heat. On heating, the arrests occur in reverse order and are caused by absorptions of heat. The critical points may be detected also by sudden changes in other physical properties, for instance, expansivity or electrical conductivity.

IRON-CARBON PHASE DIAGRAM

The complete iron-carbon phase diagram represents the relationship between temperatures, compositions, and structures of all phases that may be formed by iron and carbon under an equilibrium condition (very slow cooling). Figure 5-13 illustrates a portion of this diagram for alloys ranging up to 6.7 percent of carbon. The left-hand boundary of the diagram represents pure iron (ferrite), and the right-hand boundary represents the compound iron carbide, Fe_3C, commonly called cementite.

The beginning of freezing (change in state of metal from liquid to solid) of the various iron-carbon alloys is shown by line ABCD (fig. 5-13), termed the LIQUIDUS LINE. The ending of freezing is given by line AHJECF, termed the SOLIDUS LINE. The freezing point of iron is lowered by the addition of carbon (up to 4.3 percent) and the resultant alloys freeze over a range in temperature instead of at a constant temperature as does the pure metal iron. The alloy containing 4.3 percent carbon, called the eutectic alloy of iron and cementite, freezes at a constant temperature as indicated by point C (fig. 5-13). Eutectic is defined as an alloy or solution having its components in such proportions that the melting point is the lowest possible for this combination of components. The formation of a eutectic occurs when a molten alloy or solution of the proper composition freezes. This temperature (in iron) is 2065 °F, considerably below the freezing point of pure iron.

Carbon has an important effect upon the transformation temperatures of iron; it raises the A_4 temperature and lowers the A_3 temperature. This effect on the A_3 temperature is very important in the heat treatment of carbon and alloy structural steels, while the effect on the A_4 temperature is important in the heat treatment of certain high-alloy steels, particularly stainless types.

Solid iron can absorb various amounts of carbon, depending on the crystal structure of the iron and the temperature to which the iron is heated. The body-centered iron (alpha or delta) can absorb very little carbon, whereas the face-centered (gamma) iron can absorb a considerable amount as pure austenite, the maximum being about 2.0 percent at 2065 °F (fig. 5-13, point E). The solid solution of carbon in delta iron is called delta ferrite, and the solid solution of carbon in alpha iron is called alpha ferrite, or, more simply, ferrite.

The physical process by which iron-carbon alloys, especially those containing less than about 0.6 percent of carbon, solidify is rather complicated. All you really need to know, however, is that all iron-carbon alloys containing less than 2.0 percent of carbon (steel) will, immediately or soon after solidification is complete, consist of single-phase austenite. Cast irons containing greater than 2.0 percent carbon will consist of two phases immediately after solidification—austenite and cementite. Under some conditions this cementite formed on cooling through the temperature 2065 °F (ECF in fig. 5-13) will decompose partly or completely into austenite and graphite.

The part of the iron-carbon phase diagram that is concerned with the heat treatment of steel is reproduced on an expanded scale in figure 5-15. Regardless of the carbon content, steel exists as austenite above line GOSE. Steel of 0.80 percent carbon is designated as eutectoid steel, and those with lower or higher carbon as hypoeutectoid and hypereutectoid, respectively.

A eutectoid steel, when cooled at very slow rates from temperatures within the austenitic field, undergoes no change until the temperature reaches 1330 °F (line PSK) (fig. 5-15). At this temperature

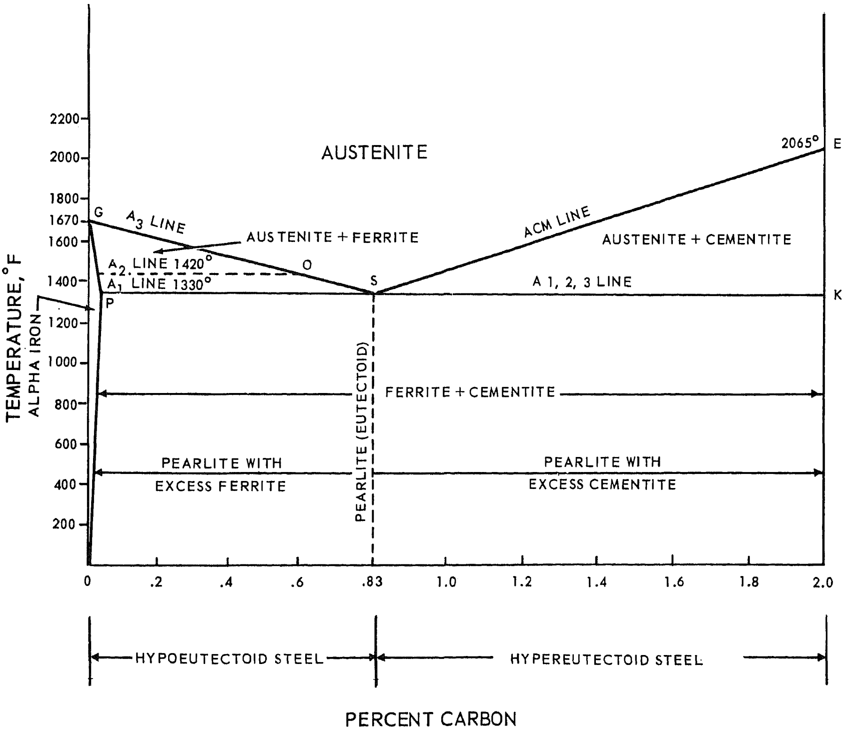

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Figure 5-15.—Phase diagram for carbon steels.

(known as the A_1 temperature), the austenite transforms completely to a mixture of ferrite and cementite having a typical lamellar structure (fig. 5-16). The mixture is known as pearlite, and the A_1 temperature is, therefore, frequently referred to as the pearlite point. Since the A_1 transformation involves the transformation of austenite to pearlite (which contains cementite—Fe_3C), pure iron does not possess an A_1 transformation (fig. 5-15). Theoretically, iron must be alloyed with a minimum of 0.03 percent of carbon before the first minute traces of pearlite can be formed on cooling (fig. 5-15, point P). If the steel is held at a temperature just below A_1 (either during cooling or heating), the carbide in the pearlite tends to coalesce into globules or spheroids; this phenomenon, known as SPHEROIDIZATION, will be discussed later.

A hypoeutectoid steel (less than 0.83 percent carbon), cooled slowly from a temperature above the A_3 temperature, begins to precipitate ferrite when the A_3 line is reached. This ferrite is often called pro-eutectoid, since it forms before the eutectoid temperature is reached. As the temperature drops from the A_3 to the A_1, the precipitation of ferrite increases progressively, and as the amount of the remaining austenite decreases progressively, its carbon content increases. At the A_1 temperature the remaining austenite reaches eutectoid composition (0.83 percent carbon) and, upon further cooling, transforms completely into pearlite (fig. 5-16, point D). The microstructures of slowly cooled hypoeutectoid steels thus consist of mixtures of ferrite and pearlite (fig. 5-16, points B and C). The lower the carbon content, the higher is the temperature at which ferrite begins to precipitate and the greater is the amount of hypoeutectoid steel in the final structure.

The temperature range between the A_1 and A_3 points is called the transformation range. Theoretically, the critical points in any steel should occur at about the same temperatures, whether the steel is being heated or cooled very slowly. Practically, however, they do not since the A_3 and A_1 points, affected slightly by the rate of heating, are affected tremendously by the rate of cooling. Rapid rates of heating raise these points only slightly, but rapid rates of cooling lower the temperatures of transformation considerably. To differentiate between the critical points on heating and cooling, the small letters *c* (for chauffage, meaning heating) and *r* (for refroidissement, meaning cooling) are added. The terminology of the critical points thus becomes Ac_3, Ar_3, Ac_1, Ar_1, and so on. The letter *e* is used to designate the occurrence of the points under conditions of extremely slow cooling on the assumption that this represents equilibrium conditions (Ae_3 and Ae_{cm}).

EFFECTS OF HEATING, HOLDING, AND COOLING

We have seen what happens to the structure of an iron-carbon alloy containing 0.8 percent carbon when it is cooled very slowly so that all of the transformations occur at the points indicated on the equilibrium diagram. In the same manner, we could use the equilibrium diagram to find the transformation points or ranges for other iron-carbon alloys containing different percentages of carbon.

If we want to create a metal that has a specific property or set of properties, we have to create a specific grain structure in the metal. We do this primarily by (1) heating the metal at a certain rate to a certain temperature, (2) holding or soaking it at that temperature for a specified time, and (3) cooling it at a specified rate. Thus the three major factors involved in all heat-treating processes are (1) rate of heating, (2) holding time (or soaking time) at the specified temperature, and (3) rate of cooling. A fourth factor—the chemical composition of the material surrounding the alloy during heat treatment—is important in nearly all treating processes.

The rate of heating determines where the changes will occur in the material as it is heated. Increasing the rate of heating raises the temperatures at which the transformations occur. Within certain limits, the faster the material is heated the higher its transformation temperatures will be. The temperature to which the material is raised and the time it is held at that temperature affect the size of the grains in the final structure. The rate of heating also partially determines whether or not stresses will be set up in the material by the process of heating.

The holding time (or soaking time) at temperature is important for a number of reasons. The holding time must be sufficient to allow all parts of the piece to come to a uniform temperature, except in those cases involving localized hardening of certain areas. If the rate of heating is very slow, uniformity of temperature may be reached with a short holding time. But if the rate of heating is rapid, a longer holding time will probably be required. In any case, holding time must be sufficient to allow the

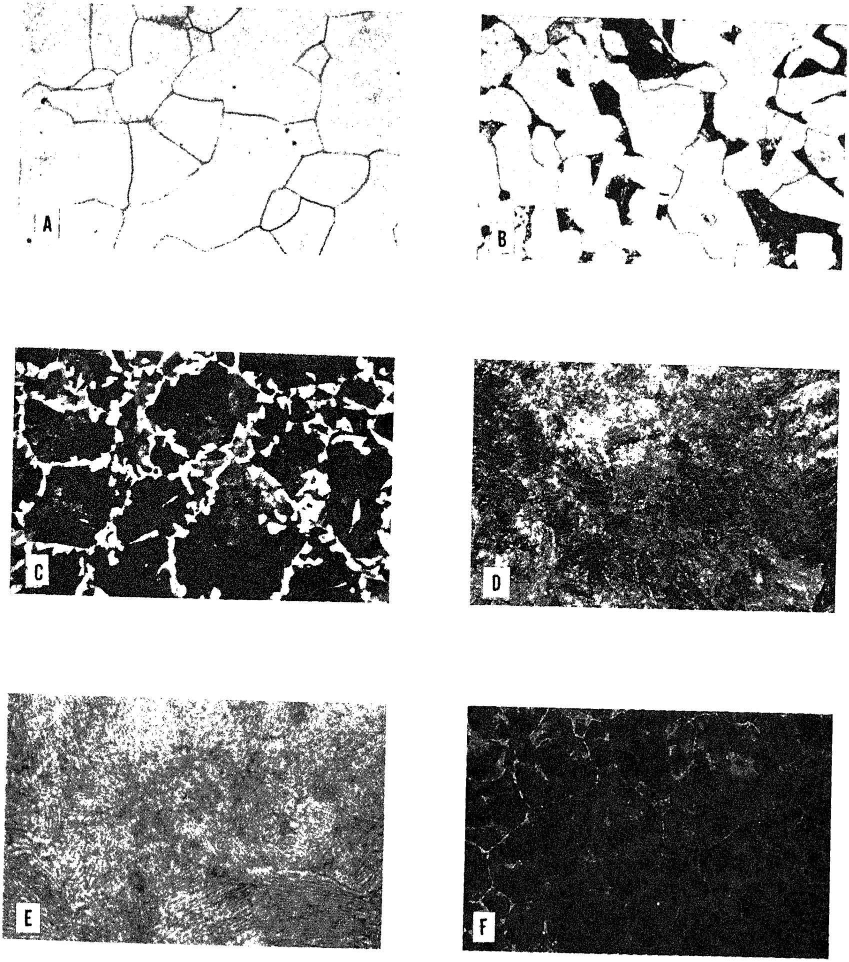

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Figure 5-16.—Microstructural constituents of slowly cooled carbon steels (all etched with either picral or nital).

required transformations to take place. As we have seen, the transformations do not occur instantaneously but require a definite time for completion.

The rate of cooling is tremendously important in most heat-treating processes. Increasing the rate of cooling lowers the temperatures at which the transformations occur; and the lower the transformation temperature, the stronger and harder the final product will be. Very rapid cooling does not allow time for the transformations to be completed in the normal manner, resulting in quite different structures than those obtained by very slow cooling of the same material. Remember this fact about cooling—if you do not cool a metal properly, you will not get the desired results, no matter how carefully you heat and soak the metal. In addition, very rapid cooling can cause internal stresses in your material, which may lead to cracking.

In plain carbon steel, the properties of the material are largely determined by the form and distribution of the ferrite and the cementite. Most heat treatment of plain carbon steels consists of heating the material slightly above its transformation temperature, holding it at this temperature until it is completely austenitic, and then cooling it at the rate required to produce a particular kind of structure. Thus austenite, a solid solution of carbon and gamma iron, might be considered the basis from which all plain carbon steel structures are derived.

As noted before, the very slow cooling of austenite to room temperature produces structures that are combinations of ferrite and cementite. The particular combination depends upon the percentage of carbon in the alloy. With less than about 0.83 percent carbon, the structure is a combination of ferrite and pearlite. With just about 0.83 percent carbon, the structure is entirely pearlitic. With more than 0.83 percent carbon, the structure is a combination of pearlite surrounded by cementite at the grain boundaries.

If the steel is cooled rapidly but not quite rapidly enough to retain the austenitic structure, quite a different structure will result. The austenite will be retained until the material reaches a temperature between 1100°F and room temperature. At this point there is a sudden transformation from austenite to a structure called MARTENSITE. Martensite is a very hard and highly stressed structure that is partially like a solid solution and partially like a mechanical mixture. It is formed at the moment gamma iron changes to alpha iron. Since gamma iron can hold a great deal more carbon in solid solution than alpha iron can, the change from gamma iron to alpha iron causes a sudden dispersion of very fine particles of carbon. Because the transformation from austenite is so rapid, these fine particles of carbon are trapped throughout the structure.

The rate of cooling is controlled by selecting an appropriate quenching medium and cooling procedure. Fresh water, brine, oil, and caustic soda in water are commonly used for rapid quenching. Slower cooling is obtained by air cooling, by packing, and by furnace cooling. Packing consists of burying the heated metal in sand, ashes, or some other substance that is a poor conductor of heat. Furnace cooling consists of shutting off the heat and leaving the piece in the furnace, so that the metal and the furnace cool together. Ferrous metals are sometimes cooled in baths of molten lead or molten salts. Occasionally, solid materials are used as quenching mediums. In each instance, the quenching medium and the quenching procedure must be selected on the basis of the nature of the material being treated, the size and design of the piece, and the properties that are required in the final product.

Isothermal Transformation

The course of transformation of austenite when the steel is quenched to and held at various constant elevated temperature levels (isothermal transformation) is shown by a diagram known as the transformation diagram (I-T diagram). This diagram is also called the Bain S-curve or the TTT diagram, for time, temperature, and transformation. Such a diagram for eutectoid carbon steel is shown in figure 5-17. The I-T diagram of a steel is a map that charts the transformation of austenite as a function of temperature and time and shows approximately how a particular steel will respond to any rate of slow or rapid cooling from the austenite state.

PEARLITE.—Austenite containing 0.80 percent of carbon, cooled quickly to and held at 1300°F, does not begin to decompose (transform) until after about 15 minutes, and does not completely decompose until after about 2 hours (fig. 5-17). Thus, at temperatures just below the critical temperature (Ac_1), austenite is stable for a considerable length of time. The product of the decomposition of austenite at this temperature is coarse pearlite of relatively low hardness. If the austenite is quickly cooled to and held at a somewhat lower temperature, say 1200°F, decomposition begins in about 3 seconds and is

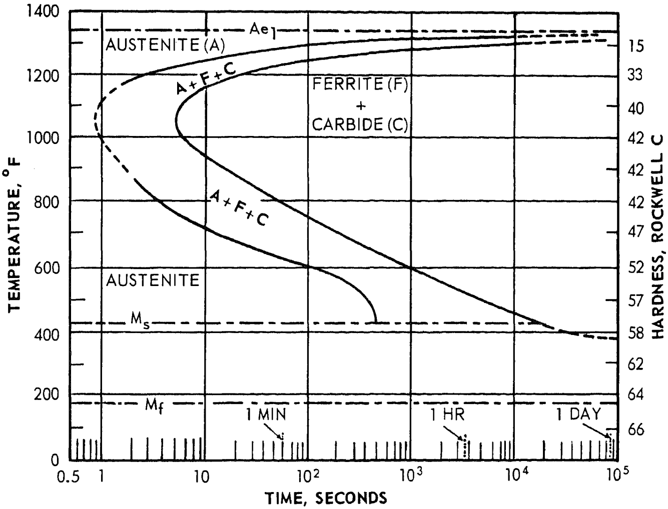

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Figure 5-17.—Isothermal transformation diagram (S-curve) for eutectoid carbon steel.

completed after about 30 seconds, the resultant pearlite being finer and harder than that formed at 1300 °F. At a temperature of about 1050 °F, the austenite decomposes extremely rapidly, with less than 1 second elapsing before the transformation starts and 5 seconds before it is completed. The resultant pearlite is extremely fine and its hardness is relatively high. This region of the S-curve where decomposition of austenite to fine pearlite proceeds so rapidly is called the "nose" of the curve.

BAINITE.—If the austenite is cooled unchanged to temperatures below the nose of the S-curve (1050 °F), the time required for its decomposition begins to increase. The final product of decomposition now is not pearlite, but a new structure, called bainite, possessing unusual toughness with hardness even greater than that of very fine pearlite. Depending on the temperature, a certain interval of time is necessary before austenite starts to transform into either pearlite or bainite. Additional time is necessary before the transformations are completed.

MARTENSITE.—If the austenite is cooled unchanged to relatively low temperatures (below about 430 °F for the eutectoid carbon steel under consideration), partial transformation takes place instantaneously; the product of transformation is martensite. Austenite transforms into martensite over a temperature range with the amount that transforms being a function of the temperature. Only minute amounts will transform at about 430 °F; practically all of the austenite will be transformed at about 175 °F. The beginning of this transformation range is termed the M_s (martensite start) temperature and the end of the range is termed the M_f (martensite finish) temperature. As long as the temperature is held constant with the M_s-M_f range, the portion of the austenite that does not transform instantaneously to martensite remains untransformed for a considerable length of time, eventually transforming to bainite.

In ordinary heat treatment of the plain carbon steels, austenite does not transform into bainite. Transformation of the austenite takes place either above or at the nose of the S-curve, forming pearlite, or in passing through the M_s-M_f range, forming martensite or both. For austenite to be transformed entirely into martensite, it must be cooled rapidly enough so that the temperature of the center of the steel, which cools more slowly, is lowered past the nose of the transformation to start at this temperature. If this is not done, part of the steel transforms into pearlite at the high temperature and the remainder transforms into martensite at the low temperature (M_s-M_f temperature range). The resulting material will then transform to a non-uniform structure that is usually not desirable.

Continuous Cooling

Figure 5-18 represents a theoretical S-curve on which are superimposed five theoretical cooling curves. Curves A to E represent successively slower rates of cooling that would be obtained, for instance, by cooling in (A) iced brine, (B) water, (C) oil, (D) air, and (E) the furnace.

Steel cooled according to curve E begins to transform at temperature t_1 and completes transformation at t_2; the final product is coarse pearlite with relatively low hardness. When the steel is cooled according to curve D, transformation begins at t_3 and is completed at t_4; the final product is fine pearlite and its hardness is greater than that of the steel cooled according to curve E. When the steel is cooled according to curve C, transformation begins at t_5 and is only partially complete when temperature t_6 is reached; the product of this partial transformation is very fine pearlite. The remainder of the austenite does not decompose until the M_s temperature is reached; then it begins to transform to martensite, and completes this transformation at the M_f temperature. The final structure is then a mixture of fine pearlite and martensite (typical of an improperly quenched steel) with a higher hardness than was obtained with the steel cooled according to curve D. The rate of cooling represented by curve B is just sufficient to intersect the nose of the S-curve. Consequently, only a minute amount of the austenite decomposes into fine pearlite at temperature t_7; the remainder of the austenite is unchanged until the martensite transformation range is reached. If the steel is cooled at a slightly faster rate, so that no transformation takes place at the nose of the S-curve, the steel is completely hardened; this particular rate is termed the critical cooling rate and is defined as the slowest rate at which the steel can be cooled and yet be completely hardened. Since this rate cannot be directly determined, the rate indicated by curve B, producing only a trace of fine pearlite, is frequently used as the critical cooling rate. The hardness of the resultant martensite is equivalent to the maximum that can

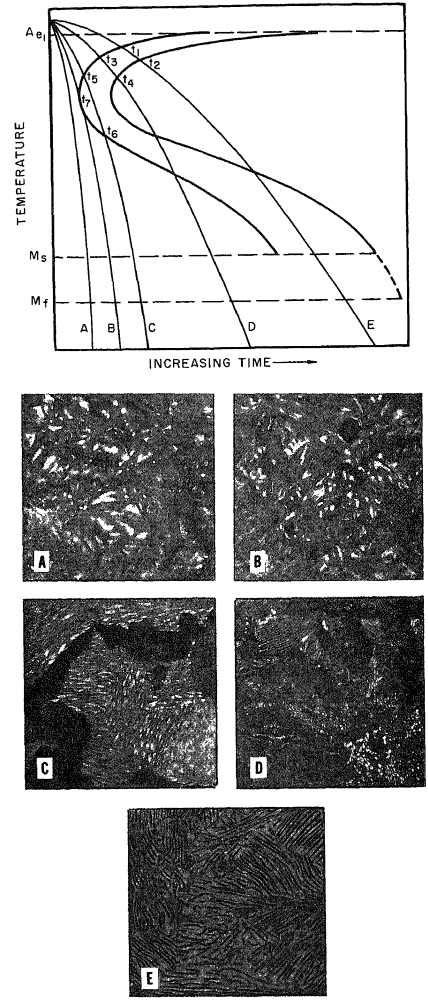

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Figure 5-18.—Schematic diagram illustrating the relation between the S-curve, continuous cooling curves, and resulting microstructures of eutectoid carbon steels.

be obtained. Samples cooled at a faster rate, such as that indicated by curve A, are also completely martensitic but are no harder than the sample cooled according to the critical cooling rate.

