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ABSTRACT

This course in mechanical devices and systems is one of 16 courses in the Energy Technology Series developed for an Energy Conservation-and-Use Technology curriculum. Intended for use in two-year postsecondary technical institutions to prepare technicians for employment, the courses are also useful in industry for updating employees in company-sponsored training programs. Comprised of eight modules, the course is an in-depth study of the principles, concepts, and applications of various mechanisms that may be encountered in industrial application of energy use and conservation. Operational procedures, uses, maintenance, troubleshooting, and repair and replacement procedures are covered. The application portions of the modules emphasize practical maintenance and installation of equipment and specification of proper replacement components for manufacturers' catalogs. Written by a technical expert and approved by industry representatives, each module contains the following elements: introduction, prerequisites, objectives, subject matter, exercises, laboratory materials, laboratory procedures (experiment section for hands-on portion), data tables (included in most basic courses to help students learn to collect or organize data), references, and glossary. Module titles are Belt Drives, Chain Drives, Gear Drives, Drive Train Components I and II, Linkages, Fans and Blowers, and Valves. (YLB)

MECHANICAL DEVICES AND SYSTEMS

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

601 LAKE AIR DRIVE

WACO, TEXAS 76710

JUNE 1981

PREFACE

ABOUT ENERGY TECHNOLOGY MODULES

The modules were developed by TERC-SW for use in two-year postsecondary technical institutions to prepare technicians for employment and are useful in industry for updating employees in company-sponsored training programs. The principles, techniques and skills taught in the modules, based on tasks that energy technicians perform, were obtained from a nationwide advisory committee of employers of energy technicians. Each module was written by a technical expert and approved by representatives from industry.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Laboratory Materials, which identify the equipment required to complete the laboratory procedure.

Laboratory Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

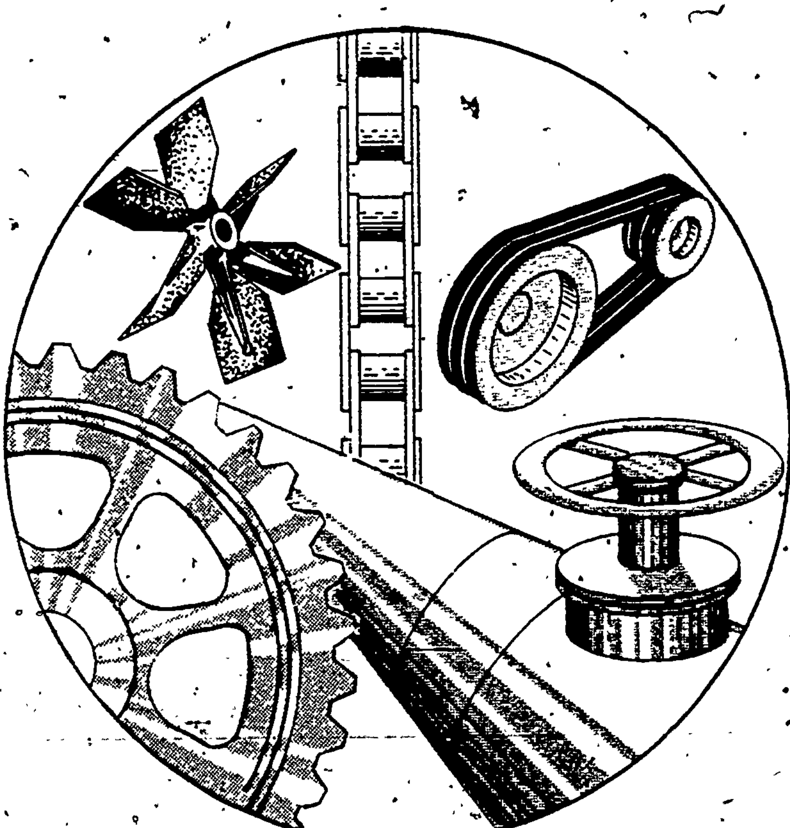
References, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of the prestated objectives.

CONTENTS

ENERGY TECHNOLOGY
CONSERVATION AND USE

MECHANICAL DEVICES AND SYSTEMS



MODULE MS-01

BELT DRIVES

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INTRODUCTION

Belt drives comprise the most widely-used medium of power transmission in industry. Their popularity exists because of their efficiency, compactness, quietness, and resiliance (capacity to absorb load shock).

Such drives utilize the following belt types: flat belts, round belts, or V-belts. V-belts are the most commonly-used of the three types, largely as a result of their wedge shape that causes them to be held firmly into the grooves of pulleys under load. Variable-speed pulleys and belts provide a system with the capacity to change speed during operation.

The proper installation and maintenance of belt drives can result in substantial energy conservation and equipment protection. For example, if a large drive system with a number of belts is adjusted in such a manner that the belts are much too tight, the following malfunctions, among others, can occur: (1) premature belt damage and wear, (2) bearing failure, and (3) increased load on drive motor, requiring more energy.

This module introduces belt drives and discusses their design, installation, use, maintenance (including trouble-shooting procedures), and conservational operation. In the laboratory, the student will inspect and adjust a belt-drive system.

PREREQUISITES

The student should have completed the following Unified Technical Modules: Concept Modules 1-0, "Force," 2-0, "Work," 6-0, "Power," and 8-0, "Force Transformers"; and Application

Module 8M3, "Drive Systems." One year of high school algebra also must have been completed.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List the three mechanical systems most often used to transmit rotary mechanical power.
2. Given each of the following types of belts, cite at least one specific application for each type:
   a. Round belt.
   b. Flat belt.
   c. V-belt.
   d. Double Angle V-belt.
   e. Banded V-belt.
   f. Linked V-belt.
   g. Positive Drive belt.
   h. V-ribbed belt.
   i. Variable-speed belt.
3. List at least two advantages and disadvantages of the below listed belts:
   a. Flat belts.
   b. V-belts.
   c. Linked V-belts.
   d. Positive Drive belts.
   e. V-ribbed belts.
   f. Cog and notch belts.
4. Describe the design characteristics which distinguish the following:
   a. Round belt pulleys.
   b. Flat belt pulleys.
   c. V-belt pulleys.

5. Determine the width and length of a belt from the code printed upon it.
6. Given the diameters of the pulleys in a flat-belt system, the center distance between them, and the applicable formula, calculate the belt length required for the system to operate efficiently.
7. Given the diameter and rate of revolution of a flat-belt pulley and applicable formula, calculate belt velocity.
8. Given the diameter of one pulley in a belt system, calculate the most energy-efficient diameter for the other pulley.
9. Given a spring scale, a straight edge, a ruler, and the applicable manufacturers' table, and an over- or under-tensioned belt installed in a belt-drive system, check tension of belt according to procedures outlined in the module, and determine correct tension for belt.
10. Describe at least two ways an improperly-maintained belt system can lose energy.
11. Given a belt with one or more of the following defects, identify all defects, and cite at least one possible cause for each:
    a. Fabric rupture.
    b. Cover tear.
    c. Worn sides.
    d. Cross cracking.
    e. Burns.
    f. Gouges.
12. Describe how properly to install a V-belt on pulleys.
13. Given a V-belt system with one or more of the following defects, inspect the system, correctly diagnose all defects, and cite at least one cause for each defect:

a. Misalignment of pulleys.
b. Incorrect V-belt size.
c. Defective belt.
d. Improperly matched belts.
e. Defective sheaves.
f. Incorrectly tensioned belt.

MECHANICAL DRIVES

Three systems are used ~~more~~ extensively than any others to transmit rotary mechanical power (Figure 1):

- Belts and pulleys.
- Chains and sprockets.
- Gears.

These systems are called "drives," and are used to transmit power between adjacent shafts, as illustrated in Figure 1.