The rate at which a steel cools through the temperature in the vicinity of the nose of the S-curve is of critical importance. Somewhat slower rates of cooling above and below this temperature range can be tolerated and a completely hardened steel (one that is completely martensite) can be obtained if the cooling through the temperature interval at the nose of the S-curve is sufficiently fast. In practice, however, steels are usually cooled rapidly from the quenching temperature to relatively low temperatures (20° to 250°F) and then tempered immediately to prevent cracking.

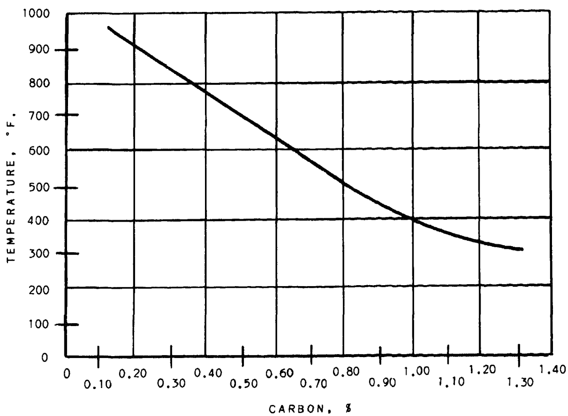
Although the above discussions of the decomposition of austenite have been limited to a steel of eutectoid composition, other steels behave in a similar manner, at different temperatures and times of reaction. In hypoeutectoid steels, free ferrite plus pearlite are formed if transformation begins above the temperature range at the nose of the S-curve. The amount of free ferrite decreases as the temperature of transformation approaches the nose of the curve. In hypereutectoid steels, free ferrite plus pearlite are formed if transformation occurs above the nose. The time for the start of the transformation at the nose increases as the carbon increases up to the eutectoid composition, and then decreases with further increase in carbon. That is, the nose is shifted to the right on the time axis (fig. 5-17) as the carbon is increased to 0.8 percent and back to the left with further increases in carbon content.

The temperature of formation of bainite is not appreciably affected by carbon content, but the time for its formation increases with the carbon.

Both the M_s and the M_f temperatures are lowered significantly by increasing carbon content as shown for M_s in figure 5-19. The M_f temperatures of the plain carbon steels have not been adequately determined; available information indicates that the M_f of high carbon steels is actually below room temperature. Slight amounts of austenite are frequently retained in quenched steels, especially in the higher carbon grades, even when they are cooled to room temperature.

HEAT-TREATING FERROUS METALS

The heat-treating processes most commonly used for ferrous metals are hardening, tempering, annealing, normalizing, spheroidizing, and case hardening. Annealing is the only one of these



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processes that is also used for nonferrous metals. Some nonferrous metals (including some aluminum alloys and some magnesium alloys) can be hardened by a process generally referred to as precipitation heat treatment. Precipitation hardening is discussed in the section of this chapter on nonferrous metals. Figure 5-20 shows the heat treatment temperature ranges. You should refer to this figure as you study the following information on hardening, normalizing, and spheroidizing temperatures.

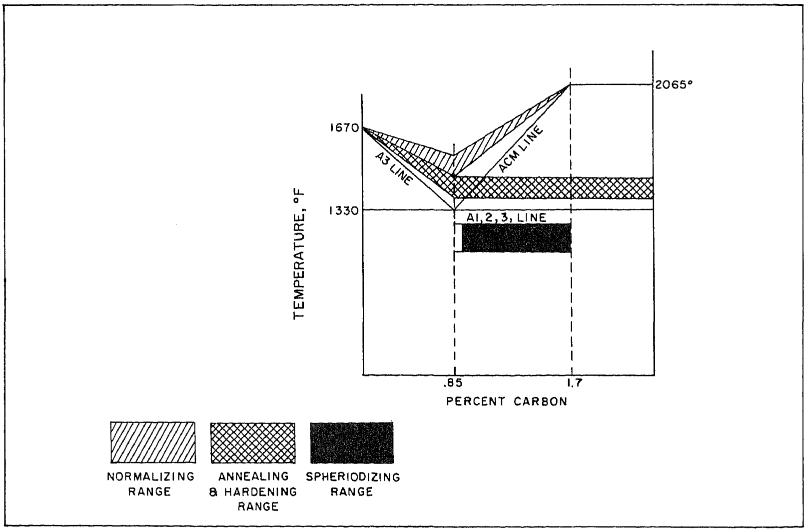
HARDENING

Many tools and pieces of equipment must be hardened before they are used. Cutting tools, chisels, twist drills, and other tools must be hardened so that they can retain their cutting edges. surfaces of roller bearings, parallel blocks, and armor plate must be hardened to prevent wear and penetration. Hardening is used to increase tensile strength as well as to increase hardness. Since hardening increases the brittleness of the material, most alloys are tempered after being hardened.

Steels are hardened by being heated to a temperature just above the upper transformation temperature, soaked long enough to ensure a completely austenitic structure, and then cooled rapidly. This result is either fine-grained pearlite, bainite, or martensite. If maximum hardness is to be developed, the austenite must be transformed to martensite. Martensite is extremely hard and strong, has great resistance, and has practically no machinability.

Carbon steels are usually quenched in brine or water to ensure rapid cooling. The production of martensite throughout a plain carbon steel is extremely difficult, requiring that the steel be cooled to below 1000 °F in less than 1 second, and that the remainder of the cooling be quite rapid. If more than 1 second is taken for the first part of the cooling (to below 1000 °F), some of the austenite will transform into fine pearlite. Pearlite varies in hardness, but it is much softer than martensite. If the purpose of the hardening is to develop something less than maximum hardness, the first part of the cooling (to below 1000 °F) must still be accomplished within 1 second; then the remainder of the cooling must be done at a somewhat slower rate.

The rate of quenching alloy steels depends upon the composition of the material. In general,



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a slower quench is used for hardening alloy steels than is used for hardening plain carbon steels.

Various quenching mediums are used to produce the desired end results. The more common quenching mediums are oil, water, and brine. When water or brine is used, the temperature of the bath must not rise above 80 °F. Generally, 70 °F is the best temperature for these quenching mediums. Above 80 °F, water loses thermal conductivity.

The plain carbon steels are generally quenched in water or brine; brine is preferred because it has less tendency to cause steam pockets to form. Steam pockets may cause soft spots or uneven stresses. These steel require a very active agitation or shaking action when quenched. The agitation removes the steam bubbles from the surface of the metal. When the quenched material reaches about 200° to 250 °F, or a temperature low enough to dry the material thoroughly without too much sizzle, it can be removed from the water and tempered immediately.

The alloy steels, with the exception of the high-alloy air-hardening steels, are generally oil quenched. The oil bath should be maintained at a temperature of 100° to 130 °F. (This is just below the M_f line of most low-alloy steels.) At this temperature the heat-treating oils have a higher viscosity and therefore a better and more uniform cooling effect. The arm oil also results in a more moderate coolng rate, which lessens the chance of residual stresses and cracking.

Although steels must be heated and soaked so the structure becomes completely austenitic, you should take care to see that they are not overheated and that they are not held too long at temperature. Using too high a temperature or too long a soaking period allows a coarse grain structure to develop.

TEMPERING

After hardening, most alloys are tempered to reduce brittleness and to relieve some of the high internal stresses developed during hardening. Tempering always follows, rather than precedes, the hardening process. Tempering is occasionally done after materials have been normalized, but its major use is after hardening.

In high-speed steels, tempering increases hardness. In most other materials, however, tempering causes an unavoidable loss of some hardness. The amount of hardness removed by tempering depends upon the tempering temperature; the higher the temperature, the softer the material will be.

Tempering is always done at temperatures below the lower transformation point. In this respect, tempering differs from hardening, annealing, and normalizing, which all involve heating the material to temperatures above the upper transformation point.

The temperatures used for tempering are selected on the basis of the properties required in the final product. For example, permanent magnets are tempered at 121 °F because they must retain considerable strength and hardness. Case-hardened objects are also tempered at relatively low temperatures (212° to 400 °F) because the surface of such objects must remain hard. Many cutting tools are tempered at 430 °F or below so they will retain hardness. Battering tools must have great impact resistance and must be able to cut or penetrate metal; therefore, battering tools are tempered between 450° and 600 °F even though the higher temperatures mean some sacrifice of hardness in order to produce impact resistance. Springs are tempered between 600° and 900 °F because the property of elasticity is more important in a spring than the property of hardness. Tools made of high-speed steels are tempered at 1050° to 1100 °F. Note, however, that with high-speed tools the high tempering temperature increases, rather than decreases, hardness. This increase in hardness occurs because high-speed steels retain austenite during quenching; when the hardened steel is tempered, the austenite changes to martensite.

Since tempering uses temperatures below the lower transformation point, the rate of cooling generally has no effect upon the structure of the material. However, some nickel-chromium steels and a few other special steels become brittle if they are heated to the tempering temperature and then allowed to cool slowly. These steels, which are often called temper brittle or blue brittle steels, must be quenched rapidly from the tempering temperature to prevent brittleness. In general, however, steels are cooled slowly from the tempering temperature by cooling in still air.

Tempering is usually done before the material has completely cooled from the hardening process. The holding time at temperature varies according to the thickness of the material, but the minimum time is about 1 hour. If the part is more than an inch thick, the holding time should be increased by about 1 hour for each additional inch of thickness.

ANNEALING is a term used to describe any heat-treatment process that is used for the primary purpose of softening the metal. Two types of annealing processes are commonly used. FULL ANNEALING is done in order to soften the metal and make it more ductile, and to relieve internal stresses caused by previous treatment such as casting, cold working, or hot working. The operation known as PROCESS ANNEALING or STRESS RELIEF ANNEALING is done to soften the metal somewhat, although not as much as by full annealing, and to relieve internal stresses.

In general, full annealing requires higher temperatures, longer soaking time, and slower cooling than process annealing. In the full annealing of steels, the steel is heated to a temperature that is 50° to 100°F above the upper transformation point. In the process annealing of steels, lower temperatures (1020° to 1200°F) are generally used. The rate of cooling used for annealing varies greatly, depending upon the metal being annealed and the degree of softening required. When a steel is to be softened as much as possible, the rate of cooling is slowed either by packing or by furnace cooling. When less softening is required, a faster rate of cooling is used; air cooling is commonly used in annealing both ferrous and nonferrous metals.

NORMALIZING

The form of heat treatment known as NORMALIZING is used only for ferrous metals. Normalizing is in many respects similar to annealing, and is often regarded as a special form of annealing. Normalizing is sometimes used as a preliminary step before full annealing. The chief purposes of normalizing are (1) to relieve internal stresses caused by forging, bending, machining, or other working, or by uneven cooling; and (2) to give a uniform predictable grain structure. Steel that has been normalized is soft and ductile enough for many purposes, but it is harder than steel that has been fully annealed. Normalizing is sometimes followed by tempering, particularly in the case of certain steels that tend to become brittle when normalized.

In normalizing, the steel is heated to a temperature above the upper transformation point and is cooled in still air.

SPHEROIDIZING is a term used to describe any heating and cooling process that produces a rounded or globular form of iron carbide in the steel. This globular or spheroidal form of iron carbide is developed when fine pearlite is heated to a temperature just below the lower transformation point of the steel, held at this temperature for a long time, and then cooled very slowly. Temperatures, holding time, cooling rates, and other details of the process vary, depending upon the carbon content of the steel and the extent of spheroidizing that is required. In general, the object of spheroidizing is to improve machinability. Spheroidizing is sometimes regarded as being a special annealing or normalizing process. The typical globular form of spheroidized steel is illustrated in cross section in figure 5-21.

AUSTEMPERING

AUSTEMPERING is a hardening treatment of metals that involves quenching the metal in a bath of molten salt maintained above the start of the martensite temperature and holding it until transformation is complete. The product formed is called bainite.

There are two distinct advantages of austempering—(1) the high degree of freedom it provides from distortion and quenching cracks,

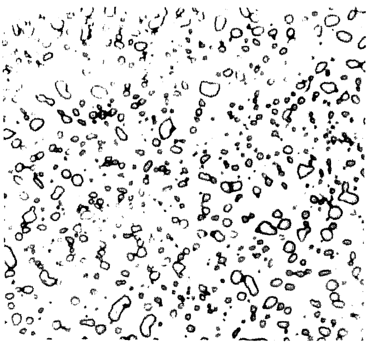

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Figure 5-21.—Microscopic structure called spherodite magnified 1000 times.

and (2) normal tempering is not required after the process.

MARTEMPERING

MARTEMPERING is the quenching from the normal austenitizing temperature in a molten salt bath maintained at approximately the start of the martensite temperature. The part is held at this temperature long enough to allow equalization of temperature throughout the piece, but not long enough to allow any transformation to take place. The material being heat-treated is then removed from the hot bath and allowed to air cool through the martensite temperature range, followed by tempering to obtain the desired mechanical properties. This two-step cooling process has the same advantage as austempering—freedom from distortion and quenching cracks.

CASE HARDENING

CASE HARDENING is a process by which a steel can be given a hard, wear-resistant surface while retaining a softer but tougher interior than would be possible if the whole piece were hardened. Steels may be case hardened by carburizing, cyaniding, nitriding, and various other processes.

CARBURIZING is a term applied to several case-hardening processes in which carbon is introduced into the surface layer of the steel. The steel is heated in contact with a substance that has a high carbon content; it is held at a temperature above the upper transformation temperature for a suitable length of time, and is then quenched rapidly to produce a hardened outer layer or "case" over a softer, tougher core. As a rule, carburizing increases the hardness to a depth of from 0.02 inch to about 0.06 inch.

Sometimes the steel to be carburized is packed in a substance such as charcoal and is then heated in a furnace. The length of time the piece is left in the furnace determines the depth to which the carbon will be absorbed. For many pieces the procedure is to carburize the material, allow it to cool slowly, reheat it, and then harden it by quenching. Small pieces are sometimes dumped into the quenching medium as soon as they are removed from the carburizing furnace.

Other methods of carburizing use gases or liquids that have a high carbon content. Although these methods also use the principle of increasing the carbon content in order to harden the outer shell or case of the steel, they use different equipment and different procedures.

CYANIDING is a case-hardening process that gives a very thin case or skin of hardened steel. As a rule, the hardened case does not exceed 0.010 inch. The steel to be cyanided is put into a bath of sodium cyanide, at a temperature between 150° and 1600°F, and is left there for the time required to develop the desired depth of hardening. The steel absorbs some of the carbon and nitrogen that are liberated as the sodium cyanide is heated in contact with air. After being removed from the sodium cyanide bath, the steel is quenched immediately in water or oil.

NITRIDING is still another method by which a case or skin of hardened steel can be produced. The piece to be case hardened is put into a furnace and heated to between 900° and 1200°F and, at the same time, is exposed to ammonia gas. The heat of the furnace causes the ammonia to break down into nitrogen and hydrogen. Some of the nitrogen combines with the elements in the steel to form chemical compounds called nitrides in the outer layer of the steel. These nitrides give the surface its hard, wear-resistant qualities.

CARBON TOOL STEELS

Carbon tool steels used by the navy are listed under QQT-580. The Navy classes C1, C2, C3, C4, C5, and C6 are no longer classified as such. Use the following list as a guide:

	Federal Class	SAE#
C1	W1-10	SAE 1095
C3	W1-09	SAE 1090
C4	W1-08	SAE 1080
C5	01	None
C6	W1-NDR or W1-12	None

The carbon content of plain carbon steels ranges from about 0.70 to 1.13 percent. To heat treat these steels, heat them uniformly to 1450° to 1550°F, using the lower end of the temperature range for the higher carbon content. Use brine or water as the quenching medium, and agitate the part vigorously to prevent the accumulation of bubbles on the surface of the metal. Do not remove these steels from the quench until they have reached a temperature of less than

200° to 250°F. To prevent cracking, do not allow the steel to cool below 125°F and follow the cooling immediately with tempering. Tools made from these steels do not have to withstand severe usage or high cutting speeds. Some examples are wrenches, hammers, pliers, knives, simple dies, and low-speed cutting tools.

Table 5-4 will assist you in choosing the proper quenching medium and temperatures for the standard SAE steels.

ALLOY TOOL STEELS

The number of alloy tool steels is too great to include them all in this text, so we will deal with the type most important to you. You, as a Machinery Repairman, are concerned primarily with the manufacture of taps, dies, reamers, hobs, and form tools. An all-around tool steel for this purpose is type 01. This steel is listed under QQT-570 and is available in the standard stock system in various shapes and sizes. Type 01 is suitable for all applications except where a high-speed steel is required. It heat treats well and is readily machinable in the spheroidized condition. Type 01 stock replaces the 46S40 class C-5.

Type 01 should be preheated slowly to 1200°F, then transferred to an oven at 450°F and soaked at heat for about 20 minutes per inch of cross section, and then quenched in warm oil (120° to 140°F). Do not remove the material from the oil bath until you can hold the work comfortably in your hand. This procedure should result in a minimum hardness of 65 Rc. Temper to the desired hardness. Use the following tempering temperatures as a guide for type 01 steel:

Tempering Temperature (°F)	Hardness (Rc)
300	64-65
350	63-64
375	62.5-63
400	62-62.5
450	60-62
500	59-60
600	57-58
700	54-55

HEAT-TREATING NONFERROUS METALS

The information in this section deals primarily with the heat-treating of nonferrous alloys. For specific information on a particular composition, consult the *Metals Handbook*, published by the American Society for Metals, or any handbook that deals with heat-treating nonferrous metals.

You can anneal most nonferrous metals by heating them uniformly within a certain temperature range, soaking them within this temperature range, and then cooling them back to room temperature. In most cases, the annealing temperature for most nonferrous metals is the temperature at which recrystallization takes place. For example, aluminum recrystallizes at a temperature of 300°F and copper recrystallizes at 390°F.

The rate at which the metal may be cooled from the annealing temperature depends upon the type of metal. If the metal is pure, or nearly so, or if it remains a solid solution without precipitation when cooled, any method of cooling is usually satisfactory. If, on the other hand, the constituents precipitate during or after cooling, furnace cooling may be necessary for complete annealing to occur.

There are two types of heat treatment of nonferrous alloys—the solution treatment and the precipitation treatment. Some alloys require both treatments. Others require only the solution treatment.

The solution treatment consists of heating the alloy to the temperature at which the principal constituents go into solid solution, soaking the alloy at this temperature to produce a uniform structure, then cooling it at a rate fast enough to retain the solid solution at room temperature. You should remain aware that different alloys have different solution temperatures.

After a nonferrous alloy has been solution treated, it is in a form of supersaturated solid solution. For the alloy to attain maximum hardness and strength, excess hardening constituents that are soluble at room temperature must precipitate from the solid solution. After the precipitation is complete and the alloy has reached its full hardness and strength, it is said to be AGE HARDENED. Alloys that do not precipitate at room temperature are given the precipitation treatment called artificial aging. Precipitation from aging or artificial aging usually causes an increase in hardness strength and a decrease in ductility.

The following definitions will aid you in understanding some of the terminology used in heat-treating nonferrous alloys:

- Homogenizing—a mill process that uses high temperature for prolonged periods to

Table 5-4.—Heat Treating Temperatures and Quenching Medium for Standard SAE Steels

SAE NO.	NORMALIZING TEMP. (° F)	HARDENING TEMP. (° F)	QUENCH	TEMPERING TEMP. (° F)
1020	1650-1700	1600-1650	water	200
1030	1650-1700	1600-1650	water	200
1040	1600-1650	1500-1550	water	200
1050	1600-1650	1500-1550	water	200*
1060	1550-1600	1450-1550	water or oil	200* #
1070	1550-1600	1450-1550	water or oil	200* #
1080	1550-1600	1450-1500	water or oil	200* #
1090	1550-1600	1450-1500	water or oil	200* #
1345	1600-1700	1450-1500	oil	200*
2345	1600-1700	1450-1500	oil	200*
3140	1600-1650	1500-1550	oil	200*
4130	1600-1650	1550-1600	water	200*
4140	1600-1650	1525-1575	oil	200*
4340	1600-1650	1475-1525	oil	200*
4060	1550-1600	1500-1550	oil	200*
5140	1600-1650	1500-1550	oil	200*
5210	1550-1600	1425-1475	water	200*
6150	1600-1650	1550-1600	oil	200*
8630	1600-1650	1550-1600	water	200*
8640	1600-1650	1525-1575	oil	200*

*Stress relieve at 200° F for one hour immediately after quenching. Temper to desired hardness.