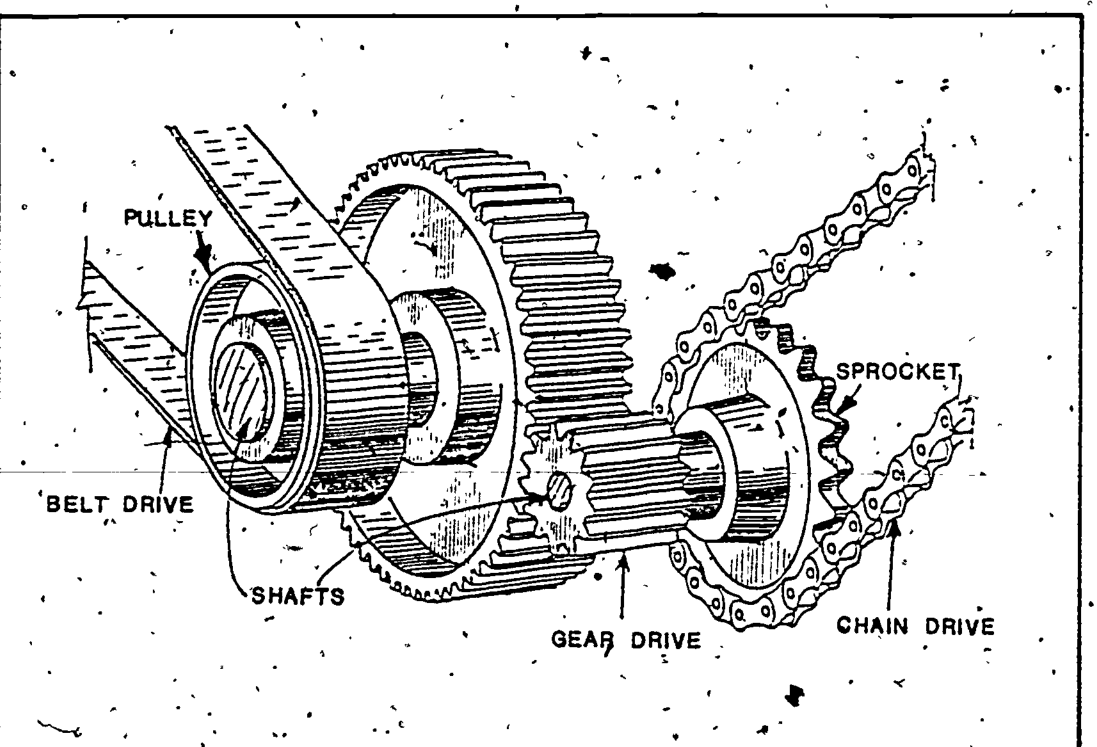


Figure 1. Belt, Gear, and Chain Drive Systems.

THE BELT DRIVE

Belts and pulleys normally are used to transmit power between two parallel shafts. One shaft is the driver; the other the driven. Belt drives transfer force through frictional contact between the surfaces of the belts and of the grooves on the pulleys. These drives commonly are used between shafts too far apart to be coupled economically with gears. They are important in industry and, in one form or another, have been in use for a long time. Some of the earliest applications were in spinning wheels, lathes, windmills, and waterwheels.

TYPES OF BELTS

Figure 2 displays the three most frequently-used belts — (a) the round, (b) the flat, and (c) the V-belt. Each belt type requires a special pulley, as shown; and each is suited for its own special applications. Other belt types, many of which are discussed later, are variations of these three basic designs.

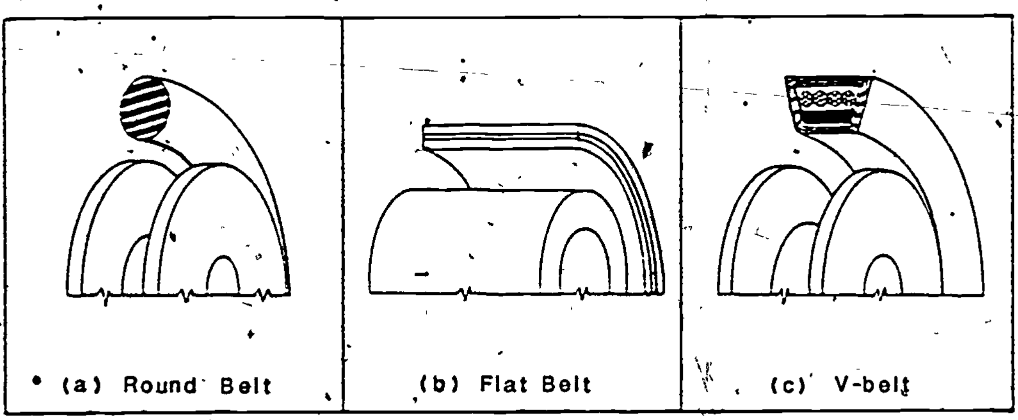


Figure 2. The Three Basic Belt Designs.

Round belts (Figure 2a) are designed to handle light loads. Usually constructed of neoprene or of some other synthetic material, they are employed in light-duty equipment, such as sewing machines and tape recorders. Pulleys for round belting have a concave face to fit the belt's cross section.

Today, flat belting (Figure 2b) is not used in industry for power transmission as frequently as before, although it is widely used in conveying.

The V-belt (Figure 2c), the most widely used of the three basic types, is discussed in detail in a later section of this module.

FLAT BELTS

Although flat belts are bulky and less flexible than V-belts, they are simple, strong, and resistant to dusty conditions.

Flat conveyor belting moves coal, brick, sand, cement, glass, soybeans, fertilizer, scrap metal, wood chips, detergents, and many other materials. There are special food-handling belts that resist greases and odors; Teflon belts, used to convey materials that are being spray-painted; and belts made of special rugged materials for handling sharp pieces of metal. Such large systems, if improperly set up or improperly maintained, can waste energy. Figure 3 shows a typical flat-belt conveying system. Takeup screws are used to adjust friction of the belt on the pulley.

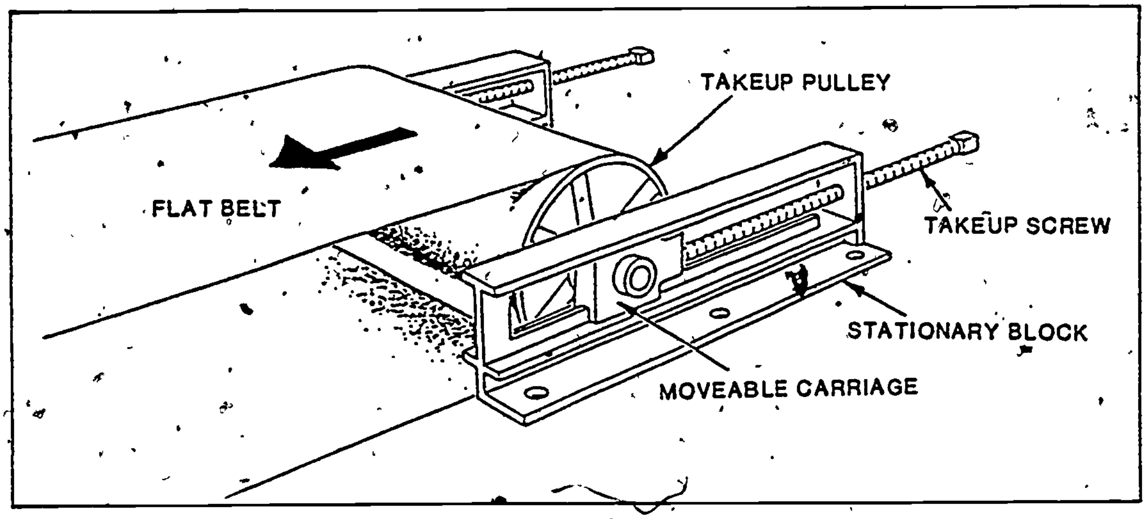


Figure 3. Flat-belt Conveying System with Takeup Pulley.

Pulleys for flat-belt applications can be either flanged (made with a rim on each edge of the pulley) or crowned; Figure 4 illustrates both. The crowned pulley has a raised, sloping surface, or crown, designed to prevent a flat belt from slipping off the surface. Pulley sizes range from a few inches to over ten feet in diameter.

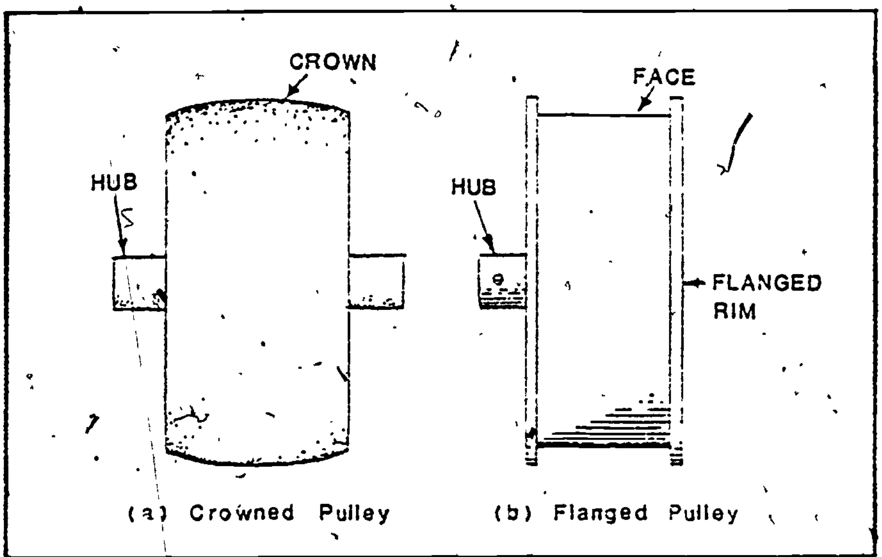


Figure 4. Crowned and Flanged Pulleys.

LENGTH MEASUREMENT AND CALCULATION

The technician should ensure that these belt-drive systems are economic and energy-efficient. The actual design of a system is ultimately an engineering responsibility; however, the technician may be called upon to access, and even to redesign, outmoded systems. An important first step in this process is to determine the actual length of flat belting needed for efficient operation.

Direct length measurement often is the simplest and surest method. This method involves the use of a long steel measuring tape that is adjusted over the aligned pulley crowns in the same path as the belt. To this measured length, a reasonable length should be added for the joining process where applicable.

Sometimes, direct measurement is impractical because of pulley location. In this case, length can be calculated with Equation 1, as shown in Example A.

$$L_b = 2\ell_c + 1.6\,(D + d) + \frac{(D - d)^2}{4\ell_c} \qquad \text{Equation 1}$$

where:

L_b = Belt length needed.
ℓ_c = Center distance between pulleys.
D = Diameter of large pulley.
d = Diameter of small pulley.