#Use water for maximum hardness. Use oil for toughness and for intricate shapes.

Note: Temperature of water quench is 70° F.
Temperature of oil quench is 120-150° F.

eliminate or decrease segregation in castings that are to be hot- or cold-worked. This process is usually used for copper alloys.

- Stress equalizing—a low temperature heat treatment used to balance stress in cold-worked material with decreasing mechanical strength properties induced by the cold-working. Nickel and nickel alloys may be subjected to this heat treatment, depending on their chemical composition, and the fabrication requirements and intended usage of the parts made from the metals.

HEAT-TREATING PROBLEMS

No matter how carefully you follow instructions for heat-treating, you may occasionally find yourself with a job that just will not turn out right. To some extent you can avoid this problem by knowing in advance something about the many problems encountered in heat-treating metals and alloys. The most common heat-treating problems include (1) design problems, (2) cracking, (3) warping, (4) soft spots, (5) size changes, and (6) spalling.

DESIGN PROBLEMS

Although you are not usually in a position to do much, if anything, about the design of a piece to be heat treated, you should have some knowledge of the effects of design upon heat treatment. Unsatisfactory performance of tools and structural parts is often the result of poor design rather than poor materials, poor fabrication, or incorrect heat treatment. Errors in design cannot be corrected by heat treatment, but you can minimize the problems of heat-treating a poorly designed piece if you know how to compensate for design errors when heat-treating the piece.

When a piece of metal is removed from the heat-treating furnace, its temperature is uniform throughout. Whether or not this piece will cool uniformly depends largely upon the design. Uniform cooling is, of course, a slightly inaccurate term; no piece of metal can cool with perfect uniformity, since some parts of it must always cool before others. In a well-designed piece, however, the cooling is as uniform as possible for a piece of that particular composition and size.

For example, consider the cooling of a cube of steel. The surfaces of the cube will cool evenly except at the edges and at the corners. At each edge there are two surfaces that dissipate heat at the same time, and at each corner there are three surfaces. Consequently, the corners cool more rapidly than the edges, and the edges cool more rapidly than the surface areas that are not at the edges or corners. If the rate of cooling is extremely rapid, the difference in cooling rate between corners, edges, and other surface areas could be sufficient to cause cracking.

Unequal masses in a single piece are likely to cause trouble when the piece is heat treated. View A of figure 5-22 shows a cam that might very well become distorted or cracked during heat treatment because the mass of area X is smaller than the mass of area Y. View B of figure 5-22 shows how the masses of the two areas may be equalized, while still keeping the required shape of the cam. The design shown in part B would not be as likely to distort or crack during heat treatment.

The piece shown in view A of figure 5-23 has two design features that would make heat treatment difficult. First, it has unequal masses; and second, it has sharp junctions where the smaller mass joins the larger end portions. A better design for heat treatment is shown in view B of figure 5-23. Although the piece must necessarily have unbalanced masses, the use of a fillet (indicated by an arrow in figure 5-23, part B) at each junction of the smaller and the larger masses

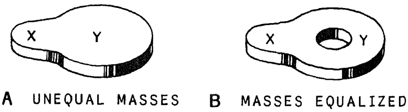

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Figure 5-22.—Design of a cam. A. Unequal masses not satisfactory for heat treatment. B. Equalized masses satisfactory for heat treatment.

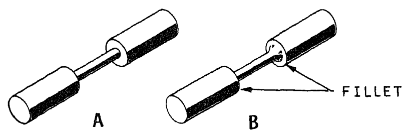

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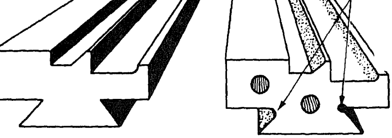
Figure 5-23.—A. Part with unequal masses and sharp corners. B. Use of fillet design to reduce danger of cracking during heat treatment.



A INCORRECT B CORRECT

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Figure 5-24.—Two designs for undercutting a form tool. A. Poor design. B. Correct design.

vould tend to reduce the danger of the piece :racking from heat treatment.

Figure 5-24 shows two designs for an ındercutting form tool. The design shown in part A does not lend itself to heat treatment because of the combination of heavy and light sections and because of the sharp corners. The design shown n part B corrects both of these errors. The :orners have been rounded where possible, and holes have been drilled through the two heaviest sections to make the masses more nearly balanced.

In general, parts that are designed with sharp :orners or unequal masses are extremely difficult o heat-treat. When the design cannot be mproved, you will have to determine the best way o heat-treat the part to reduce the chances of :racking or distortion.

Even with a poorly designed part, there are wo ways in which you can usually reduce the problems of heat-treating. First, you can select he method of cooling that will be safest while still producing the required properties in the metal. For example, flush quenching of some areas might help to solve the problem. And second, you can shield the danger spots by packing them with asbestos and sheet steel or other materials to reduce the rate of heating and the rate of cooling n the areas that would otherwise tend to distort or crack. Shielding materials for steel are usually fastened in place with soft iron wire; the wire must have a very low carbon content, so that it will not become hard and brittle and fall off during the heat treatment. Holes near an outside edge or between an edge and an interior opening are usually packed with asbestos rope. Asbestos tents are sometimes used to retard the rate of heating of thin sections. These tents are removed before he piece is quenched, so they are usually

CRACKING

Cracking during heat treatment may be caused by heating the material unevenly, by heating it to too high a temperature, by soaking it for too long a time, or by quenching it so that it cools unevenly. Some steels are given extra preheats to minimize the danger of cracking from uneven heating. Steel that has been overheated or soaked should be allowed to cool in air to room temperature, and then it should be heated to the correct temperature. However, metals and alloys that have been severely overheated cannot be salvaged; they are actually burned, and no amount of subsequent heat treatment can restore them to their original condition.

Uneven cooling is a major cause of cracking, particularly in some steels. Factors that contribute to uneven cooling are poor design, the presence of scale or other material on the surface of the metal, and the presence of gas pockets in various recesses of the part. Scale should usually be removed before the material is quenched. Gas pockets in recesses of the part can be avoided by circulation or agitation of the quenching medium.

Tool steels that have been deformed or worked while cold tend to crack during hardening unless they are fully annealed before the hardening treatment is started. These steels must also be tempered immediately after they are hardened.

WARPING

Any change of shape in the form of a twist or a bend is known as warping. Poor design, uneven heating through the lower temperature range, and uneven cooling are common causes of warping. Preheating tends to minimize the danger of warping from uneven heating. Annealing parts before hardening them will sometimes prevent warping; this is particularly true of parts that are rough machined on one side and smooth ground on the other. Air-hardening steels tends to warp them if they are not protected from drafts while being cooled.

SOFT SPOTS

Soft spots in a hardened piece can usually be traced to the use of the wrong quenching medium, the use of incorrect quenching procedures, the presence of scale on some parts of the surface, or the use of the wrong kind of tongs for handling the material. Soft spots in case-hardened steels are usually caused by packing the pieces so that they touch each other or by not having the packing compound touching the piece completely.

Soft spots will result when plain water is used as a quenching medium, if the vapor stage of the quench is not broken up. In this stage, air bubbles or air pockets form on the surface of the metal and retard the cooling rate wherever they touch the metal. Listed below are some precautions you should take to avoid creating soft spots.

- Use tongs that coincide with the shape of the piece. Covering too large a surface area will often retard the cooling rate.

- Do not handle the piece while it is hot with tongs that have not been preheated. If you do, you will tend to draw the heat from the piece and will bring the temperature below the required range.

SIZE CHANGES

Some permanent change in dimensions may occur during heat treatment. In some cases this change of size is unavoidable; in others it is merely the result of incorrect heat treatment.

Oil-hardened and air-hardened steels tend to shrink during hardening. This size change is normal, and cannot be prevented. However, it must be allowed for in the design of any part that must be precisely dimensioned. These steels tend to shrink excessively, more than the normal amount, if they are not heated sufficiently for hardening. They tend to increase in size if they are overheated. Very close control of temperature is necessary for successful heat treatment of these steels.

When metal scales, some of the surface metal is lost. Thus, scaling causes a decrease in size. Scaling can usually be prevented by controlling the furnace atmosphere. If furnaces with controlled atmospheres are not available, use a reducing atmosphere for stainless steels and high-speed steels, and an oxidizing atmosphere for carbon steels and oil-hardened steels.

Nitrided steels increase in dimension during the nitriding process. This increase in size cannot be prevented, but parts to be nitrided should be machined slightly under size to allow for the increase.

Steel that has been cold-drawn may undergo a permanent increase in size when it is heated, chiefly because cold-drawing leaves the metal highly stressed. The size increase in cold-drawn steel can be avoided by annealing the steel before machining the parts to size.

Excessive shrinkage occurs whenever there is a great difference in the cooling rates of the outer and the inner portions of the metal being heat-treated. The flush quenching method should be used to prevent shrinkage of the metal being heat-treated.

SPALLING

Spalling is the surface cracking or flaking of steel. The cracks are usually very shallow, but in severe cases fairly large sections of the surface may peel away.

In carburized steel, spalling is caused by an undesired carbide network which forms of the grain boundaries. To prevent spalling in carburized steel, quench the parts immediately upon removing them from the carburized medium if the grains have not increased in size. If there has been an increase in grain size, reheat the metal to its critical temperature of the core and the case. Improper use of a grinding wheel and insufficient use of coolant to keep the surface of the metal cool at all times will also cause spalling.

BLISTERING

Special care must be taken in heat-treating wrought aluminum alloy to prevent blistering. It is caused by overheating and, in some cases, oversoaking. Parts that have been blistered by heat-treating can be placed in service by scraping.

CHAPTER 6

MACHINE TOOL MAINTENANCE

Maintenance is one of the most important jobs you will encounter in the Navy. The degree of accuracy to which you can machine a part is often directly related to the condition of the machine tool you are using. As a Machinery Repairman you may be assigned to a tender, to a repair ship, or to various shore installations that have a variety of equipment. You will be responsible for the preservation, maintenance, and repair of equipment in your shop. One of your jobs, as an MR1 or MRC, will be to enforce the proper use and care of machinery. Therefore, you should be familiar with the operating procedures for every piece of equipment in the shop. Proper care and maintenance of materials, tools, and equipment are closely related to efficient, safe, and economic operation of the machine shop. As a supervisor, you must ensure your people are fully qualified to operate a piece of equipment before allowing them to work with limited supervision.

MAINTENANCE PROGRAM

Establishing a MAINTENANCE PROGRAM in your shop and making sure it is carried out will ensure your equipment will receive the proper care it deserves. The maintenance program must be designed locally to meet local needs since no two machine shops are arranged in exactly the same way or are equipped with identical tools. The Navy implemented the *Ships' Maintenance and Material Management (3-M) Manual*, OPNAVINST 4790.4 (series), as an answer to the problem of maintaining a high degree of operational readiness. The 3-M Systems, together with the maintenance manual of each machine, cover most of the maintenance required on machine tools used by Machinery Repairmen and must be applied to the equipment maintenance program. The following is a brief summary of the Ships' Maintenance and Material Management (3-M) Systems.

THE 3-M SYSTEMS

The Ships' 3-M Systems are management tools designed to provide an efficient and uniform method for conducting and recording PREVENTIVE and CORRECTIVE maintenance in a way that allows fast and easy access to the collected data. Preventive maintenance includes actions taken to prevent equipment from failing, such as changing the oil, cleaning or replacing filters, making required calibrations, or simply cleaning each machine before and after its use.

If preventive maintenance is not done properly, or not done at all, your equipment may be put out of commission until repairs are made.

The other type of maintenance, corrective maintenance, includes all the actions required to restore equipment to an operational condition.

The Ships' 3-M Systems apply to all ships' service craft, small boats, and nonaviation fleet support equipment. Equipment used ashore, which is identical to shipboard equipment, must be maintained under the Preventive Maintenance System. OPNAVINST 4790.4 (series), contains all of the detailed procedures and instructions for the effective operation of the 3-M Systems. Other instructions on the 3-M Systems are found in the type commander's maintenance manuals.

This section of the chapter will discuss the most common records of the 3-M Systems that must be kept current in the Engineering Department.

PLANNED MAINTENANCE SYSTEM (PMS)

The Planned Maintenance System is a standardized method for planning and scheduling preventive maintenance. You must give careful attention to the PMS schedules to ensure they are accurately filled out and posted in a timely manner. PMS schedules are categorized as cycle, quarterly, and weekly.

The cycle schedule identifies all the planned maintenance assigned to the work center and the quarter in which the maintenance is to be done. A quarter is a 3-month time frame, such as January, February, and March. The schedule runs from one overhaul to the next overhaul.

The quarterly schedule is based on the cycle schedule. The planned maintenance checks listed for the quarter on the cycle schedule are transferred to the quarterly schedule. The quarterly schedule assigns checks on the basis of weeks. A check is placed in the proper column to show in which week of a quarter a check has to be made. If the maintenance is a monthly check, you must list it three times, once in each month.

The weekly scheduled is based on the quarterly schedule. At the end of a week, all of the checks listed for the next week are transferred to the weekly schedule and placed in the column for the day desired. Daily and weekly checks appear only on the weekly schedule.

The major components of the PMS are the maintenance requirement card (MRC), the maintenance index page (MIP), and the list of effective pages (LOEP). These components are discussed in your 3-M manual.

SHIP'S MAINTENANCE ACTION FORM

The Ship's Maintenance Action Form, OPNAV 4790/2K, is used by maintenance personnel to report both deferred and completed maintenance actions (including those previously deferred). This form also allows the entry of screening and planning information for management and control of intermediate maintenance activity workloads.

The OPNAV 4790/2K is originated in the work center, screened by the division officer and engineer officer for accuracy and legibility, and initialed by the division officer and the engineer officer before being forwarded to the 3-M coordinator. When the OPNAV 4790/2K is used to defer maintenance, the 3-M coordinator will send two copies of the form back to the originating work center to hold on file. When the deferred maintenance is completed, one of the copies is used to document the completion of the maintenance.

CURRENT SHIP'S MAINTENANCE PROJECT (CSMP)

The standard CSMP is a computer-produced report listing deferred maintenance and alterations that have been identified through Maintenance Data System (MDS) reporting. Copies of the CSMP should be received aboard ship monthly. The engineer officer is provided a copy for each of the engineering department work centers, and each work center is provided a copy listing only its own deferred maintenance.

The purpose of the CSMP is to provide shipboard maintenance managers with a consolidated listing of deferred corrective maintenance so they may manage and control its accomplishment. The work center supervisor is responsible for ensuring the CSMP accurately describes the material condition of his work center.

Each month when a new CSMP is received, verified, and updated, the old CSMP may be destroyed.

OPNAVINST 4790.4 (series) contains complete instructions and procedures for completing and routing all 3-M Systems forms.

MAINTENANCE DATA SYSTEM (MDS)

The MDS is used to identify problems with a piece of equipment or a system and to recommend a course of corrective action through the chain of command. To accomplish this, you need to know how to fill out the Ship's Maintenance Action Form (OPNAV 4790/2K) properly. You may submit the OPNAV 4790/2K for any of several reasons, such as

1. to state why planned maintenance is not being completed on a certain piece of equipment
2. to report an equipment or a system failure
3. to request outside assistance
4. to report completion of an important corrective action

Some of the information the OPNAV 4790/2K form contains includes

1. the ship's identification
2. the work center identification
3. the equipment/system identification
4. the date when the problem was discovered
5. the suspected cause of the problem

6. the operational status of the equipment/system
7. the reason for the deferral
8. a description of the problem and the recommended corrective action if the form is used as a deferral, or what action was taken if the form is used to report a completed action
9. the originator's assigned priority
10. the names of two contact personnel
11. whether the form is being used as a deferral or to report a completed action

Shipboard copies of completed 4790/2Ks can provide you information about the status of required jobs, the operational readiness status of your equipment, and the history of your equipment.

The Navy Maintenance Support Office (NAMSO) maintains records of all OPNAV 4790/2Ks submitted. By making sure all the information is entered correctly, you help make available a valid history of your equipment. If other commands have the same equipment, and if their forms are properly completed, you can compare the histories to resolve a problem. You may find the problem pertains only to your piece of equipment. Or you may find there is a problem with the overall design of the equipment. For material history to work properly, you must be sure to record all the important work that was done.

As a work center supervisor, you must ensure that a ship's force work list (SFWL) is maintained for your work center. You should identify in the SFWL work that cannot be taken care of immediately. If the work is not completed within 30 days, you must submit an OPNAV 4790/2K to defer the job. You should make an appropriate entry in the SFWL to indicate that the job has been deferred. When the job is completed, submit a 4790/2K to document the completed action and make an entry in the SFWL.

If you have to requisition repair parts for a job, enter the job in the SFWL, even if it will be completed within the 30 days. Enter the job sequence number (JSN) on the requisition form (NAVSUP 1250 or DD Form 1348). The supply department assigns the requisition number which you will write in the SFWL under the corresponding JSN. This provides you a record of what is on order for a particular job.

If your portion of the MDS contains the correct information, and if you use it properly, you will find it to be of great assistance. Your work center supervisor, the division officer, the department head, and the commanding officer will all benefit from it. All concerned will be able to keep abreast of the status of the equipment under the responsibility of your work center.

From the information in the preceding paragraphs, you can now see the importance of the MDS.

FEEDBACK REPORT (FBR) FORM

The PMS Feedback Report, OPNAV 4790/7B, provides maintenance personnel the means to report discrepancies and problems and to request PMS software. All PMS FBRs are sent to either NAVSEACENs or TYCOMs, depending on the category of the FBR.

Feedback reports are originated in the work center and must be signed by the originator. They are then screened and signed by the division officer and the engineer officer before being forwarded to the 3-M coordinator. The 3-M coordinator dates and signs the FBR, serializes it, and returns the green copy to the originating work center. The originating work center must file the green copy until an answer to the FBR is received.

Now that you have gained the basic knowledge of maintenance under the 3-M Systems, you are ready to install new machines as well as maintain them for longer life. For more detailed information on the 3-M Systems, consult OPNAVINST 4790.4 (series) (3-M Manual).

THE NEW MACHINE

You may at some time have the task of receiving and installing a new machine aboard ship. The new machine should be completely checked over for any visible damage that may have occurred during shipment. This should be done before the machine is cleaned of the slushing compound used to protect it during shipment. If you find any damage, you may have to ship the machine back to the manufacturer. If you did not find any damage, have the machine cleaned completely of the slushing compound. Use any approved cleaning solvent and follow the manufacturer's instructions. NEVER use air pressure in the cleaning process. Doing so may force grit and dirt that were picked up in transit between bearing surfaces.

There are many factors you must consider when you install a new machine. Take care not to limit the machine's capacity any more than machines side by side and mill a boat shaft in one machine, could the other machine be used at the same time? It might be possible to angle each of them a little and overcome this problem. Consider all such factors prior to installing a machine. Once you select a location, you must consider the deck and the frames of the ship. Place the machine over a frame, not between two of them. If this cannot be done, use a large plate across the frames to reinforce the deck. Remember, in selecting a foundation you must consider the weight of the machine itself and all tools or accessories that may be used with it. Regardless of the type of foundation used, the machine should always be bolted down solidly. Do not, under any circumstances, weld the machine to the deck. Most machines are equipped with leveling screws. Anchor the machine so the leveling screws will have ample adjustment. A machine not equipped with leveling screws will require flat metal shims to level it. Do not use wooden shims or shingles because they will compress and cause the machine to go out of line.

Most machine tools are preset at the factory. But during the initial installation, you must consider lubrication. Be sure the oil reservoirs are filled with the proper type of oil. Consult the manufacturer's technical manual. Since Navy lubricating oils and greases are a primary concern, they are discussed in detail in this chapter. Make sure all parts of the machine are free and moveable by hand before you start the machine for the first time.

LUBRICATION

Too much emphasis cannot be placed on the importance of proper lubrication of machinery. Moving surfaces, such as ball and roller bearings, high-speed gear trains, and other devices having relatively small surface areas in contact, must be steadily supplied with the proper kind of lubrication. These lubricants must be maintained at specified standards of purity, designated pressures, and specified temperatures. Lubricants form a film between contacting surfaces, thereby separating the surfaces and reducing friction; consequently, wear and seizing of parts are also reduced. Figure 6-1 shows a typical lubrication chart of a horizontal boring, drilling, and milling machine.

Friction-generated heat must be rapidly dissipated to prevent damage to equipment. as heat. It also reduces the amount of energy required to perform mechanical actions. Furthermore, proper lubrication prevents corrosion, which will be discussed later in this chapter.

Since friction is of great concern in the design and operation of machinery, it is discussed in detail in the following paragraphs.

FRICTION

The friction that exists between a body at rest and the surface upon which it rests is called STATIC FRICTION. The friction that exists between moving bodies (or between one moving body and a stationary surface) is called KINETIC FRICTION. Static friction, which must be overcome to put any body into motion, is greater than kinetic friction, which must be overcome to keep the body in motion.