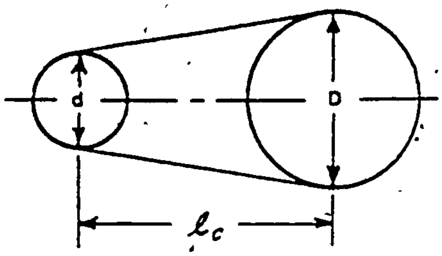
EXAMPLE A: FLAT-BELT LENGTH CALCULATION.

Given: 24" diameter of large pulley = D

9" diameter of small pulley = d

72" center distance between pulley = ℓ_c.

Find: Belt length required (L_b).



Solution: Use Equation 1:

$$L_b = 2\ell_c + 1.6\ (D + d) + \frac{(D - d)^2}{4\ell_c}$$

Substituting:

$$L_b = (2 \times 72) + 1.6\ (24 + 9) + \frac{(24 - 9)^2}{4 \times 72}$$

$$= 144 + (1.6 \times 33) + \frac{15^2}{288}$$

$$= 144 + 52.8 + 0.78$$

$$L_b = 197.58".$$

BELT-SPEED CALCULATION

Flat belts are manufactured to operate most efficiently at a particular speed stated in the manufacturers' specifications. At any other speed, frictional and electrical energy losses occur. The actual speed of a flat belt can be calculated by the use of a stroboscope or special tachometer to find the r/min of the pulley to which the belt is attached.

Once this speed and the diameter of the pulley are known, actual belt speed can be determined from Equation 2.

$$M = \frac{D}{12}\pi n \qquad \text{Equation 2}$$

where:

- M = Speed of belt in ft/min.
- π = 3.14.
- n = Pulley speed in r/min.
- D = Pulley diameter in inches.

Equation 2 is utilized to calculate flat-belt speed in Example B.

EXAMPLE B: CALCULATION OF ~~FLAT~~-BELT SPEED.

Given: A 6'0" diameter pulley rotating at 3 revolutions per second.

Find: Belt velocity.

Solution: Use Equation 2.

$$M = \frac{D}{12}\pi n.$$

Convert all quantities to appropriate units:

$D = 6'0" = 72"$

$M = 3 \text{ RPS} = 3 \times 60 = 180 \text{ r/min.}$

Substitute in equation:

$$M = \frac{72}{12} \times 3.14 \times 180$$

$$= 6 \times 3.14 \times 180$$

$$M = 3392 \text{ ft/min.}$$

Calculated belt speed should be checked against the manufacturer's specifications to ensure that the belt is operating at or near optimum speed; otherwise, the belt may be overloaded or inadequately tensioned. Belt speed must also be considered when a new system is designed. Once the rate at which the driving shaft revolves is known, belt speed can be calculated. Manufacturers' specifications then are consulted for the best belt for the job.

These few simple calculations cannot be employed to design a complete drive for a specific application. Formulas for design are complicated and may be found in engineering textbooks. The length and speed calculations just discussed are used best to determine the efficiency of existing drives.

THE POSITIVE-DRIVE BELT

The positive-drive belt (Figure 5) is a unique concept in power transmission. Essentially a flat belt with teeth, it combines the advantages of the chain and of the gear with those of the belt. The belt teeth, which fit into corresponding pulley teeth, provide a drive with no slippage; that is, a "positive" drive.

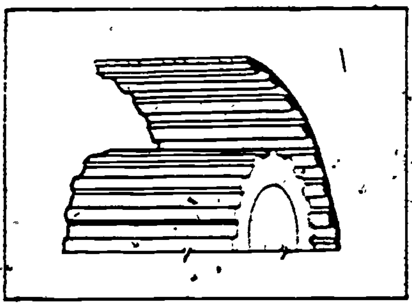


Figure 5. The Positive-Drive Belt.

Because of this lack of slippage and the compactness of positive-drive belts, they are used widely as "timing belts" in engines.

Among the other advantages of positive-drive belts are the following:

- The belt teeth throw off heat.
- They operate with less tension and, therefore, with less bearing load.
- They have a high speed range — up to 16,000 ft/min.
- They can be used on drives having up to 600 hp.
- They require little maintenance.
- They require no tensioning devices, such as idler pulleys.
- They are cost- and energy-efficient.
- They are long-lasting.

Although at first utilized primarily in synchronous applications, positive-drive systems are gaining a wider acceptance, even replacing chains, gears, and standard V-belts in some operations. (In those systems, however, that possess great load shock, the positive-drive belt may not allow enough absorbence of shock, unless an appropriate shock coupling is used.)

MAINTENANCE OF FLAT BELTS

SPLICING OF FLAT BELTS

Most flat belts are spliced to make them endless. They can be spliced with cement; with lap, butt, or apron lacing; or with hooks and plates. Belt splicing is made easier when special belt clamps are employed to hold the belt straight. A straight splice is required to assure proper belt operation. Splicing techniques are available from various belt manufacturers.