There are three types of kinetic friction: sliding friction, rolling friction, and fluid friction. SLIDING FRICTION exists when the surface of one solid body is moved across the surface of another solid body. ROLLING FRICTION exists when a curved body, such as a cylinder or a sphere, rolls on a flat or curved surface. FLUID FRICTION is the resistance to motion exhibited by a fluid.

Fluid friction exists because of the COHESION between particles of the fluid and the ADHESION of fluid particles to the object or medium that is tending to move the fluid. Cohesion is the molecular attraction between particles that tends to hold a substance or a body together; adhesion is the molecular attraction between particles that tends to cause unlike surfaces to stick together. If a paddle is used to stir a fluid, for example, the cohesive forces between the molecules of the fluid tend to hold the molecules together and prevent motion of the fluid. At the same time, the adhesive forces of the molecules of the fluid cause the fluid to adhere to the paddle and create friction between the paddle and the fluid.

For lubrication, adhesion is the property of a lubricant that causes it to stick (or adhere) to the parts being lubricated; cohesion is the property that holds the lubricant together and enables it to resist breakdown under pressure.

Cohesion and adhesion are possessed by different materials in widely varying degrees. In general, solid bodies are highly cohesive but

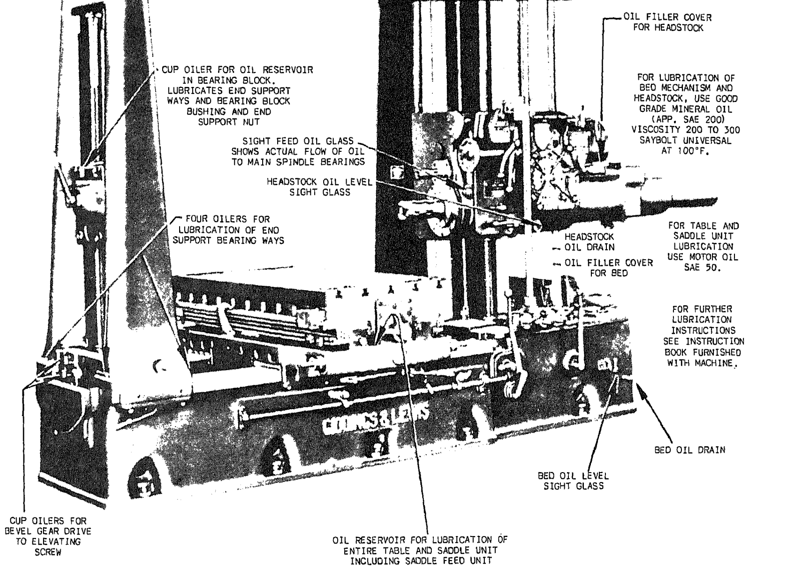

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Figure 6-1.—Typical lubrication chart.

only slightly adhesive. Most fluids are highly adhesive but only slightly cohesive.

Fluid Lubrication

Fluid lubrication is based on the actual separation of surfaces by the fluid so that no metal-to-metal contact occurs. As long as the lubricant film remains unbroken, sliding friction and rolling friction are replaced by fluid friction.

In any process involving friction, some power is consumed and some heat is produced. Overcoming sliding friction consumes the greatest amount of power and produces the greatest amount of heat. Overcoming rolling friction consumes less power and produces less heat. Overcoming fluid friction consumes the least power and produces the least amount of heat.

Factors Affecting Lubrication

A number of factors affect the ability of an oil film to lubricate. These factors include pressure, temperature, viscosity, speed, alignment, condition of the bearing surfaces, running clearances between the bearing surfaces, starting torque, and the nature and purity of the lubricant. Many of these factors are interrelated and interdependent. For example, the viscosity of any given oil is affected by temperature, and the temperature is affected by running speed; hence the viscosity is partially dependent upon the running speed.

A lubricant must be able to stick to the bearing surfaces and support the load at operating speeds. More adhesiveness is required to make a lubricant adhere to bearing surfaces at high speeds than at low speeds. At low speeds, greater cohesiveness is required to keep the lubricant from being squeezed out from between the bearing surfaces.

Machines with large clearances between their bearing surfaces require the use of highly viscous and cohesive lubricants to maintain the lubricating oil film. As the clearance increases, the lubricant must have greater resistance to being pounded from between the bearing surfaces in order to preserve the lubricating oil film.

High unit loading on a bearing requires the use of a highly viscous lubricant because a lubricant subjected to high loading must be sufficiently cohesive to hold together and maintain the oil film.

LUBRICANTS

Although there is growing use of synthetic lubricants, the principal source of the oils and greases used in the Navy is still petroleum. By various refining processes, lubricating stocks are extracted from crude petroleum and blended into a multiplicity of products to meet all lubrication requirements. Various compounds or additives are used in some lubricants (both oils and greases) to provide properties required for specific applications.

Lubricating Oil Characteristics

Lubricating oils used by the Navy are tested for a number of characteristics, including viscosity, pour point, flash point, fire point, autogenous ignition temperature, neutralization number, demulsibility, and precipitation number. Lubricating oil characteristics enable the Navy to classify its widely used oils. Classification of oils is by military symbols (table 6-1). Additional information is contained in NAVSEA 59086-H7-STM-000/CH 262. Standard test methods are used for making all tests. These characteristics are briefly explained in the following paragraphs.

The VISCOSITY of an oil is a measure of the oil's resistance to flow. It is determined by measuring the time required for a fixed volume (at a given temperature) to flow through a calibrated orifice or capillary tube. Viscosity decreases as the temperature rises and increases as the pressure increases. Because numerous types of test apparatus are used, viscosity is expressed in a variety of units. In the past, Saybolt universal second (SUS) units were commonly used. Some ships may still have the Saybolt viscosimeter. Recently, emphasis has been placed on the CENTISTOKE (CST) unit of viscosity. Today, most oil specifications will require kinematic viscosity in centistokes of two standard temperatures: 37.8 °C (100 °F) and 98.9 °C (210 °F). As a result of metrication, oil viscosities will be specified at 40 °C (104 °F) and 100 °C (212 °F). If you need to convert to different viscosity units, use conversion charts. You can obtain these charts from various manufacturers of lubricants or you may consult NAVSEA 59086-H7-STM-00/CH 262.

To help ensure proper lubrication and to extend the service life of your machinery, always use lubricating oil whose viscosity is best suited for the environment in which your machinery is operating.

Table 6-1.—Lubrication Oils by Series

Lubricating Oil Series	Type or Use
1	Aircraft engine
2	Forced feed lubricant or hydraulic system
3*	General purpose
4	Compounded, emulsifying
5	Cylinder, mineral
6**	Compounded (acidless tallow or equivalent)
7**	Compounded (acidless tallow or prime lard oil)
8	Compounded (prime lard oil)
9	Diesel Engine

*Specifications for this series have been cancelled. No longer available in the supply system
**This series has a different compounding material

a container. At a temperature below the pour point, oil congeals or solidifies. A low pour point is an essential characteristic of lube oils used in cold weather operations since the oil must continue to flow at low temperatures to be an effective lubricant. (NOTE: The pour point is closely related to the viscosity of the oil. In general, an oil of high viscosity will have a higher pour point than an oil of low viscosity.)

The FLASH POINT of an oil is the temperature at which enough vapor is given off to flash when a flame or spark is present. The minimum flash points allowed for Navy lube oils vary from 148.9°C (300°F) for the lightest to 265.6°C (510°F) for the heaviest (forced-feed) oils.

The FIRE POINT of an oil is the temperature at which the oil will continue to burn when ignited.

The AUTOGENOUS IGNITION TEMPERATURE (AIT), or SPONTANEOUS IGNITION TEMPERATURE (SIT), is the temperature at which the vapors from a sample in the test apparatus, under specified conditions, will ignite spontaneously (without the application of a spark or flame).

A term with which you should be familiar is BASE NUMBER. This number applies to oils that have special additives, such as the additives that neutralize acids formed during combustion. For example, the base number for new 9250 oil is 9000. As the oil continues to be used, the additives are consumed and the base number gradually decreases toward zero. Although you have no way to measure the base number directly, you do have oil service life recommendations made by the oil's manufacturer. These recommendations are derived from base numbers. If you follow the manufacturer's recommendations, you can assure yourself that you are maintaining lubricants at their proper additive levels.

The NEUTRALIZATION NUMBER of an oil is the measure of the oil's acid content and is defined as the number of milligrams of potassium hydroxide (KOH) required to neutralize the acids in one gram of the oil. All petroleum products deteriorate (oxidize) in the presence of air and heat. The products of this oxidation include organic acids, which, if present in sufficient concentration, have harmful effects on alloy bearings at elevated temperatures and change demulsibility of the oil.

cleanly from any water present—an important factor in forced-feed systems. It is especially important to keep water (fresh or salt) out of oils. Any change in demulsibility is important in turbine installations because sludge and emulsions too stable to be broken by the means available may be formed. An increase in acidity is an indication that the lubricating oil is deteriorating.

The PRECIPITATION NUMBER of an oil is a measure of the amount of solids classified as asphalts or carbon residue contained in the oil. The number is determined by diluting a known amount of oil with naphtha and separating the precipitate by centrifuging—the volume of separated solids indicates the precipitation number. The test is a quick means of determining the presence of foreign materials in used oils. An oil with a high precipitation number may cause trouble in an engine by leaving deposits or by plugging up valves and pumps.

Shipboard machinery uses two lubricant specifications.

1. Military specifications—used primarily by the Department of Defense (DOD)

Example: MIL-L-9000G

MIL—indicates a military product
L—indicates a lubricant (lube oil)
9000—number given in sequence as lubricant category
G—indicates the revision of the lubricant specification

2. Federal specifications—used by military and civilian agencies of the government

Example: VV-L-825

VV—indicates the identity of the lubricant
L—indicates a lubricant (lube oil)
825—number given in sequence as the lubricant category

The absence of a letter after the category number indicates the specifications have not needed to be revised.

LUBRICATING GREASES

Lubricating greases are gels formed by adding a thickening agent—soap or a clay such as BENTONITE. The soap is a chemical compound formed by combining fatty acids with various alkali metals such as calcium, sodium, aluminum, zinc, barium, lithium, lead, or potassium.

Classification of Greases

Greases are generally classified according to their use and hardness (consistency of flow). The determination of the hardness of lubricating grease is based on penetration values established by the American Society of Testing and Materials (ASTM). Greases are classified into grades by the use of standards set by the National Lubrication Grease Institute (NLGI) based on penetration test values. Some of the frequently used shipboard greases are as follows:

1. High performance ball and roller bearing—used in equipment operating at temperatures up to 148.9 °C (300 °F)

2. High temperature—used in equipment operating above 148.9 °C (300 °F)

3. Water resistant—two types, used in areas where water contamination is possible

   a. General purpose—used to lubricate bearings operating in areas exposed to water contamination, such as stern tube bearings and periscope bearings

   b. Wire rope—used to protect wire rope surfaces from seawater contamination and to protect exposed gears

4. Extreme pressure (EP)—used on heavily loaded bearing surfaces for which ordinary grease cannot maintain a film to prevent contact of the rubbing surfaces

Table 6-2 shows the classification of lubricating grease by grade.

Table 6-2.—Grease Classification by Grade

NLGI	Penetration
000	445-475
00	400-430
0	355-385
1	310-340
2	265-295
3	220-250
4	175-205
5	130-160
6	85-115

Common Terms Associated with Lubricating Greases

Hardness (consistency of flow)—the depth to which a standard cone penetrates a sample of grease, measured in tenths of a millimeter. The temperature at which the grease is sampled is maintained at 25 °C (77 °F).

Dropping point—the lowest temperature at which the lubricating grease passes from a semisolid to a liquid state.

Load (carrying capacity)—the maximum load or pressure the grease can sustain without allowing the bearings to fail or wear excessively.

Table 6-3 shows some of the common lubricating greases stocked aboard a naval ship and at shore bases.

Always read the manufacturer's lubricating instructions when you maintain your machinery. If you desire an in-depth study of lubricating greases, refer to NAVSEA S9086-H7-STM-000/CH 262 and MIL-HDBK-267, *Guide for Selection of Lubricants and Hydraulic Fluids for Use in Shipboard Equipment*.

PREVENTION OF CORROSION

Preventing corrosion, particularly corrosion resulting from continuous exposure to a marine environment, is one major problem machinists must address, both on board naval vessels and at shore naval bases. Therefore, to prevent or reduce corrosion, you must clearly understand what causes corrosion. Equipment being used as well as equipment in temporary storage or in standby condition requires protection from corrosion to prevent premature equipment failure.

Greases with corrosion inhibitors are often used as preservatives for equipment on standby because they are lubricants that do not need to be removed when the equipment is reactivated. Before applying oil, grease, and dry films to metal surfaces, be sure the surfaces are clean. This will enable the coatings to protect the surfaces from air and moisture, thus retarding corrosion.

The four main methods of corrosion protection are (1) use of corrosion-resistant metals and alloys, (2) application of corrosion-resistant coverings, (3) change of the surface composition of the metals, making them resistant to corrosive attack, and (4) use of cathodic protection devices.

Table 6-3.—Lubricants Commonly Used in Shipboard Hull, Mechanical, and Electrical Equipment

Specification Number	Specification Title	Military Symbol	NATO Symbol
	Greases		
MIL-G-6032	Grease, plug valve, gas & oil resist.		
	Type I can	GRG	G-363
	Type II stick	-	-
MIL-L-15719	Grease, hi-temp, electric motor, ball & roller bearings	GHT	-
MIL-G-18458	Grease, wire rope-exposed gear	-	-
MIL-G-23549	Grease, general purpose	GGP	-
MIL-G-24139	Grease, multipurpose, quiet service	-	G450
DOD-G-24508	Grease, hi-perf, ball and roller	-	-
MIL-G-27617	Grease, aircraft, fuel & oil resistant (hp air & oxygen systems)	-	-

CORROSION-RESISTANT METALS AND ALLOYS

One of the most basic ways of improving corrosion resistance is to use a more corrosion-resistant metal. Although use of such metal may not appear to be cost effective, savings resulting from decreased maintenance and replacement charges may well exceed the initial cost of the special metal.

CORROSION-RESISTANT COATINGS

There are two types of corrosion-resistant coatings, organic and inorganic.

Organic coatings are films, such as paints, resins, and varnish, made from previously living materials. Other organic materials are tar, grease, asphalt compounds, and adhesive plastic tapes. Although some of these, such as paints, often contain inorganic substances, the effective ingredients are organic materials. Since these coatings are organic, they are subject to deterioration at high temperatures and are recommended only for use at or below the boiling temperature of water.

Inorganic coatings may consist of either ceramic or metallic materials. Ceramic materials coat surfaces of objects such as enameled cooking utensils, bathtubs, and washbasins. These coatings resist elevated temperatures and are usually hard, wear resistant, and brittle. Metallic coatings are used either to protect against structural damage or to preserve appearance.

Metallic coatings are applied by electroplating, dipping, and spraying with atomized molten metal.

CATHODIC PROTECTION

This protection is provided by attaching to a primary metal another metal that is more readily attacked by corrosion than the primary metal. For example, pieces of zinc are attached to an outboard motor to protect the motor's aluminum from corrosion since zinc corrodes more easily than aluminum. To protect the underwater components of ships, such as the hull, rudder, propeller struts, and shafting, from corrosion, shipbuilders attach anodes made of either zinc or magnesium to the outside of the hull. Some anodes are allowed to corrode slowly through natural chemical reaction. Newer systems aboard ship pass very small electrical currents through the cathodic protection system, causing the sacrificial anodes to corrode more rapidly and provide more protection to the ship's underwater components.

GENERAL CARE

Good housekeeping is as necessary in a machine shop as it is in a home. Periodic cleaning of machines is essential to trouble-free operation and long machine life. Bearing surfaces and bright machined parts that rust rapidly should be wiped frequently with a clean rag and soaked with a clean rag containing mineral oil. Caustic, gritty cleaners should never be used on such parts.

Periodic cleaning will also give the operator a chance to discover any minor machine troubles, such as loose nuts, bolts, and screws. The operator can then correct such trouble before serious damage occurs. Many times, periodic cleaning discloses other small necessary repair or maintenance jobs needed. The machine operator should report repairs, adjustments, or replacements of any magnitude to the shop supervisor.

Care of the machine should be extended to include care of the tools and the accessories that accompany the machine. When tools and attachments are kept clean and stored in an orderly fashion, the operator reduces setup time and increases the overall operating efficiency of the machine.

CHAPTER 7

MACHINE SHOP MANAGEMENT

Every manager of a machine shop, to be successful, must apply a wide variety of technical and administrative knowledge and skills in supervising shop operations.

When you become a shop supervisor, you will have to use your expertise as a machinist to determine and to manage material assets. You will also have to use sound administrative and human relations techniques to train, to understand, and, especially, to gain the respect of and to promote rapport among your subordinates.

In running a machine shop, you will also need the ability to cope with a multitude of details that influence the smooth operation of the shop. These include, but are not limited to, the specifics of requisitioning, handling, stowing, and accounting for supplies and repair parts; maintaining accurate records of all phases of operations; and submitting reports required by higher authority.

As a Machinery Repairman, you will probably be assigned to a repair ship or a tender at some point in your Navy career. Before we discuss the methods of organizing and supervising a shipboard or ashore machine shop, you must consider the organization of the repair department. The repair department organization is discussed in your *MR 3 & 2*. When your assignment sends you to duty ashore, you will work within the framework of a similar organization having a similar mission. Having a thorough understanding of team spirit that prevails in the repair procedures will give you a clearer picture of how the machine shop fits into the scheme of the total repair mission.

Your duties as an MR1 or an MRC will require you to have a complete knowledge of the operation and maintenance of machine tools. You will make working sketches of machine parts. You will make repairs to pumps and valves. You will be responsible for all required shop inspections and tests on repaired machinery and equipment; and you will estimate time and material needed for specific machine shop jobs. Above all, you will assign personnel to machines in your shop and will properly supervise working procedures.

The following are examples of specific duties you may expect as an MR1 or an MRC aboard a repair ship or a tender and possibly on shore bases.

SHIP SUPERINTENDENT

You may be assigned as ship superintendent or as a repair department progressman. These jobs require considerable knowledge of repair procedures, especially those relating to administrative practices for processing work requests and for maintaining logs and reports to provide the repair officer with information on the status of work being done on ships alongside. The responsibilities of ship superintendent and progressman often overlap, and you may perform both functions at the same time.

Collectively, the duties of a ship superintendent and progressman are as follows:

1. Act as coordinator of shop work on the ships assigned to you.
2. Act as liaison between the ships and the tender in regard to repair department jobs.
3. Report daily to the commanding officers (or their representatives) of the ships assigned to you, to ensure that the work is progressing satisfactorily as far as the ship is concerned.
4. Report on Friday of each week, or sooner if required, to the repair officer the status of each job, bringing to his attention any high priority jobs that are behind schedule. Include in this report recommendations for shifting work or material procurement, and whether or not the job can be completed on time.
5. Use the ship's superintendent report to maintain a daily progress report concerning completion of jobs, material on order, delays in production, and availability of prints, sketches,

or samples needed to complete the jobs. This report is usually published daily or biweekly.

6. Maintain a followup check on material ordered to ensure the timely receipt of the material. The shop will also have a record of material on order.

7. Obtain signatures from officers concerned in any cancellation of a job order, or completed job.

8. Notify the ships to pick up completed material on the tender or to provide additional information.

9. Secure signatures from officers concerned on completion of job orders.

10. Notify ship's personnel to witness tests on machinery, compartments, and tanks, required by work performed. The ship will receive a copy of the quality assurance (QA) form.

QUALITY ASSURANCE INSPECTOR

As a work center supervisor you will be responsible for the quality control program in your work spaces. You must do the following:

1. Develop a thorough understanding of the QA program.
2. Inspect all work for conformance to specifications.
3. Train personnel in quality control.
4. Maintain records to support the QA program, following the QA manual.
5. Ensure only calibrated equipment is used in acceptance testing and/or inspection of work.
6. Initiate a Departure from Specifications Report (QA Form 12) when required.
7. Ensure all inspections beyond the capabilities of the shop's QA inspector are performed and accepted by the intermediate maintenance activity (IMA) before final acceptance/installation of the product by the ship.
8. Witness and document all tests.
9. Ensure adequate protection (overload, overpressure, and so forth) is provided for all tests.
10. Ensure all material or test results that fail to meet specifications are recorded and reported.
11. Report all deficiencies/discrepancies to the engineer through the ship's QA coordinator, keeping the coordinator's division officer informed.
12. Develop controlled work packages for all ship repair work requiring QA controls.

QUALITY ASSURANCE PROGRAM

The quality assurance program was established by the Commander, Naval Surface Force, U. S. Atlantic Fleet (COMNAVSURFLANT) to provide personnel with information and guidance necessary to administer a uniform policy of maintenance and repair of ships.

The *Quality Assurance (QA) Manual 9090.1* sets forth minimum quality assurance requirements. If more stringent requirements are imposed by higher authority, such requirements must have precedence. If conflict exists between the QA manual and previously issued COMNAVSURFLANT letters and transmittals, the QA manual takes precedence. Such conflicts should be reported to COMNAVSURFLANT.