TROUBLESHOOTING OF FLAT BELTS

Table 1 presents corrective measures for flat-belt problems. Alignment is critical. The first alignment step is to adjust both pulley shafts to parallel by first measuring the distance between each end of the shafts. When pulleys are separated by long distances, a trial-and-error method must be used. If the belt is straight, the pulleys can be aligned by adjusting them on the shafts until the belt runs straight on both pulleys. When the pulleys are close, the alignment method for V-belts can be used.

TABLE 1. FLAT-BELT TROUBLESHOOTING.

TROUBLE	CAUSE	CORRECTION
Belt Slipping or Squealing	(a) Belt too thin (b) Belt too narrow (c) Pulley crown too high (d) Drive overloaded	(a) Use thicker belt (b) Use wider belt (c) Reduce pulley taper (d) Increase drive capacity
Belt Stretches	(a) Belt too thin (b) Belt too narrow	(a) Use thicker belt (b) Use wider belt
Belt Runs off Pulley	(a) Pulleys out of alignment (b) Center distance too great	(a) Align pulleys (b) Shorter center distance
Belt Whips and Flaps	(a) Loose belt (b) Belt too narrow (c) Belt too thin (d) Belt crooked (e) Motor poorly braced (f) Lopsided pulley (g) Crooked shaft	(a) Tighten belt (b) Use wider belt (c) Use thicker belt (d) Straighten joint or replace belt (e) Brace motor (f) Replace or repair pulley (g) Replace or repair shaft

Table 1. Continued.

TROUBLE	CAUSE	CORRECTION
Cracked Outside Ply	(a) Belt too tight (b) Pulley diameter too small	(a) Loosen belt (b) Replace with larger pulley
Cracked Inside Ply	(a) Belt too loose (b) Pulley crown too high (c) Belt too thin (d) Belt too narrow (e) No belt dressing	(a) Tighten belt (b) Reduce crown taper (c) Use thicker belt (d) Use wider belt (e) Apply belt dressing
Belt Runs Crooked	(a) Belt stretched when forced over pulley (b) Belt unevenly spliced (c) Pulleys out of alignment	(a) Replace belt if problem serious (b) Resplice or replace (c) Align pulleys
Belt Runs to One Side of Driven Pulley	(a) Belt too slack (b) Belt too thin (c) Belt too narrow (d) Belt crooked (e) Pulleys out of alignment	(a) Tighten belt (b) Use thicker belt (c) Use wider belt (d) Resplice or replace (e) Align pulleys
Belt Weaves Backward and Forward, causing belt wear	(a) Pulley wobbles (b) Bent shaft (c) High spot on pulley	(a) Secure pulley properly on shaft (b) Repair or re-place shaft (c) Repair or re-place pulley
Belt Peals and is Covered with Grain	(a) Belt slippage (b) Proper dressing not applied to belt (c) Oil or other material being thrown on belt (d) Chemical fumes	(a) Tighten belt (b) Apply dressing made for belt (c) Stop from reach-ing belt; clean the belt and scrape off grain (d) Stop from reach-ing belt if prac-tical

V-BELTS

V-belts are vital to industrial operations because they possess a tighter grip than other belts and a power transmission efficiency as high as 95%. Figure 2c shows a V-belt cross section. A V-belt can transmit large loads because it is rugged and dependable. Steel or fiber reinforcement is provided in the outer layer of the belt to increase tensile strength; the inner layers are constructed of compressible rubber (usually synthetic).

The V-belt's shape causes it to wedge firmly into the pulley, or sheave, groove. The section going around the pulley tends to bulge under load and to press firmly against the flanges for increased traction. Four or more V-belts often are placed on a pulley as shown in the multiple V-belt drive in Figure 6. All belts on a multiple drive must be matched in length.

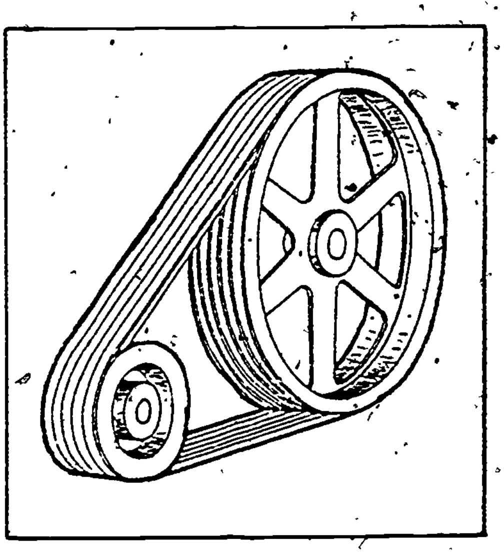


Figure 6. Multiple V-Belt Drive.