The instructions contained in the QA manual apply to every ship and activity of the force. Although the requirements are primarily applicable to the repair and maintenance accomplished by the force IMAs, they also apply to maintenance performed aboard ship by the ship's force. In all cases, specifications must be met. If specifications cannot be met, a Departure from Specifications Request must be completed and reported. Departures from specifications must also be reported to appropriate levels so that departure approvals or restrictions may be issued.

Because of the wide range of ship types and equipment and the varied resources available for maintenance and repair, the instructions set forth in this manual are necessarily general in nature. Each activity must implement a quality assurance program to meet the intent of the QA manual. The goal should be to have all repairs conform to QA specifications.

PLANNING AND ESTIMATING DIVISION

You may at times also be assigned to the planning and estimating division. You will be responsible for planning work which you have screened to be done by the IMA, and, perhaps, revising as necessary the planning information received from another IMA. You may also have to supervise the operation of a technical library, coordinate the efforts of the repair organization in the advanced planning of work to be done, periodically review the job estimation guide, and update the master job catalog.

There are several planner's handbooks that you should be familiar with. Two of these are the *IMA Surface Ship Planner's Handbook* (S9AAO-AC-HBK-010) and the *Submarine Planner's Handbook* (S9002-AG-HBK-010).

SUPERVISING A MACHINE SHOP

As an MR1 or MRC, one of your major responsibilities will be to supervise the manufacturing and repairing of parts and the overhauling of machinery. To do this successfully, you must rely on your past experience in shop work and repair procedures. You must also maintain certain records and reports, conduct and supervise an effective training program, and give accurate estimates of the time required to complete repair work.

It is impossible to cover all the tasks and problems included in the work of a shop supervisor. However, the following section is designed to make you aware of some of the things that occur, particularly regarding setting up shop procedures, and the methods by which everyday problems are solved in a machine shop.

RECORDS AND REPORTS

As you advance to MR1 or MRC, you will be required to assume more responsibility for the paper work necessary in a well organized shop. In fact, to avoid bogging down completely in the mass of details, you will probably delegate some of these duties to an assistant in the shop. Keeping all your records up to date will enable you to keep a close check on each job, each worker, and each piece of equipment under your supervision. The ship will have standard forms for keeping some of the required records; for example, work request forms, supplementary job order forms, and the necessary requisitions for obtaining repair parts and supplies. You may want to supplement these forms with shop logs and notebooks of your own design to meet your specific needs. Keep as many logs as you feel you will need, in addition to those that are required.

A WORK PROGRESS LOG is a record of all the current and completed work assigned to your shop and to each person in your shop. This log may be of your own design, but it should contain the following pertinent data: job order and work request number, date received, name of the activity requesting the work, brief description of the job, and the number of man-hours expended. The daily shop run will contain all of the above information.

A MATERIAL EXPENDED RECORD is a running inventory of your stockpile, including such information as the date the material was received, the jobs on which the material was expended, and the balance on hand. To help in the preparation of stub requisitions, you may also wish to record such data as quantities listed on the shipboard allowance list, location of the spaces where the materials are stored, and stock numbers. The record is particularly valuable on repeat jobs, such as the repair of Grove reducers and Leslie regulators. In some cases, you will be required to possess level one material and controlled material. This material is kept separate from your other material and under lock and key. In most cases, there will be a material control petty officer who will keep these specific records, which will be audited, so this job should be assigned to a very reliable petty officer and an equally reliable alternate.

An EQUIPMENT LOG is a list of the various tools charged to you. The log also specifies their location—whether in the shop or in the storeroom or assigned to an individual. The location of repair parts boxes can also be logged in this notebook. An equipment log kept up to date with adequate tool descriptions—make, model, and serial number—will be of great assistance to you in making periodic inventories. This log is usually kept and maintained by your toolroom petty officer to assure proper calibration of the equipment.

DIRECTIVES

Directives are instructions or notices used at any echelon of command to prescribe policies, organizations, procedures, or methods which serve as guides for controlling the decisions and actions of subordinates. The *Navy Directives System*, SECNAV Instruction P5215.1 (revised), establishes the directive system for the Navy and sets forth a simple and uniform plan for issuing, filing, and maintaining directives under the system. Directives are assigned identifying numbers according to their subjects as listed in the *Navy-Marine Corps Standard Subject Classification System*, SECNAV Instruction P5210.11 (revised).

The following definitions of policies, procedures, orders, instructions, and regulations should help you understand the purpose of directives:

1. A military POLICY prescribes the course of action to be followed in a given situation. Policies are best put into practice through written means, since they are used to indicate the action required in recurring situations. Policies established at the top echelon are broad and general, whereas those established at lower echelons must be specific and conform to the policies established by higher command.

2. A military PROCEDURE is a series of coordinated steps to be followed in the performance of a function.

3. A military ORDER is a formal oral or written command, issued by a superior officer to a subordinate, which establishes a rule or regulation or delegates authority for the performance of a function.

4. The term INSTRUCTION denotes the imparting of information concerning the methods for the accomplishment of a mission and specifying the manner and conditions of performance in the execution of projects and programs.

5. A military REGULATION is a rule that sets forth standards governing or restraining the conduct of individuals.

Navy INSTRUCTIONS are directives that have a long-term reference value and continue in effect until canceled by the originator. Instructions may contain information of a continuing nature or information that requires continuing action. Instructions are also used to direct action that cannot be completed in the near future or action that must be taken at a future date.

Navy NOTICES are directives that are applicable for a brief period of time (usually 6 months or less) and provide for automatic cancellation on a prescribed date or under a certain condition. Notices may require action that can be completed upon receipt or may contain announcements and items of current interest.

A directive may be issued either as a letter or as a publication. A publication differs from a letter in that the publication normally has covers and contains a title page, a letter of promulgation, a record of changes page, a table of contents, and an alphabetical index of contents. The *Ship's Organization and Regulations Manual* (OPNAVINST 3120.32) is a publication. Certain shipboard directives, however, are excluded from the directives system. The directives excluded are the captain's night order book, the ship's plan of the day, the engineer officer's night order book, the OOD's standing order book, and the OOD's memoranda.

The commanding officer puts the ship's directives system into effect by issuing two instructions. One instruction prescribes the directives to be issued in the system, the responsibilities of the originators of the directives, the directives control points and their functions, instructions for departmental and divisional use of the system, and standards for reproducing the ship's directives. The other instruction establishes the distribution lists for the ship's directives.

The ship's directives system disseminates the policies of the commanding officer, the executive officer, and the heads of departments, and provides subordinate officers with a medium for issuing amplifying and supplementary instructions to place the polices into effect. By permitting the integration of the ship's directives with those from higher authority, the system ensures that the policies and procedures used in the administration and operation of the ship follow the plans and policies of the Navy Department and of fleet and type commanders.

All directives are maintained as required by the commanding officer. In most cases this includes keeping them properly indexed and arranged in binders.

COORDINATED SHIPBOARD ALLOWANCE LIST (COSAL)

The COSAL is a technical and supply management document published by the Ship's Parts Control Center (SPCC).

A COSAL is prepared for an individual ship, and it lists the tools and equipment necessary to provide the ship maximum self-supporting capabilities for an extended period of time. Included in the COSAL are equipment and components, repair parts, special tools, and miscellaneous portable equipment required for the care and upkeep of the ship.

The COSAL is technical in that it lists nomenclature, operating characteristics and guidelines, technical manuals, specifications, replacement parts, and other technical data pertaining to all installed equipment and machinery.

The COSAL, as a supply management document, informs the supply officer about the items needed to be stocked and the quantity of each item needed aboard ship.

During peacetime operations, the ship's operating schedule is generally well known within the ship's command structure. The supply officer can replenish the storerooms for an operation because the ship's destination, the length of deployment, and the supply support available are known. During wartime or other emergencies, the length of deployment or the destination of a ship may not be available to the command structure. The supply officer must then load the ship with supplies to last an indefinite period of time. For most operating supplies, the past records are available. From these records, the supply officer can calculate a balanced load that will provide proper support. But what about repair parts? No one can predict when a bearing on the freshwater pump will wear out or a vital tube in the radar will fail. This is where COSAL takes over. Computers have analyzed the frequency of failures of parts used aboard ships. Based on the equipment aboard your ship, computers have developed an allowance of repair parts that you should stock.

The key word in COSAL is COORDINATED. Computers assemble all of the allowed parts from the hundreds of allowance parts lists/allowance equipage lists (APL/AELs) into lists of repair parts to be stocked by the ship. These lists are prepared by various activities and cover all of the equipment they support.

Thus, the COSAL, aided by experience and advice from technical ratings, helps the supply officer stock the necessary repair parts and items.

Of course, the COSAL will not provide parts for every equipment breakdown. To do this, you would have to carry a complete set of spare equipment and machinery in the storeroom. However, carrying a complete set of spare equipment and machinery is not practical.

You will find that the COSAL is very beneficial when you order spare parts for a piece of equipment, since the parts are identified by both nomenclature and stock number.

For more detailed information on the COSAL, refer to SPCCINST 4441.170, *Use and Maintenance Manual*, Naval Ship's Parts Control Center.

FLEET COSAL FEEDBACK REPORT (FCFBR)

This document is used to report inaccuracies, insufficient descriptions, or other specific COSAL problems. There are two exceptions to using the FCFBR: (1) to request a change in allowance for repair parts or equipment, use Allowance Change Request (ACR), NAVSUP Form 1220-1; and (2) to report equipment configuration changes, use a Configuration Change Form (CCF), OPNAV Form 4790/CK. When completing the FCFBR, be sure to include the technical manual name and number, the page number on which the item is listed, the circuit symbol, the national stock number, the part number, and the federal stock number, to minimize the time for processing the paper work. The FCFBRs are important, not only to the fleet as a method to call attention to COSAL problems, but also to the supply community as a source of information for further improvement to the program.

SHIP EQUIPMENT CONFIGURATION ACCOUNTING SYSTEM (SECAS)

Many shore-based activities play a part in supporting the equipment and components aboard your ship. One of these activities is the Ship Equipment Configuration Accounting System (SECAS). SECAS is designed and operated to provide the configuration and logistics information that will ensure the fleet receives first-rate material support. The job of SECAS is to provide activities supporting your ship with configuration data that accurately reflects the equipment and components aboard your ship. Supporting activities must know what equipment and components are installed on your ship in order to support them. Although we have given only a brief explanation of SECAS, in this section you, as a supervisor, should be familiar with the entire concept of SECAS (NAVSEA T0752-AA-MAN-010 to 080/SECAS).

PLANNING THE WORK

The remainder of this chapter is written to speak to you as if you are now, or soon will be, a shop supervisor. If you are aboard a large ship in a nonsupervisory position, use the text to prepare yourself to become a shop supervisor.

You, with the assistance of your leading petty officers, must plan each phase of each job assigned to your shop. In planning the day's work, you must consider the lead jobs, assist (supplementary) jobs from other repair shops, routine upkeep and maintenance, and non-productive work, such as working parties. Lack of good planning will usually result in confusion, delay, and sometimes failure to meet the commitments of the shop. You must plan for the coordination of the various steps in the work. This involves considering available manpower, equipment, materials, and the workload of the other repair shops.

Planning does not stop in the machine shop. The repair officer must know how many productive hours will be available for repair work during a specific availability, to enable him or her to know how much work can be accepted during this period of time. Thus, your planning could ultimately affect your ship's operational schedule. This is where estimating comes into the picture. As a shop supervisor, you must have the ability to give an accurate estimate of the time each of the jobs assigned to your shop will consume. To do this, you will rely heavily on your past experience and the experience of your leading petty officers. You must also estimate the nonproductive hours that will be required to meet your shop's obligations to provide working parties, mess cooks, special liberty, and so forth.

In planning the work, you must consider the capabilities of your personnel. Assigning an inexperienced person to a difficult job requires that an experienced person be on hand to give direct supervision at all times. If the workload of the shop is light, this is a good training opportunity. However, if the shop has a heavy workload, the inexperienced person will be of more value assigned to a job requiring skills more in line with his or her experience.

Another estimate to be made is the number of personnel required to accomplish a job. Having too many people working on the same piece of equipment is sometimes worse than having too few. You must analyze each job step by step, and then assign the required number of personnel.

Be sure to consider the use of equipment when you plan a job. Some jobs may be done by using one of several machines. For instance, a split bearing may be bored in an engine lathe, in a vertical boring mill, or in a horizontal boring mill. The best machine to use for this job will be determined by the characteristics of the bearing. If the bearing requires only boring and has a small diameter, a lathe will do the job satisfactorily. If the bearing has a large diameter, requires facing of the ends, cheeking, and the cutting of oil grooves, then boring in the lathe would require too many time-consuming setups. In this instance the lathe would not have the capacity to do the job within a reasonable amount of time and with a minimum of setups.

Still another factor you must consider is the material necessary to accomplish the needed repairs. What kind of material, how much is needed, where you can get it, and how much time will be required to get it are all questions that you must consider. Perhaps the material called for in the blueprint is no longer available. The research required to find a suitable substitute takes time. These are just a few of the factors you must consider as the supervisor of the machine shop.

There are some materials that can be kept in the machine shop in sufficient quantities to avoid delay caused by frequent trips to the issue room. These are the frequently used items, such as studs, bolts, gasket materials, and parts to repair regulators and reducing valves. For some items, a 30-day supply is adequate; for others, a 90-day supply may be necessary.

You will probably know from experience and from memory where each item is in the shop. However, you should attach a list of contents to each drawer or cabinet so that the rest of the personnel in the shop will also know where things are stowed. Remember the importance of good housekeeping in getting the work out. Have a place for everything and keep everything in its place. Your storage facilities must also have adequate provision for securing for sea.

As we mentioned earlier, estimating the amount of material required to complete a job is your responsibility. Unless you are able to estimate with accuracy the amount and kind of materials required by your shop, you will either be caught short without the items you need or you will find your shop cluttered with items you do not need. A high inventory level of slow-moving materials ties up division funds that might be used to better advantage. Remember that running a shop is like running a business; you must operate within a budget. Much of the guesswork in estimating can be eliminated if you make proper use of records of material expended during the previous quarter. Include the amount of material required for any special work you know is to be done during the period for which you are estimating. Plan and place shop orders for materials in advance with the supply officer through the division officer or the department head. Do not bypass any of the normal supply channels of authority.

Inventory levels for most consumable items and repair parts are maintained by the supply department. Aboard some repair ships or tenders, you will assist the supply officer in maintaining the inventory on metal bar stock. Usually a high limit will be kept on hand. Before the low limit is reached, request that material be obtained to replenish the stock and to maintain the high-limit supply. In ordering, consider the rate of use, the balance on hand, and the expected delay in shipment and delivery.

In planning a job, you must first perform the job step by step mentally. This will help prevent the unintentional omission of some important step of the job. When you are sure you have identified all the steps, consider each step to make sure you have taken all requirements into account. In some cases you may have to use a written procedure.

If part of the job must be done by other shops, you must consider not only the time actually required by these shops but also the time that may be lost if one of them holds up your work and the time spent to transport the material between shops. Each shop should make a separate estimate, and the estimates should be combined to obtain the final estimate. Do NOT attempt to estimate the time that will be required by other shops. Attempting to estimate what other shops can do is risky because you cannot possibly have enough information to make an accurate estimate.

When you have finished planning the work, follow the plans carefully. You should, however, be flexible, in order to meet any unforeseen circumstances or to make emergency repairs. If a change in plans is indicated, you must reevaluate the whole plan and make whatever changes you believe are necessary. Careful planning and followup of these plans will enable you to run your shop with the utmost of efficiency and productivity.

Laying-Out and Assigning Work

A Navy machine shop is primarily concerned with repair work. The assignment of work changes constantly according to the amount and type of work being done in the shop. When the workload is light, the less experienced personnel may be assigned to complicated jobs under the supervision of experienced machinists. When the workload is heavy, your most experienced machinists will have to be assigned to the complicated jobs and to jobs that are of an urgent nature. At times reassignment of work must be made to prevent delays, to accomplish added new work, or to expedite emergency jobs.

Information on Incoming Jobs

Job orders generally will be received in the shop several days in advance of the work. You should start planning as soon as possible to gain an advantage of time. Much of your planning may be done before the work is delivered to the shop. Jobs that have been done before may be planned so that the necessary parts are on hand or that the blueprints are obtained from the technical library. Usually the activity requesting the repairs will provide the plans or blueprints along with the job order.

Another source of information is the manufacturers' technical manuals. Many of these may be found in your own technical library or may be obtained from the activity requesting the repair work. You can use these sources of information to do a great deal of advanced planning prior to the delivery of the equipment to be repaired.

Priority of Jobs

In planning and scheduling work in the shop, you will have to give careful consideration to the priority of each job order. Priorities are generally classified as urgent, routine, or deferred.

Deferred jobs do not present much of a problem, as they are usually done when the workload of the shop is light and when there are few jobs of a higher priority to be done. Also, when these jobs are approved it is with the understanding that they will be done when the time, the personnel, and the equipment are available.

The majority of job orders will have the routine priority assigned to them. Routine jobs make up the normal workload of the shop, and they must be carefully planned and scheduled so that the daily organization and production can be maintained at a high standard.

The urgent priority jobs require immediate planning and scheduling. Other jobs, of lower priority, may have to be set aside so that these urgent jobs can be done. At times it may be necessary to assign personnel to a night shift so that these jobs can be completed on time.

Determination of Required Repairs

When a job is delivered to the shop, one of the first things you must do is determine what kind of repairs are required. This is where the years of practical experience and up-to-date knowledge on different types of repair procedures are invaluable. During the planning stage, check with some of the leading petty officers in the shop for ideas on how best to accomplish the necessary repairs. Perhaps one of them may have done the same job before. It may be possible to assign some of the planning work to them; for example, a job of laying out a gear may be given to a person in the shop who has demonstrated the ability to do this type of work.

After you have determined what repairs are necessary, make sure the repair parts or materials are available. If they are not available on board, they must be requisitioned through the supply department. The activity requesting the repairs may even have the necessary repair parts on hand. If so, your activity may be able to get the parts from the requesting activity and then replace them when replacements are available. Usually though, your shop will have to either manufacture repair parts or make temporary repairs to the old parts. Matters of this nature must be cleared up before the job is laid out and assigned to less experienced personnel in the shop.

ESTIMATING TIME FOR A JOB

Estimating time for the completion of a job requires considerable thought and foresight. Your estimate may directly affect the success or failure of your ship to meet its operational commitments. Failure to complete a job in the allotted time can result in considerable unnecessary expense and loss of valuable time. Each estimate you make must be realistic, accurate, and dependable. An estimate, in a very real sense, is a guess, but it should be an intelligent guess based on the proper use of records and experience.

For most of the routine jobs that come into the shop, you may give a quick estimate of the probable time of completion. Generally, there is no necessity for completing routine jobs within any set time as long as the repairs are completed before the end of the availability and in sufficient time for the ship's force to install the repaired equipment.

The estimation of time required to complete priority jobs must be given considerable thought. If a last minute job comes up near the end of the repair period, or if a ship in port only for a day or two requires an urgent repair job, the time required to make the repairs is an important consideration. In jobs such as these, the time estimate must be extremely accurate to avoid the waste that would result from starting a repair job that could not be completed. Frequently, you, as the shop supervisor, will make the final decision; because of your experience in repair work, your knowledge of the current workload, and your knowledge of the personnel and machines in the shop, you should be able to give an accurate estimate of the time required to complete almost any repair job.

Before you can make an estimate, you must have detailed information on the job. Where necessary, you should study blueprints and manufacturers' technical manuals. You must make a thorough study of the time requiring repairs because the job might require repairs or replacements in addition to those originally specified. You must also determine the amount of repair work to be done. To make such a determination, you must clearly understand detailed procedures on how best to accomplish the repairs.

When you have determined the necessary repairs, you may begin considering a time estimate. Be sure to consider the various phases of the repair operation when you calculate the time it should take to perform a given operation on any part and on any specific machine.

Teardown Time

In any repair job, the machinery to be repaired is disassembled only as required to enable the repairs to be accomplished without damage to other parts of the equipment. Teardown time is the time required to disassemble a piece of equipment after it has been delivered to the shop. As you prepare your time estimate, double the teardown time to allow sufficient time for reassembly. If any dismantling is required before the part or piece of equipment is delivered to your shop, get an estimate of this time from the ship's force of the customer ship or from other repair department personnel.

Machine Setup Time

There are many elements you must consider in estimating the setup time. A certain amount of time may be required to make the machine ready for the machining operation. This may include changing the type of cutting fluid in the sump, changing the cutter, installing and aligning work-holding devices or jigs, adjusting the machine table, or removing accessory equipment from the machine.

The operator must go to the toolroom to obtain the required tools and measuring devices. These items can all probably be obtained in one trip if the machine operator has thought out the job ahead of time. Still another consideration in setup time is the time the operator needs to study drawings or blueprints.

Some consideration must be given to the location of the machine being used for the job. A heavy piece of equipment being machined requires that lifting equipment be rigged if there is no crane or trolley available in the vicinity of the machine being used. Setup time, then, includes all the time required to prepare the machine for the machining operation.

Machine Operation Time

The next phase to be considered is that of the actual machining operation. This includes all the time needed to perform all of the elements of the machining operations. Some jobs require the use of more than one machine to complete all of the repair work. All of this time is included as operation time in the one estimate. If, for example, you are estimating time for machining a new gear, you should include time for the lathe, the milling machine, and possibly the vertical shaper.

In estimating operation time, you will have to take into account the physical movements required of the operator during the machining operations. This includes the movements of the lathe carriage after each cut, feeding in the cross slide to start a new cut, or applying lubricant to the dead center.

Still other things you must take into account are the machining elements. These elements start when the cutting tool touches the work end and when the tool leaves the work. Having a thorough knowledge of the speeds and feeds that may be used to machine different materials will enable you to calculate the machining time with little trouble.

Machine Teardown Time

The machine teardown time will be very small but, nevertheless, must be taken into consideration. All that is necessary to include in this part of your estimate is the time required to remove the work from the machine.

Miscellaneous Time Allowances

The final factor to consider in estimating time is often overlooked. This is the time that falls into the category of miscellaneous. Some causes of miscellaneous time are fatigue from mind and muscle exercise, head calls, rest breaks, meals, and other factors or actions not directly associated with the repair operation.

The time factors that have thus far been considered are those that have to do with the machining of a piece of equipment or the making of repair parts. There are certain other factors you must consider in order to make a realistic and accurate time estimate. Some of these are the shop workload, the procurement of parts or materials, the workload of other repair shops, and any time-consuming errors or machining accidents that might occur during the job.

SHOP WORKLOAD

You should carefully consider the workload of the shop before you approve a new job for completion by a certain time.

After a decision has been made as to what repairs or replacements are necessary, you will be able to determine what machine tools and personnel should be used for the job. The next step is to find out what work is being performed on, or is planned for, the machine required for the new job. If an urgent priority has been given to the new job, the work being done on the required machine tool(s) must be set aside until the new job has been completed. If the new job does not have an urgent priority, it must be dovetailed, based on its priority, into the schedule of work being done by the required machine(s), with an estimate to be made of when the machine(s) will be made available to start on the new job.

Another decision you must make concerns the personnel to be assigned to the new job. The new job may require experienced personnel who may have to be taken off other jobs; or again, it may be a routine job for which you may use the same machine tool operators without any shifting of personnel. If the new job is a complicated one, you may have to assign a leading petty officer to process the job through the shop, including disassembly, inspection, assembly, and testing. You must consider the number of required personnel as well as their technical ability. (Sometimes, a job can be completed in less time by assigning more personnel to do the work.

However, there are limitations to the number of personnel you can put on a given job. Do not assign unneeded personnel.)

Another determination you must make is the number of hours per day you will allow for personnel to work on the new job. If the new job is a routine job, consider normal working hours. If it is a rush job with an urgent priority, you may have to assign three shifts to the job, having shop personnel work 24 hours a day on it.

In brief, the selection and assignment of personnel and machine tools depend upon the magnitude and the complexity of the new job as well as its assigned priority. These, in turn, depend upon the workload of the shop, except when the new job is given an urgent priority.

REQUIRED PARTS AND MATERIAL

When you know the extent and the nature of the repairs that are required, check to see if the required material and parts are on board ship. The material must be available before you attempt to estimate the time needed for a repair job. For a job requiring a pump shaft be made, you should have someone check the storeroom to make certain that the right size and type of metal stock is on hand. Do not overlook such items as gaskets, studs, bearings, and shaft keys that may be required.

Naval ships carry an allowance of repair parts for machinery and equipment on board ship. A check of the manufacturer's technical manual or the ship's COSAL will show if a certain part is carried on board. There have been instances where this check has been overlooked by the ship or activity requesting repairs. There is certainly no need to manufacture an item such as a gear if the ship carries gears for the machine or equipment that requires repair, so your repair time estimate should reflect the availability of spare parts.

OTHER REPAIR SHOPS

For most repair jobs, you must find out what part of the work will have to be done by other shops. If a new casting must be made, the services of the Patternmaker and the foundry will be required. Perhaps the electric shop may have to do some part of the repair job. You will have to consider not only the actual time required by these other shops, but also the time that may be lost if one of them holds up the work of the machine shop.

You, as the machine shop supervisor, will usually estimate the time required for the work to be done by your shop. However, you should not attempt to estimate any work that must be done by another shop; instead, you should obtain such estimates from the appropriate shop personnel. You must clearly understand all aspects of the repair job before you can make an accurate estimate of the time required for a job.

CONSIDERATION OF OTHER AREAS OF DIFFICULTY

Experience is an excellent teacher of things that may go wrong when you are doing a repair job. An experienced supervisor can avoid many of the difficulties that may arise in performing repair work. Whenever you plan and estimate a repair job, carefully consider the possible difficulties that may arise, and allow extra time for them. Adequate blueprints or other drawings should be on hand. If you have sufficient information before starting the job, and a clear view of the total amount of repair work that will be required, you can more easily avoid mistakes and delays.

The repair job itself may cause a certain amount of breakage or damage. For example, when steam machinery or fittings are being repaired, some of the studs may break instead of coming out; and the supervisor who has estimated 30 minutes for removal of the studs may find that the whole job actually takes 4 hours.

Failure to make the machine tool operator understand the details of the work may result in rework. You may have all the details concerning a job, but if you fail to pass on the appropriate information to the person who does the job, or if the person misunderstands what should be done, the job may be ruined. You must make sure the people doing the actual work thoroughly understand the detailed instructions. Some relatively inexperienced personnel fear appearing ignorant and try to make a good showing by saying they understand the instructions, without fully appreciating what you mean. When the job, or part of it, has to be done over, the original estimated time of completion will no longer hold true.

When the unit to be repaired consists of a number of assembled parts, such as a pump or an auxiliary turbine rotor, there may be difficulties in removing the various parts. Parts may be so rusted or frozen that they are extremely difficult to remove. On the original inspection of the item in need of repairs, you should watch for any indication that the unit may be difficult to disassemble. If necessary, you should make an extra allowance of time in your estimate to cover this phase of the repair job.

If an item fails to pass any required tests after repair, additional work will be necessary. Include time for the required tests, and the possibility of additional work associated with tests in your time estimate.

When repairs are made to high-speed rotating machinery, the repair work itself may unbalance the rotating assemblies. If there is any doubt of the original balance or of how repair work will affect the balance, make plans to balance the unit upon the completion of repair work. Include the time required for balancing in your time estimate.

The time required to deliver the piece of machinery or equipment to the shop should not be included in the estimated time to do a repair job in the shop. When boat and crane service are involved in a proposed job, bring this fact up for consideration by the person or activity requesting an estimate of the time required by the machine shop. If you are requested to estimate this time of transportation, make an estimate, distinct and separate from that for the book of your own shop. Boat and crane service may be unpredictable at times, so you should check with the officer of the deck and the crane operator before making an estimate of this kind.

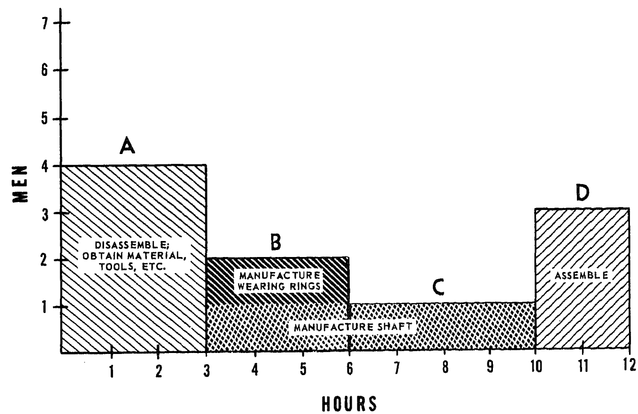
When planning on the required personnel for the job, check for possible inspections, drills, and working parties that may delay the repair job. If the assigned personnel cannot be excused from these activities, add extra time for the completion of the repair job.

The problems we have mentioned are not all the things that may go wrong on a repair job, but they indicate the types of things you must consider when you estimate the time required to do a repair job.

CALCULATING THE ESTIMATE

There are no set rules for estimating the time a repair job will take. Although many types of repairs are repeatedly done in the shop, each job requires its own investigation and estimate. The experienced supervisor will approach the estimating problem in his or her own way. The relatively inexperienced supervisor probably will find it best to (1) divide the total repair job into the various phases or steps of procedures that have to be done on the job, (2) make separate estimates of the time required for each step, and (3) add these estimates to obtain the total time required to complete the job.

As an aid in estimating the time required to complete a job, you may want to draw a diagram or a chart showing how many workers can be assigned to each step of the job and how long each step is likely to take. Figure 7-1 shows a chart



(graph) made up to estimate the time required for a pump repair job.

The graph shows that step A requires 3 hours; step B, 3 hours; step C, 4 hours; and step D, 2 hours. Adding these figures gives you the length of time required for the job—12 hours. The diagram also shows the number of hours required for each step. If you add these—12 man-hours for step A, 6 for step B, 4 for step C, and 6 for step D—you get a total of 28 man-hours required for the the entire job . What does this mean? Does the number of man-hours tell you how long the job is going to take? Can you safely assume that a job requiring 28 man-hours can be done in 4 hours if you assign seven workers to it? Obviously not, since there is a limit to the number of people who work on a job at any given time. For example, manufacturing a shaft is a one-person job requiring 7 hours.

The unit man-hours, then, is a measure of the amount of work, but not of the amount of time. You should be very cautious in using man-hours when estimating how long a job will take, because this measure does not allow for the sequence in which the work must be performed, the number of steps required, or the number of personnel who can work on the job at any given stage.

Discuss shop problems with your personnel. Help them feel free to offer suggestions. If you develop those suggestions you will often come up with a working procedure that will provide greater efficiency in the shop without sacrificing quality. When a person offers a suggestion that cannot be used, be diplomatic and explain the error in reasoning. It is a rare job that can be accomplished in only one way. If a suggestion made by one of your personnel is as good as your own, make use of it. By so doing, you will gain your subordinates' confidence, foster initiative, increase efficiency, improve quality, save time, and in the long run make your own time estimates more accurate.

MATERIAL ESTIMATES

The material used on a given job should be identified in specifications or plans. If the material is not specified, you will have to decide what is needed and then select the material. This decision should be based on the purpose of the structure or the object, and its operating requirements and conditions. Some of the "in-service requirements" are resistance to corrosion, resistance to acids, and resistance to wear. Representative in-service conditions are the weight to be supported, the pressures to be withstood, and the working stresses that may be encountered. Safety, too, is an important factor to consider in determining the material to use on a particular job. There is no set rule to follow. Each problem must be considered on its individual merits.

In most jobs, a careful study of the detailed plans will reveal the exact amount of material needed for a particular repair job. However, it is sometimes impossible to obtain the exact amount of required pipe or bar stock. Likewise, it is seldom possible to get the exact sizes of plate or sheet metal. Some waste is unavoidable, and an allowance for such waste is necessary in material estimates.

Weight considerations are important in shipboard repairs and alterations. Consequently, you may not only have to determine the amount of material required for a job, but also to calculate the weight of the material going into the job. You can determine the weight of pipes, tubes, plates, sheets, and bars in either of two ways: (1) by referring to tables in a handbook and locating the weight per linear or square foot of the particular material in question; or (2) by arithmetical computation. For example, suppose you are working with a steel angle bar, 1 1/4 inches × 1 1/4 inches × 3/16 inch. Referring to an appropriate table in a handbook, you will find that this material weighs 1.48 pounds per linear foot. This value, multiplied by the number of linear feet of angle bar in the completed job will give the weight contributed by this material. By treating each element in the same manner, you can arrive at a fairly accurate estimate of the total weight increase.

If such tabulated information is not available, you will have to determine the volume of metal involved and multiply the result by the weight of the metal per cubic inch. Obviously, to calculate the weight of a particular structure, you must be able to break the whole down into its component geometrical parts—such as circles, squares, rectangles, and pyramids—and to determine their respective volumes. Further, you need to know the weight of the metal per cubic inch. You can find this information in a variety of handbooks readily available in the engineering or repair department office. Table 7-1 gives the information for a few of the more common metals.

The individual job does not present a difficult estimating problem, but when it comes to estimating material requirements for future use you will have to anticipate your needs. This is

Table 7-1.—Weight (Density) of Common Alloys

Material	Pounds per cubic inch
Aluminum	0.098
Yellow brass	.307
Naval brass	.304
Copper-nickel	.323
Cast iron	.258
Steel	.284
Lead	.411
Copper	.321
Tin	.265

not just so much guesswork. By the proper use of records and foresight, you can eliminate a great deal of guesswork.

SCHEDULING OF WORK

The main object in the scheduling of work is to have the one job follow another smoothly and without delay, since lost time between jobs lowers the overall efficiency of the shop. Because of the variety of jobs you and your personnel will be required to perform, specific work schedules must be prepared to ensure that all work is completed. Although these schedules list specific job assignments, they must be flexible enough to allow for changes in priorities, transfer of personnel, temporary breakdowns of equipment, unscheduled ship drills, or any emergency that may arise.

Usually the jobs that require the longest period of time are started at once and kept in progress to be completed on time. Smaller jobs are performed on unassigned machines and also are dovetailed into the schedule so they can be done as soon as machines and personnel become available.

The priority of job orders, as well as the length of time required to complete the jobs, will determine the scheduling of work. Jobs of urgent priority will be completed before routine jobs are started. The deferred jobs or the jobs of least importance are left until last; then they can be done or canceled, depending upon the workload of the shop.

You may have to change the schedule of work in the shop when new high-priority jobs come in. Sometimes you may have to set other work aside temporarily until these urgent jobs are completed.

Remember this point. Experience, judgment, and foresight are required to maintain an organized schedule of work in a large machine shop to get the numerous jobs finished on time.

SUPERVISING REPAIR WORK

One of the most important duties of an MR1 or an MRC is that of supervising the repair work in the machine shop. As a supervisor, you must instruct shop personnel concerning the different repair jobs that have to be done; you must check on the progress of the work, and give additional advice or instructions when necessary; and you should check the completed job to see that it has been done properly and according to your instructions.

After you have obtained complete information on a new job and have decided what repairs or replacements are necessary, you must decide who is to do the job. To make this decision, you must know what experience the workers have had with different types of repair work, and what skills they have in operating the various machine tools.

You should see that all items coming into the machine shop are properly tagged. Instruct the personnel in the shop to replace any tags that have been removed to do machine operations. The mix-up of some items, such as valves, can cause, at the very least, a lot of unnecessary confusion and lost time.

Starting the Job

The person who is going to do the repair job must be given detailed information on how the job is to be done. Be sure to see that the operator fully understands what is to be done to prevent mistakes due to a misunderstanding of instructions. The amount of instruction depends upon the knowledge and experience of the operator concerned. If the operator is experienced, you may only have to provide a blueprint and specify what parts have to be made or what repairs are to be done. There will be times when blueprints will not be available. You will then have to make a sketch of the part or parts to be manufactured. This sketch will make the job easier and more understandable for the person doing the work. If you do not thoroughly understand sketching, review *Blueprint Reading and Sketching*, NAVPERS 10077.

Inexperienced personnel will need additional instructions for setting up the work in the machine and information on the proper procedure for doing the job. Workers in the shop should be made to understand that they are free to ask questions if they are in doubt about any details of their assigned work. Your people will ask questions when they see that it is to their advantage to do so.

In addition to giving instructions on how a job is to be done, you should give your workers some information concerning the importance of the job, the origin of the job, the part that each person will play in accomplishing the complete repair job, and the reasons for certain specifications. In general, workers are interested in why a job is done and how it is done, and will usually turn out better work if they have a clear picture of the whole job.

Checking the Progress of Work

The assignment of a job is only the first step in processing a job through the shop. You must know your personnel. You should have a fairly good idea of each person's skills, ability, and knowledge regarding the operation of machines and the accomplishment of repair work.

The best way in which you can obtain this knowledge is to inspect the shop frequently and check the progress of the various jobs in the shop. In that way, you will have a good idea of which jobs or which workers will require the most checking or inspecting.

A good practice is to make sure, before a job is set up, the right type and proper size of material is selected. Selecting the wrong type or the wrong size of material are two common operator errors you should be aware of and should check on.

When checking on the progress of work, you should be sure that the workers are observing proper safety precautions, both concerning themselves and the machines they are operating. In addition, you should see that each person is using the proper tools and machine setups, and should note the quality of work being produced. In case of any doubt, you should check that the workers understand your instructions properly and that they are doing the work correctly, as indicated by the blueprint or drawing. If necessary, provide additional instructions to give a better understanding of the job or to improve workmanship. By frequently talking to the workers and answering their questions, you can prevent jobs from being reworked, as might happen if you are not available to give the correct details on the jobs. If you show interest and confidence in your personnel and their work, you will find that they have confidence in you as a good shop supervisor.

Complications may develop on some repair jobs, which may require additional planning and revised repair procedures. By observing the progress of the various jobs and whether any are ahead or behind the planned schedule, you will be able to change the schedule of some jobs in order to prevent "bottlenecks" and to keep the most important jobs moving.

Checking on Completed Jobs

When a job has been completed in the shop, you should inspect and approve the job. Inspection is necessary to ensure that the repair job or the manufactured replacement parts will be satisfactory both to the repair activity and to the requesting activity. Your inspection may be visual, or it may require measuring instruments. You may also want or need to perform a shop test to check the condition of repaired equipment or machinery.

certain conditions. Your check should involve answering the following questions, as a minimum:

1. Have all the machining and finishing operations been completed?
2. Have the repaired or manufactured parts been correctly formed and accurately dimensioned according to detailed instructions or blueprints?
3. Is the repaired item or replacement part free from defects in the material and the workmanship?
4. Have all parts or accessories to the repaired equipment or machinery been replaced or returned with the repaired unit?
5. Have all items, such as screws, bolts, studs, keys, lock washers, gaskets, and packing, been replaced or renewed according to original instructions?
6. Where applicable, has the part or item been properly checked for any unbalanced condition?
7. Has the proper material been used in making repairs or replacement parts?

These are just some of the things you must consider before you certify the job as complete and ready to be removed from the shop. No one should let work leave the shop until you and the person receiving it are satisfied with it. The workers, as well as you, should take pride in their workmanship.

The completed job order should show the man-hours, the material used, and a full description of the work accomplished. In addition, the necessary shop records and paper work should be correct and up to date. When the job has been completed, interested parties should be notified as soon as practicable; completed jobs should not be left to accumulate in the shop, as some of the items may become mixed up, damaged, or lost.

Before releasing a completed item, check to be certain (1) the correct job order is signed by a representative of the requesting activity, (2) the identification on the item and on the job order coincide, and (3) all manufacturers' technical manuals and blueprints furnished with the job order are returned.

TRAINING SHOP PERSONNEL

The first impression formed by a new person in the shop will be a lasting one. If you have a well-planned program for introducing new One of the best stimulants for the development of high morale among new personnel is to have them realize that their boss appreciates their feeling of strangeness in new surroundings and is aware of their desire to succeed. There is often a gap between the point at which a person is assigned and the time that person develops into a satisfied worker. Proper introduction to the work, a well-planned training program and counseling when necessary will turn the ill-at-ease person into a confident and interested worker.

You will benefit greatly from reviewing with each new worker such matters as the mission of the ship and how the shop fits into the overall picture, the person's rate, duties, drills, the ship's liberty and leave policy, and what is expected of the person as an individual. You should be sincerely interested in not only getting acquainted with the person but in being sympathetic with the problems that may arise while the person is getting settled. The initial contact should be primarily to win the person's confidence. You may later turn the person over to a qualified petty officer who is capable of completing the introduction process and the early training that is necessary. Usually, you should select an experienced petty officer to help ease a new worker through the introduction period.

In carrying out your responsibility for introducing a new worker to the job, you must do a certain amount of planning if the instructions necessary for the proper indoctrination of the new worker are to be carried out effectively.

Throughout this chapter, we have suggested but have not stated a fundamental difference between your work as a supervisor and the work of your people. Your people work with machines and materials, while you work through your people to produce the desired results with the machine and the materials. The machines may be operating perfectly and the materials may be of the best quality, but unless the people who handle them are properly instructed, adjusted to their work, and aware of their place in the organization and of the policies of the department, they will not be satisfied workers. You are responsible for providing for these needs and for developing high morale in your shop.

The first step in this process is to indoctrinate each new person properly at the time of that three general areas of indoctrination.

1. Those dealing with facts, such as the shipboard rules and regulations
2. Those dealing with the worker's attitude or feelings, confidence in the organization, pride in the job, and respect for fellow workers
3. Those dealing with skills, safe working habits, and quality of work

A follow-on to indoctrination is professional development. Each person in your shop must be receptive to suggestions and training that promotes personal development, and must be willing to help develop the skills of other shop personnel. However, you have the direct responsibility for seeing that all your subordinate petty officers understand their work and its relation to the function of the machine shop so well that they automatically teach those who assist them.

REFERENCE BOOKS AND MATERIAL

Good handbooks and reference material are as important to a Machinery Repairman as are precision measuring instruments, hand tools, and machine tools. A Machinery Repairman cannot possibly remember all details or data required for daily planning and work. A well-run machine shop should have a technical library consisting of machinists' handbooks, the *Naval Ships' Technical Manual*, manufacturers' technical manuals for all the machines in the shop, books on machine shop operations and practices, and various other books of reference or instruction. The Navy furnishes a certain number of books, and others can be purchased ashore.