Pulleys for V-belt drives often are called "sheaves." Most standard sheaves are statically balanced in order that they can be operated at rim speeds of up to 6,000 feet per minute (ft/min). Most electric motors operate more efficiently at full capacity and speed (without having their speed reduced greatly by a motor control).

DESIGN VARIATIONS

There are several variations of the basic V-belt design, as indicated by Figures 7 and 8.

The double-angle V-belt is constructed with a "V" shape at both top and bottom surface, and both surfaces may contact different pulleys rotating in different directions. (A double-angle belt system is shown later as "Serpentine" drive in Figure 9.)

Banded V-belts are multiple belts permanently bonded by a tie or band at the top. They are used on drives to prevent belt roll off, jump off, or whip. (Belt whip is a kind or irregular flapping movement.)

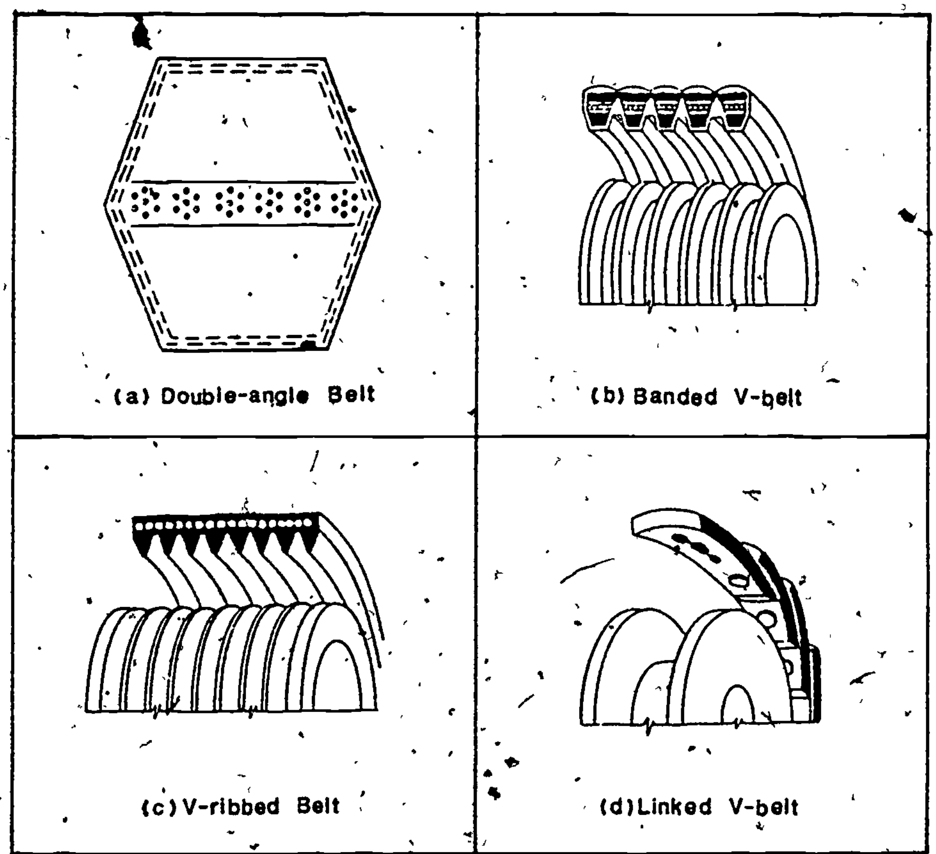


Figure 7. V-belt Design Variations.

V-ribbed belts are manufactured with multiple sharp "Vs" that provide excellent grip in a narrow width, although they require large belt tension and precise alignment.

Linked V-belts are constructed of flexible links of rubber or neoprene and fabric, held together by studs and washers. Links on these belts can be removed to match the tension requirements of different drives.

The flexibility and heat-dissipating ability of the basic V-belt is enhanced when grooves or notches are made into the bottom. The cog belt and notch belt are especially designed to be more flexible and to throw off heat more rapidly than the conventional V-belt.

VARIABLE-SPEED BELT DRIVES

In many industries, the necessity arises to change the speed of a driven machine during operation. Variable-speed pulleys and belts (Figure 8) accomplish this feat when the two halves of the pulleys are moved closer together or farther apart, forcing the belt to ride higher or lower in the pulley and to change the speed of the driven pulley. The variable-speed sheaves shown in Figure 8 operate as follows: The driver pulley contains the shifting device that changes its pitch; the driven pulley is spring mounted and merely serves as a resistance to hold the belt tightly. Other systems utilize idlers or even two shifting pulleys in synchronication.

Such drives require flexible, wide belts having great cross-sectional strength. Both the belts and the sheaves should be checked for wear periodically.