You should check your shop's library to see that reference books are available. If your shop needs additional publications, make recommendations to your division officer.

SHOP HOUSEKEEPING

Generally, you can give a workshop a good look and determine whether it is efficient and well run. Just make a quick survey for cleanliness, neat tool and stock stowage, and the condition of equipment. If your survey reveals a high quality of housekeeping, you may also assume that the shop is well organized and turns out quality work.

be stored in a convenient, secure, and orderly place. Use cabinets, shelves, bins, and racks arranged in the shop to give the greatest possible amount of free working space.

The stowage facilities must have adequate provisions for "securing for sea." Metal stowage racks for sheets and bars must be lashed down to prevent the gear from shifting when the ship is at sea. You can use packages, turnbuckles, wedges, bars, and C-clamps to satisfy this requirement.

If shop space permits and sufficient tools are available, each rated person should have a stowage drawer and tool box in which to keep the tools that are ordinarily used. Besides speeding up production of work, this method of stowage will provide better care and cleanliness of hand tools. Remember the old adage, "An untidy shop is an unsafe shop."

REPAIR PARTY

In NAVPERS 18068 (*Manual of Navy Enlisted Manpower and Personnel and Occupational Standards*), one of the requirements for an MRC is to organize and supervise a damage control repair party. As a supervisor, you must be familiar with all the equipment and the functions of the repair party. Following is a list of GENERAL functions which are common to all repair parties.

1. Each party must be capable of making repairs to electrical and sound-powered telephone circuits.
2. Each party must be capable of giving first aid and transporting injured personnel to battle dressing stations without seriously reducing the damage control capabilities of the repair party.
3. Each party must be capable of detecting and identifying radiation, measuring dose and dose-rate intensities from radiological involvement, and surveying and decontaminating personnel and areas affected by radiation.
4. Each party must be capable of detecting and identifying chemical agents and decontaminating areas and personnel affected by a biological or chemical attack.
5. Each party must be capable of controlling and extinguishing all types of fire.

area. This will include maintaining the following:

a. Deck plans showing locations of CHEMICAL, BIOLOGICAL and RADIOLOGICAL (CBR) contamination, locations of battle dressings and personnel cleansing stations, and safe routes to them

b. A graphic display board showing damage, and action taken to correct disrupted or damaged systems. Standard damage control symbology to be used is shown in *Surface Ship Damage Control* manual, NWP 62-1 (Rev B), current edition.

Figure 7-2 is a recommended preprinted damage control message format. Use of this

Figure 7-3 is a completed damage control message form. The message reports an 8-inch hole, 4 feet from the deck, at frame 38, on the starboard side of compartment 2-35-0-L.

Completed damage control message forms should be forwarded to damage control central (DCC) for plotting and for further action.

7. Each repair party must be familiar with its assigned area and with the area's damage control system and equipment. Provision must be made for all repair parties to gain access for drill and for familiarization with the spaces.

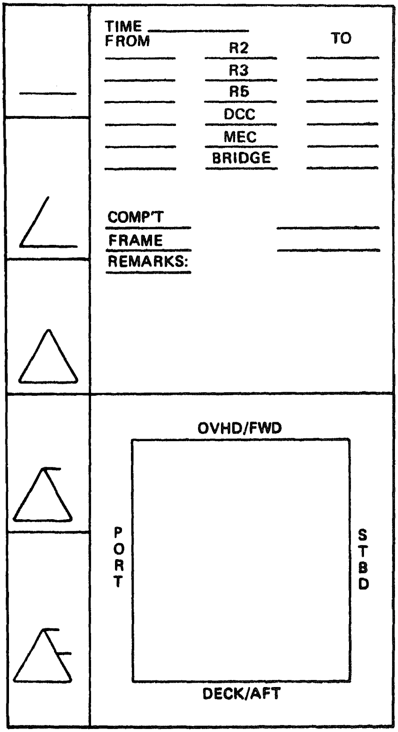


Figure 7-2.—Preprinted blank message format.

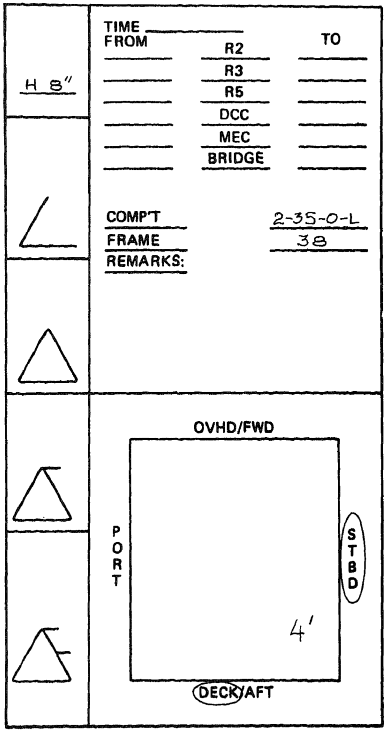


Figure 7-3.—Example of completed preprinted message format.

Some of the SPECIFIC functions for which repair parties are responsible are listed below.

Maintenance of stability and buoyancy is the responsibility of repairs 1, 2, 3, 4, and 5. These repair parties must be

1. stationed so they can reach all parts of the ship without opening watertight closures, if possible;
2. able to repair damage to structures, closures, or fittings designed to maintain watertight integrity, by shoring, plugging, welding, caulking the bulkheads and decks, resetting valves, and blanking or plugging lines through watertight subdivisions of the ship; and
3. be prepared to sound, drain, pump, counter flood, or shift liquids in tanks, voids, or other compartments, and be thoroughly familiar with the location and use of all equipment and methods of action.

For accurate evaluation of underwater damage, two status boards should be maintained. The stability status board (flooding effects diagram) is used for visual display of all flooding, flooding boundaries, corrective measures taken, and effects on list and trim. A liquid load status board is used to show the current status of all fuel and water tanks and the soundings of each tank in feet and inches.

Maintenance of ship's structural integrity and maneuverability is the responsibility of repairs 1, 2, 3, and 4. These repair parties must be able to

1. make repairs to primary and auxiliary methods of steering;
2. clear the upper decks of wreckage that interferes with operation of the battery, ship, or fire control stations or that fouls the rudder, propellers, or sides of the ship, and be ready to extinguish all types of fires;
3. maintain and make emergency repairs to battle service systems, such as ammunition supply, ventilation supply, high- and low-pressure air lines, internal communications systems, electrical systems, and cooling water systems;
4. provide emergency power to electrical equipment using casualty power cables;
5. assist the crash and salvage team as required;
6. stream and recover minesweeping equipment during general quarters;
7. rescue survivors from the water and render assistance to other ships; and
8. repair above-water damage that could cause flooding in the event of further damage.

Maintenance of ship's propulsion is the responsibility of repair 5, which must be able to

1. maintain, make repairs to, or isolate damage to main propulsion machinery and boilers;
2. operate, repair, and isolate vital systems, and modify their segregation;
3. assist in the operation and repair of the steering controls systems;
4. assist in the maintenance and repair of internal communications systems;
5. assist repairs 1, 2, 3, and 4 and the crash and salvage team when required;
6. relieve ship's propulsion personnel in the event of casualties;
7. assist in CBR recovery operations; and
8. maintain an engineering casualty control status board, showing the condition of readiness of main propulsion and principal auxiliary machinery, and providing a graphic display of engineering casualties and other pertinent information, if required by type commanders.

On larger ships, repair 5 may be split into two repair parties. Each half of repair 5 is assigned one half of the engineering plant. This arrangement provides maximum use of manpower and equipment and greater dispersal of personnel. However, on smaller ships repair 5 will usually be assigned to the repair party designated by the type commander.

Although this chapter did not discuss repairs 6, 7, and 8, you should become familiar with their responsibilities listed in *Surface Ship Damage Control*, NWP 62-1 (Rev B), current edition.

CHAPTER 8

SHIP MAINTENANCE AND MODERNIZATION

Ships can operate only a certain length of time without repairs. To keep a ship in prime condition, constant attention must be given to material upkeep and appropriate intervals of time must be allotted for general overhaul and repair.

Even when regular preventive maintenance procedures are carefully followed, accidents and malfunctions may necessitate emergency repair work. Defects and deficiencies that can be corrected by the ship's force should be dealt with as soon as possible. When repairs are beyond the capability of the ship's force, aid must be obtained from a repair activity afloat or ashore. Repair activities afloat include repair ships and tenders. Repair activities ashore include shore intermediate maintenance activities (SIMAs), naval shipyards, and naval ship repair facilities (SRFs) located outside the continental limits of the United States.

Before proceeding with the sections covering repair ships and tender maintenance and repairs, we need to define repairs and alterations.

REPAIRS AND ALTERATIONS

Corrective maintenance to ships may be divided into the general categories of (1) repairs, (2) alterations, and (3) alterations equivalent to repairs.

A REPAIR is defined as the work necessary to restore a ship or a component of a ship's system to a fully operational condition without a change in the design, location, or relationship of parts. Repairs may be made by the ship's force, by repair ships and tenders, or by naval shipyards or other shore-based activities.

An ALTERATION is any modification to the hull, machinery, equipment, or fittings that involves a change in the design, materials, number, location, or relationship of the component parts of an assembly. Alterations may be made by themselves or in conjunction with repairs. Requests for alterations may originate from the fleet, from the Naval Sea Systems Command (COMNAVSEASYSCOM or NAVSEA), or from the Chief of Naval Operations (CNO).

NAVSEA is responsible for overseeing ship alterations (SHIPALTs) under its technical control. Through its day-to-day relations with the forces afloat, naval shipyards, private industry, and research centers, NAVSEA remains up to date on technical developments. In striving to maintain the ships of the fleet in as efficient and modern a state as possible, NAVSEA may determine that a particular ship or class of ships should be altered. Alterations may require modifications to the hull, such as changes to bulkheads that will strengthen them or changes to deck arrangements that will provide space for the installation of a paint mixing and issue room.

When the commanding officer of a ship considers an alteration necessary for improving the performance of the ship, he sends a request for the alteration to NAVSEA via the administrative chain of command. NAVSEA then sends copies of the request to all the other ships of the same class for comments on applicability.

Another source of alteration is the reports of the Board of Inspection and Survey (INSURV). Upon completion of each ship material inspection, the Board, in its report of the general condition of the ship and its suitability for further naval service, furnishes a list of repairs and alterations, which, in its opinion, should be made. Alterations recommended by the Inspection and Survey Board (INSURV) normally are not acted upon by NAVSEA until after the receipt of appropriate comments from the commanding officers of the ships inspected and the recommendations of the type commanders (TYCOMs).

TERMS ASSOCIATED WITH NAVY ALTERATIONS

Approved Alteration—An alteration approved for accomplishment without funding and year of accomplishment identified.

Authorized Alteration—An alteration approved for accomplishment with funding and year of accomplishment identified.

Alteration Equivalent to a Repair (AER)—An alteration that has one or more of the following characteristics:

1. The use of different materials that have been approved for like or similar use and are available from standard stock
2. The replacement of obsolete, worn-out or damaged parts, assemblies, or equipment, requiring renewal by those of later and more efficient design previously approved by the Systems Command concerned
3. The strengthening of parts that require repair or replacement in order to improve reliability of the parts and of the unit, provided no other change in design is involved
4. Minor modifications involving no significant changes in design or functioning of equipment but considered essential to prevent recurrence of unsatisfactory conditions
5. The replacement of parts, assemblies, or equipment with like items of later or more efficient design when it can be demonstrated that the cost of installation and maintenance of the new parts, assemblies, or components is less than the cost of maintaining the installed parts, assemblies, or components

NOTE: Only the systems Command exercising technical control over the article, or the authority to whom such technical control has been delegated by that command, shall designate an alteration as equivalent to a repair and approve it for accomplishment.

Electronic Field Change—Any modification or alteration made to electronic equipment after its delivery to the government.

Machinery Alteration (MACHALT)—The MACHALT program is a kit concept that enables hull, machinery, and electrical (HM&E) changes to be accomplished in an expeditious manner, eliminating these changes from the formal SHIPALT process. A MACHALT is a planned change, modification, or alteration of any HM&E equipment in service (shipboard or shore activities) when it has been determined by the MACHALT Configuration Control Board (CCB) that the alteration or modification meets all of the following conditions:

- Can be accomplished without changing an interface external to the equipment or system
- Is a modification made within the equipment boundary or is a direct replacement of the original equipment design
- Can be accomplished without the ship being in an industrial activity
- Will be accomplished individually and not conjunctively with a SHIPALT or other MACHALT

For detailed information concerning MACHALTs, refer to the *Fleet Modernization Program Management and Operations Manual* (SL720-AA-MAN-010) and NAVSEA Instruction 4720.15, *Policy and Procedures for Implementation of Machinery Alterations on Hull, Machinery, and Electrical Equipment and Systems.*

Military Alteration—An alteration that changes or improves the military characteristics of a ship. This alteration is managed by the CNO.

Technical Alteration—An alteration that affects safety, maintainability, reliability, or system performance. This alteration is managed by the Chief of Naval Material (CNM).

Ordnance Alteration (ORDALT)—An alteration to ordnance equipment under the technical cognizance of NAVSEA and composed of the following:

Ordnance Alteration Instruction—A technical document containing instructions, drawings, test procedure, and directions to accomplish a material change, modification, repositioning, or alteration in the physical appearance of an installation of different parts in subassemblies, assemblies, or components in a weapon or system. Technical publication changes are supplied as part of that data package.

ORDALT Kit—All the material and documentation required to perform an ORDALT, which may include materials and documentation necessary for testing, operating, and maintaining the equipment after alteration. ORDALT Kits include complete hardware, special tools if required, and a copy of the ORDALT instruction. In some cases, a conjunctive SHIPALT may be required with an ORDALT.

Programmed Alteration—An alteration that is scheduled for accomplishment by CNO in the Ship Alteration Management Information System (SAMIS) on one or more specific hulls in a specific fiscal year.

Ship Alteration (SHIPALT)—Any changes in the hull, machinery, equipment or fittings that involves change in design, materials, number, location, or relationship of the component parts of an assembly. SHIPALTs are classified by title, as shown in the following:

- Title **D** Alteration—An alteration equivalent to a repair, approved by NAVSEA. Title D ship alterations are authorized by the TYCOM and funded under Operation and Maintenance of the Navy (O&MN) as operating expenses.

- Title **F** Alteration—An alteration that can be accomplished by Forces Afloat and that does not require special program material or centrally procured material for accomplishment. Title F alterations may only be authorized for accomplishment by TYCOMs, who must fund all costs except Design Services Allocation (DSA) and coordinated shipboard allowance list (COSAL).

- Title **K** Alteration—An alteration authorized for accomplishment through the Fleet Modernization Program (FMP) and usually requiring special program material. It is accomplished by industrial activities and approved by the CNO through the FMP process.

- Title **K-P** Alteration—An alteration that changes the military or technical characteristics of the ship and involves the installation of special program material, but is within Forces Afloat capability for installation. Special program and centrally procured materials required for accomplishment of these alterations are normally provided as a package by NAVSEA at no charge to TYCOM O&MN funds. Title K-P alterations may only be authorized by NAVSEA.

Alteration requests addressed to NAVSEA are endorsed by the TYCOMs (or other administrative commanders, as appropriate), with their recommendations on approval, classification, and applicability to other ships. Copies of the basic request and endorsements are forwarded to other TYCOMs, who are requested to comment for NAVSEA.

SHIPALT AUTHORIZATION LETTERS

SHIPALT Authorization Letters specify to the installing activity the alterations that are to be accomplished during an availability. They are issued by the cognizant Ships' Logistics Manager (SLM) and contain a list of all authorized alterations, material status, development status of the alteration, funding information, and pertinent instructions.

Thus a SHIPALT Authorization Letter serves three purposes:

- It provides the program authorization for alterations specifically programmed for accomplishment in the FMP.

- It provides NAVSEA with planning estimates for the program authorized.

- It provides procurement/requisitioning instructions for the material required for alteration accomplishment.

The SLM forwards separate SHIPALT Authorization Letters for each ship scheduled for an availability to the cognizant Naval Shipyard Commander 360 days prior to the start of the availability. However, SHIPALT Authorization Letters for availability scheduled to occur in commercial facilities are to be received by the cognizant SUPSHIP 360 days prior to the commencement of the availability. Included in the SHIPALT Authorization Letter are specific reporting instructions on estimated man-day and dollar expenditure rates, material costs for alterations, and program reports required by FMP financial management procedures.

The SLM includes total planning estimates of funds authorized for title K alteration accomplishment in a SHIPALT Authorization Letter; these estimates are not to exceed programmed FMP funds.

LEVELS OF SHIP MAINTENANCE

Navy policy requires that ship maintenance and modernization work be performed at the lowest effective level through the life cycles of ships. The Ship Maintenance and Modernization Program was developed to implement this policy. This is a balanced program which requires a contribution from all levels of maintenance within the Navy.

There are three specific levels of ship maintenance, each requiring a greater degree of capability. Organizational level maintenance and intermediate level maintenance are within the capability of the operating forces and are their responsibility. The greatest industrial capability resides at the depot level, composed of naval and private shipyards, ship repair facilities, and assigned Navy, Department of Defense (DOD), or commercial designated overhaul points (DOPs).

ORGANIZATIONAL (SHIPBOARD) LEVEL MAINTENANCE

Organizational level maintenance is the first level of maintenance and consists of corrective and preventive maintenance performed on a ship by the ship's force. This work is a blend of equipment operation, condition monitoring, planned maintenance actions, and repair. It ranges from simple equipment lubrication to component changeout and, in some cases, complete rework in place.

INTERMEDIATE LEVEL MAINTENANCE

Intermediate level maintenance is normally performed by Navy personnel on tenders, repair ships, aircraft carriers, fleet support bases, SIMAs and Naval Reserve maintenance facilities (SIMA NRMFs). Within the limits of each IMA's facilities, such as shops, docks, and machinery, and personnel, such as numbers, skills, and levels, IMAs perform maintenance, repair, overhaul, installation, quality assurance, tests, and related functions on the HM&E and combat equipment, and systems that are beyond the capabilities of each customer. This applies specifically to intermediate level maintenance required to support ships. The term *fleet support bases* refers to IMAs such as Trident Refit Facilities; Naval Submarine Support Facility, New London; and Submarine Base, Pearl Harbor.

DEPOT LEVEL MAINTENANCE

Depot level maintenance requires skills and facilities beyond those of the organizational and intermediate levels and is performed at naval shipyards, private shipyards, naval ship repair facilities, or other shore-based activities. During depot availabilities (yard periods), large scale maintenance and repairs requiring industrial facilities are performed. Approved alterations and modifications that update and improve a ship's military and technical capabilities are also made.

CLASSES OF SHIP SYSTEMS AND COMPONENT OVERHAULS

Work at each of the three levels of maintenance is always specified as one of five classes. The class designation system enables both maintenance personnel and their supervisors to know the extent of work requested for a particular item. The following is a brief explanation of the five classes, lettered A through E:

Class **A**—Designed to bring a system, a subsystem, or a component up to most recent design and technical specifications. Products of class A overhauls are in like new condition in appearance as well as in operation and performance. During a class A overhaul, all applicable manufacturers' and technical manual performance standards and specifications are met, all technical documentation is brought up to date, and the overhauled item is tested for compliance with government-specified performance criteria. Class A overhauls may be made to components or subsystems of ship weapons, machinery, electrical, hull, or electronics systems, or to an entire system, and include all actions required to bring the item scheduled for overhaul up to required standards. These overhauls may include ORDALTs or SHIPALTs.

Class **B**—Designed to bring a system, a subsystem, or a component back to its original design and technical specifications. Other modifications, including SHIPALTs and ORDALTs are not performed unless they are specifically requested by the customers. Maintenance and calibration routines are performed, as appropriate, and each item is tested for compliance with government specified performance criteria.

Class **C**—Involves repair work specified on a work request or work to correct deficiencies or malfunctions identified on a work request, for a system, a subsystem, or a component. The repairing activity must show that the requested work has been completed or that the deficiencies or malfunctions have been corrected. However, the repairing activity is not responsible for ensuring that components associated with the repaired item function properly or that the entire system functions properly.

Class **D**—Consists primarily of diagnostic work associated with the open, inspect, and report type of request in which the customer is not sure what is wrong with the item. The repairing activity reports its findings, recommendations, and cost estimates to the customer for authorization to begin repair work. Minor repairs and adjustments may be made, as specified by the customer, without additional authorization.

Class **E**—Involves work required to make specific modifications to a designated system, subsystem, or component. The repairing activity must show that the modifications were successful and that the item meets operational standards, but only to the extent required by the modification orders. However, the repairing activity may, at the request of the customer, conduct system tests to prove that the system will operate satisfactorily with the modified item. Repairs, if any, are minor.

SHIP AVAILABILITIES

An **AVAILABILITY** is a time period during which a ship is assigned to a repair activity so that repairs can be made or maintenance can be performed on the ship or its equipment. The types of abilities are described in the following paragraphs.

REGULAR OVERHAUL (ROH)

A regular overhaul is an availability for making general repairs and alterations at a naval shipyard, a private shipyard, or another shore-based repair activity, normally scheduled during an established cycle, such as every five years.

COMPLEX OVERHAUL (COH)

A complex overhaul is an overhaul that, because of funds, time, or manpower constraints, or due to the complexity of the various ship subsystems involved, requires extraordinary coordination and extensive management of the planning and industrial phases of the overhaul. All CV, LHA, AGF, and nuclear-powered surface ship overhauls (CGN, CVN) are, by definition, complex overhauls.

SELECTED RESTRICTED AVAILABILITY (SRA)

A selected restricted availability is an availability for making repairs and selected alterations by depot and/or intermediate level maintenance activities. These availabilities are for accomplishing work required to sustain the material condition of the ship between overhauls, particularly ships on extended operating cycles. SRAs are used exclusively for required depot level maintenance of ships on progressive or incremental overhaul schedules. SRAs are short, labor-intensive availabilities generally scheduled at specific times throughout a ship's operating cycle. They are scheduled sufficiently in advance to ensure that advanced planning time and funds are used effectively.

PHASED MAINTENANCE AVAILABILITY (PMA)

A phased maintenance availability is a short, labor-intensive availability for making general repairs and alterations by depot level maintenance activities. Ships assigned to phased maintenance programs are maintained through PMAs in lieu of regular overhauls.

EXTENDED REFIT PERIOD (ERP)

An extended refit period is a 60-day planned availability for SSBN nuclear submarines scheduled approximately 4 1/2 and 7 1/2 years after overhaul to accomplish major depot and intermediate level work.

RESTRICTED AVAILABILITY (RAV)

A restricted availability is an availability during which specific items of work are accomplished by an industrial activity with the ship present, during which time the ship is rendered incapable of fully performing its assigned mission and tasks. Restricted availabilities are assigned by TYCOMs.

TECHNICAL AVAILABILITY (TAV)

A technical availability is an availability during which specific items of work are accomplished by a repair activity, normally at a naval base, during which the ship's ability to fully perform its assigned mission and tasks is not affected.

VOYAGE REPAIR (VR)

A voyage repair is emergency work necessary to enable a ship to continue its mission and that can be completed without requiring a major change in the ship's operating schedule.

SERVICE LIFE EXTENSION PROGRAM (SLEP)

A service life extension program is a depot level program to extend the service life of a ship beyond that for which it was initially designed. Following SLEP the ship will be maintained and modernized through normal overhaul procedures.

FITTING OUT AVAILABILITY (FOA)

A fitting out availability is an availability at the shipyard designated as the fitting out activity to place aboard ship the material specified in the ship's allowance lists.

POST SHAKEDOWN AVAILABILITY (PSA)

A post shakedown availability is an availability assigned to a newly built, activated, or converted ship upon completion of its shakedown. The PSA will normally last for six calendar weeks and will be completed not later than the end of the eleventh month after the completion of fitting out, at which time the Shipbuilding and Conversion, Navy (SCN) funding and work authority terminate. Work performed normally includes correction of defects noted during the shakedown, correction of deficiencies remaining from the acceptance trials, and performance of class modifications remaining from the new construction period.

For detailed information on the above topics, refer to Maintenance of Ships; Policies and Procedures (OPNAVINST 4700.7).

REPAIR SHIP/TENDER REPAIRS

All ships are scheduled for regular tender availabilities or for upkeep periods alongside repair ships or tenders at certain intervals of time. Each availability period is usually planned far in advance and is based on the type of ship concerned and on its quarterly employment schedule.

When a ship receives its employment schedule, or is otherwise notified of an availability, it preparation of work requests is based on information contained in the ship's maintenance deferred action sheets. Completed work requests are sent with a forwarding letter to the TYCOM after they are screened by the ship's staff material officer handling material and maintenance. The amount of corrective action taken by the reviewing staff officer will depend upon how well the work requests are written and the extent that they follow established policies and procedures.

ARRIVAL CONFERENCE

An arrival conference is usually held as soon as a ship begins an IMA availability period or an upkeep period. The conference, attended by representatives of the ship, the repair department, and the TYCOM, is used to discuss relative needs of the ship and the priority of each job. The arrival conference clarifies all uncertainties for repair department personnel who have received and studied the work requests in advance. Arrangements are also made for the afloat IMA to provide, if necessary, hotel services (for example, steam and electricity). In addition to these services, the tender or the repair ship may take over communication watches. Freshwater and fuel requirements are not usually supplied except from barges.

The IMA repair department makes repairs in a manner similar to that of a production department in a naval shipyard or an SRF, even to the extent of assigning a ship superintendent (Ship Sup) as a representative of the repair officer.

WORK REQUESTS AND JOB ORDERS

Although the terms *work request* and *job order* are sometimes used interchangeably, the two terms actually have slightly different meanings. Work requests are written by the ship and are forwarded through proper channels to the repair activity. When the work request has been approved by the repair activity, it is issued as a job order.

As soon as your work requests have been approved at the arrival conference, start the jobs that require delivery to the repair activity. Starting these repair jobs early is very important in getting all necessary jobs completed. Equipment that is not needed for the operation of the ship may be disassembled in advance so that defective g should include your ship's number and name; e department, division, or space from which the m was removed; and the job order number. ou may also include additional identifying formation, if necessary. If you send reference aterial, such as drawings and technical manuals, sure they are identified with your ship's name d number.

IIP-TO-SHOP JOBS

Many repair jobs are designated by the ip or approved by the repair activity as ip-to-shop jobs. In a job of this type, the ip's force does a large part of the repair ork. For example, the repair or renewal a damaged pump shaft might well be itten up as a ship-to-shop job. The pump disassembled and the shaft is removed by e ship's force, and the shaft and any necessary ueprints are delivered to the machine shop the repair activity. The machine shop pervisor checks the job and gives an proximate date of completion. When the aft has been repaired, or when a new one s been made, it is picked up and brought back the ship by the ship's force. The pump is assembled, inspected, and tested by the ship's rce according to procedures in the appropriate chnical manual.

Repair jobs on portable equipment, such as nall gauges and valves, are almost always itten up as ship-to-shop jobs.

IECKING THE PROGRESS F TENDER REPAIR JOBS

You should know at all times the status repair work (including ship's force repair ork) being done for your work center or uipment.

You can check on repairs that are being made your own ship by discussing them with the tty officer in charge of the repair detail. ecking on the progress of work in the shops the repair activity requires planning and ordination. Personnel in the repair activity's ops are busy with their repair work, so e method you use to check on the progress work must be one that does not interfere th the work.

The primary purpose of a naval shipyard is to provide services to the fleet in the form of efficient and economical repair, alteration, overhaul, docking conversion, outfitting, and replenishment and to perform related special manufacturing when required. Naval shipyards perform many other functions, including research and design, which are not discussed here.

Naval shipyards are designated as planning yards. A PLANNING YARD is a shipyard designated by the COMNAVSEASYSCOM to undertake the design work for a particular type or class of ship.

WORK REQUESTS

The procedures for submitting shipyard work requests prior to a regular overhaul are contained in the *Maintenance and Material Management (3-M) Manual*, OPNAVINST 4790.4 (series).

TYCOMs require that work requests for work to be undertaken during a repair period (regular or interim) be submitted to them for review, approval, and forwarding to the shipyard well in advance of the beginning of an overhaul. This is necessary to permit successful preliminary planning and material procurement by the shipyard.

Aboard ship, each work request is submitted on the standard work request form. All work requests are screened and assigned a work priority at a conference of the department heads, the executive officer, and the commanding officer. A work list containing brief statements of the work to be done, arranged in the ship's priority sequence, is prepared and submitted along with the work requests to the TYCOM for screening.

FLEET MODERNIZATION PROGRAM

The Fleet Modernization Program (FMP) is a program approved by the Chief of Naval Operations (CNO) to modernize and improve ships of the fleet, by providing a structure for the orderly planning, programming, budgeting, and installation of military and technical improvements. It combines improvements from the Military Improvement Plans (MIPs) and from the Technical Improvement Plans (TIPs), and selected TYCOMs' improvements arranged by individual hull type. These are based on scheduled ship overhauls plus related non-hull identified program funding requirements (for example, design, planning, COSAL, service craft ALTs).

The FMP identifies alterations that are applicable to specific ships on a year-by-year basis within a 5-year period. The execution year program of the FMP forms the basis for implementing current year improvements as funded. The formulation year programs are used as a basis for the annual Navy budget submission; four planning outyears provide a basis for procurement of special program material and for planning other ship alterations.

Ship alterations and improvements are programmed for completion by the CNO approved FMP. The program is developed by the office of the CNO (OPNAV) hull and equipment sponsors based on the operational requirements of each fleet.

The FMP has three primary goals. They are as follows:

- To improve naval ships' capabilities and material conditions by installation of approved alterations and modifications

- To increase the fleet readiness by improving standardization within the ships' class

- To improve safety, reliability, repairability, and habitability of naval ships and equipment in the fleet.

Naval Shipyard Arrival Conference

When the ship arrives at the shipyard for a routine overhaul, an arrival conference is held. The conference is usually supervised by the planning officer of the shipyard and is attended by representatives from the ship, the TYCOM, and the naval shipyard planning department. Members of the conference review the ship's work requests and the individual item costs estimated by the shipyard planning department.

The limitations of the funds made available by the TYCOM determine to a great extent the amount of repairs that will be completed during a naval shipyard repair period. The estimated cost of each repair job, when approved at the conference, is added up to give the total cost. When the total cost equals either the amount of funds appropriated or the cutoff amount, the shipyard will not accept additional repair requests. Under this condition, when several additional important jobs should be performed, the TYCOM must either furnish more funds or revise the priority list.

Establishing the cutoff point enables the shipyard to make certain that the most important repairs and alterations are completed during the availability period. This does not imply that other items with less urgent priority will not be undertaken and completed before the end of the overhaul period. After the ship has been placed in drydock, for example, workers may find that anticipated repairs to the shafting and to the propeller are not necessary, and the funds reserved for this work can be used to finance other items. Sometimes a job may be greatly underestimated because of conditions that do not become apparent until the job is well underway. If the funds originally provided to cover the cost of the work are not sufficient, the necessary funds may have to be provided by deferring other approved items of lesser importance.

Also established at the arrival conference are tentative dates for drydocking, operation of the propulsion machinery and associated auxiliary equipment, and dock and sea trials.

When agreement has been reached at the arrival conference on the items of work to be undertaken, the planning department issues job orders authorizing the work to be performed by the production shops. Each job order clearly defines the scope of the work, includes complete specifications, and identifies the necessary plans. Job orders are not issued for all work at the same time. The first to be issued are for those jobs requiring practically the entire availability period for accomplishment. The other orders are issued as soon as possible thereafter. If design plans are required for any specific item, the issue date of the job order is coordinated with their planned completion date. In any case, job orders for all items approved at the arrival conference are usually issued during the first third of the overhaul period.

The method of numbering job orders differs somewhat among the naval shipyards. However, all of the numbering systems are used to identify each item of work by a job order number. In addition to the naval shipyard job order number, the ship's work request or work item number is shown on the job order sheets.

During a routine shipyard overhaul the ship ıst submit shipyard progress reports as required the TYCOM's instructions. Supervisory rsonnel of the ship must, therefore, keep an curate check on the progress of all work cluding the ship's force work) at all times. ındard progress charts are available for ording and reporting progress. As a rule, one ogress chart is used to record shipyard repairs, other to record alterations, and another to ord ship's force work. Copies of the progress arts should be posted and kept up to date by p's personnel.

The shipyard commander holds frequent ually weekly) conferences with the com- nding officer of the ship to review progress. e ship superintendent and other key shipyard rsonnel also attend these conferences.

You may be required to monitor the progress repair jobs from your area. Always check the ails of the job orders before you start ecking on the progress of a repair job. You can this information from the job orders issued the planning department of the yard. The ship eives three or more copies of the job orders. complete set of job orders is usually kept on aboard your ship. Your division officer should ve copies of the job orders that apply to your ision.

RYDOCKING THE SHIP

The ship is drydocked each time it goes o a naval shipyard for a regular overhaul. ydocking is usually scheduled as early as ssible in the overhaul period, since it is difficult tell in advance just how much repair work will required. Scheduling the drydocking for early the overhaul permits all necessary drydock rk to be done without interfering with work it must be done later and without interfering h machinery trials, strength tests of structural rk, and so forth. As soon as all drydock work s been completed, the ship is removed from ydock.

Before the ship goes into drydock, ship's rsonnel must have detailed information on the valves. When preparing to drydock the ship, engineer officer is required to furnish the pyard with a sea valve checkoff list indicating size, the location, and the function of each valve. The engineer officer must also furnish shipyard, the last docking report. The shipyard maintains file copies of docking drawings for each ship that it is expected to drydock. However, the engineer officer must check these drawings against the ship's copy to make any corrections reflecting work done elsewhere and to determine the last drydocking position used.

A ship entering drydock should not list and should not have trim in excess of that shown in *Naval Ships' Technical Manual*, chapter 997. Trim in excess of 1 foot per 100 feet of length is sufficient to make the docking operation hazardous. If possible, the trim should be brought below the prescribed limit before any attempt is made to drydock the ship.

While the ship is in drydock, no fuel oil, water, or other weight should be shifted, added, or removed, except as specifically authorized by the docking officer or the contractor's dockmaster. Water tanks and oil tanks should be either completely full or completely empty, if possible. When permission is given by the shipyard to shift weight, the shipyard must keep accurate records of the amount of weight shifted, the location from which it is shifted, and its new location. The responsibility for keeping an accurate record of the amount and location of weight changes made by the ship's personnel rests with the ship's commanding officer.

The propellers must not be turned without permission of the docking officer after the ship enters the dock. No fuel oil or other flammable liquid should be drained or pumped into the dock. If the need arises, the shipyard will provide special containers for the disposal of these liquids. During freezing weather, all valves, pipes, and fittings attached to the hull should be drained to prevent the liquids they contain from freezing and cracking them.

Whenever a ship is drydocked, propellers, shaft tubes, outboard portions of the shafting, couplings, bearings, and all sea valves must be examined and the results of the examination entered into the engineering log.

Examination of each sea valve should include determination of the condition of the yoke, the yoke rods, the valve stem, all securing bolts, and all internal parts of the valve. At least two of the bolts holding outboard valves to sea stools should be removed from each valve for inspection, and the remaining bolts should be sounded with a hammer. If defects are found in any bolt, all the other bolts for the valve should be removed for inspection. Whenever all bolts are removed, the gasket should be replaced. All repairs required to place the sea valves in good condition should be made while the ship is still in drydock.

While the ship is in drydock, the ship's force and shipyard personnel may need to work on the sea valves. All openings in the hull must be blank-flanged at the end of working hours. The ship's force and shipyard personnel are each responsible for closing the openings they make in the hull. At the end of each working day, the status of all sea valves must be reported to the engineer officer and entered into the engineering log.

Before the drydock is flooded, all sea valves must be carefully inspected to be sure they are properly secured. The results of this inspection should be reported to the engineer officer and entered into the engineering log.

While the drydock is being flooded, there must be continuous inspection of all sea valves until the ship is afloat and all valves are under a normal head of water. Any unsatisfactory condition must be reported at once to the engineer officer so the docking officer can be notified. A report of leakage must be made in sufficient time so the docking officer can stop flooding, if necessary, before the ship lifts from the supporting blocks.

Shortly after the undocking of a ship, the shipyard submits the docking report to NAVSEA with copies to the commanding officer and to the TYCOM. The docking report includes the name and the class of the ship, the place and date of docking and undocking, the number of days underway and not underway, the number of days waterborne since the last docking, the formula for the paint used and the extent of bottom painting, the shaft and rudder clearances, the docking position used, and the details of all other work performed.

SHIP TRIALS

Ship trials are conducted to determine such things as performance characteristics, readiness for service, the extent of necessary repairs, the adequacy of completed repairs, and the most economical rate of performance under various conditions of service. This section contains information concerning some of the trials performed to determine the condition of the ship. For an in-depth study of all the trials, refer to NAVSEA S9086-04-STM-000, chapter 094, "Trials."

CONTRACT TRIAL

A contract trial consists of the builder's trial, an acceptance trial, and a final contract trial. These trials are conducted on newly constructed ships and on ships that have undergone major conversion prior to acceptance of the ship by the Department of the Navy. These trials determine whether a ship has been built and will operate according to the contract specifications.

BUILDER'S DOCK TRIAL

A builder's dock trial (BDT) is conducted after the installation of a unit is complete and the systems test of all machinery in the engineering spaces is finished. The BDT is held to demonstrate to the supervising authority, to the Supervisor of Shipbuilding (SUPSHIP), and to the builder that the machinery is ready for a sea trial.

BUILDER'S SEA TRIAL

A builder's sea trial (BST) is conducted after dock trials have been satisfactorily completed. The BST is necessary for the proper evaluation of electronic installations and of machinery systems that require a deep water sea environment in which to operate.

All tests and demonstrations that cannot be conducted dockside should be conducted during a BST.

ACCEPTANCE TRIAL

All machinery, electronics, and combat systems installed in naval ships must meet the requirements of an acceptance trial prior to their formal acceptance and delivery to the Navy. Acceptance trial requirements are set up to ensure that a ship and its equipment meet all performance specifications.

FINAL CONTRACT TRIAL

A final contract trial is conducted prior to the end of the guarantee period for all U.S. Navy ships constructed, converted, or modernized in a private shipyard. Similar trials are held for ships constructed, converted, or modernized in naval shipyards, as required by the CNO. These trials are used to determine if there are any defects, failures, or deteriorations other than those due to normal wear and tear.

COMBINED TRIAL

A combined trial is a combination of acceptance and final contract trials. It is conducted only when authorized by the CNO.

POST REPAIR TRIAL

A post repair trial should be made when the machinery of a vessel has undergone extensive overhaul, repair, or alteration that may affect the power or the capabilities of the ship or machinery. A post repair trial is usually made when the ship has completed a routine naval shipyard overhaul period. The trial is optional whenever machinery has undergone only partial overhaul or repair. The object of this trial is to ensure that work has been performed efficiently and completed satisfactorily.

The post repair trial should be held as soon as possible after the repair work has been completed. It is held after the preliminary dock trial, and the persons responsible for the work must be satisfied that the machinery is ready for a full power trial. The conditions of the trial are largely determined by the kind of work that has been done. The ship's commanding officer and the commander of the shipyard determine the manner of the trial. In some cases, such as when repairs have been slight and the commanding officer is satisfied with the repairs, a post repair trial is not held. Minor repairs can usually be adequately tested without a full power trial.

Any unsatisfactory conditions beyond the repair capability of the ship's force should be corrected by the naval shipyard. If necessary, machinery should be opened up and carefully inspected. This is done to determine the extent of any damage, defect, or maladjustment that may have appeared during the post repair trial.

A certain number of naval shipyard personnel accompany the ship on a post repair trial. These are usually technicians, inspectors, and repair personnel. The yard personnel witness the operation of machinery that has been overhauled by the yard. If a unit of machinery is not operating properly, the yard technicians should carefully inspect it and try to determine the cause of the unsatisfactory operation.

SPECIAL TRIALS

COMNAVSEASYSCOM requires that special trials be conducted on one ship from each class of ships. This requirement covers both new construction and major conversions. These trials are made to determine various characteristics of the class and to supply data for the development of operational information furnished to all ships of the class. The trials may also be of an experimental nature not related to class performance but conducted to obtain specific data for design purposes. Special trials may also be conducted on ships not considered as new construction or major conversion. This is to determine the effect of the installation of newly designed equipment, such as a propeller or rudder. In addition to miscellaneous experimental trials and tests, special trials include standardization trials, tactical trials, plant efficiency trials, vibration trials, and noise trials. All of these trials require the installation and operation of special instruments and are conducted by experienced technical personnel.

COMNAVSEASYSCOM selects a ship for special trials and submits a letter to the CNO outlining the scope and duration of the trial and requesting that the ship be made available for conducting the trials. When the ship is made available, the cognizant TYCOM makes arrangements with the COMNAVSEASYSCOM for conducting the trials. NAVSEA prepares and issues to all participating activities an agenda outlining the procedures for the trials. The procedures assign responsibility for preparing the ship, conducting the various trials, preparing trial reports, and removing test equipment upon completion of the trials. Preferably, members of the engineering department of the ship act as engineering observers and record data during the trials.

One example of these special trials is the *Ship Shock Trial*. Primary objectives of the trial are to demonstrate the ability of the ship to operate in a simulated combat environment and to validate the shock hardening designs incorporated into the ship. Since validation is a basic objective, many of the trial preparations center upon identification and correction of potential shock deficiencies. The ship's force plays an important role in this preparation. Awareness of good shock design and installation practices allows the ship's force to identify potential problems for correction. The trials themselves consist of the detonation of a series of large high explosive charges at carefully controlled standoff distances. During each shot the ship is at General Quarters, with all systems operational. Following each shot, the ship's force maintains system operation through reconfiguration as required. Detailed inspections are then conducted and deficiencies are documented for correction. Repairs that are outside the capability of the ship's force and available industrial facilities are deferred until the post shock availability. In many cases the post shock availability is incorporated into the post shakedown availability. Lessons learned from the trial are incorporated into a follow-up action plan that results in the development of SHIPALTs required to correct any design deficiencies that have been uncovered during the trial. Additional by-products of these trials are heightened crew awareness of what combat-induced shock is and firsthand knowledge of how to prepare for shock and how to recover from its effects.

APPENDIX I

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