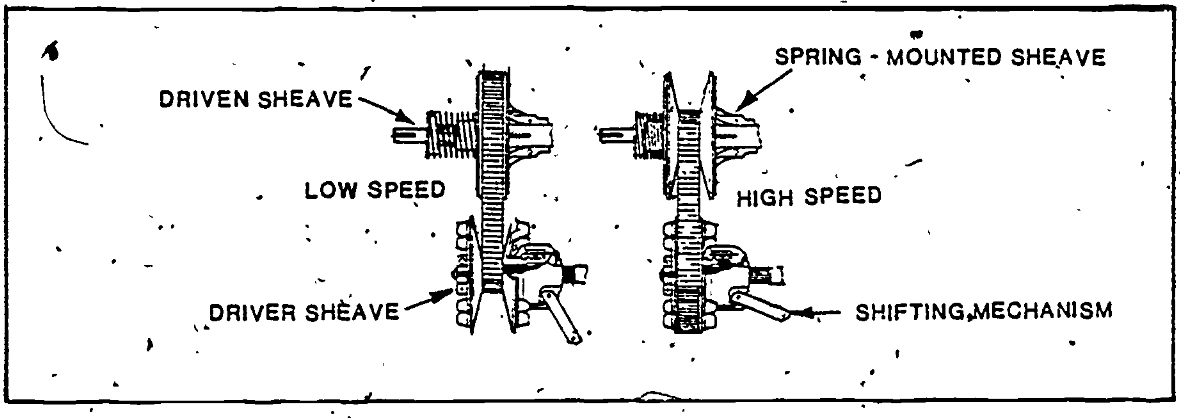


Figure 8. Variable-speed Belt and Pulleys.

FORMS OF BELT DRIVES

Figure 9 illustrates the five major configurations of belt drives: Open, Turned, Crossed, Serpentine (which uses either a flat belt or a double-angle V-belt), and Mule.

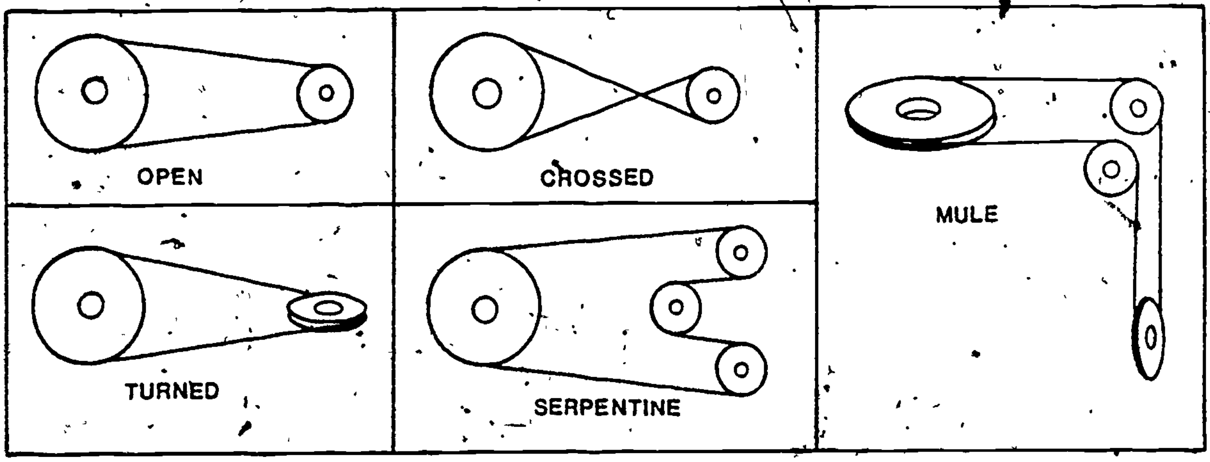


Figure 9. Forms of Belt Drives.

V-BELT SIZES AND MATCHING NUMBERS

V-belts are made in many sizes, ranging from 1/2 to 1 1/2 inch widths. Numbering systems are used to indicate width, duty type, length, and matching number of each belt. These codes are marked on each belt and vary with each manufacturer; for example, a typical marking such as B210.....50 can be interpreted as follows:

- B indicates that the width is 21/32 inch; that is a standard industry code. The common width designations for heavy industrial belts are A (1/2"), B (21/32"), C (7/8"), D (1 1/4"), and E (1 1/2").
- 210 indicates the belt length in inches. The last digit indicates tenth of an inch. The B210 is 211.8 inches in length, or slightly longer than the belt number, which is measured along the inside surface. (Most V-belting is endless, or unjoined; however, it also is manufactured in lengthy rolls for use on line shafts or when extra-long belts are required. Such belting is spliced with hinged metal fasteners.)
- 50 indicates the matching number, in order that belts used on a multiple-belt drive can be matched precisely in length. (If the belts are not matched, some will be loose and others tight, which reduces belt life.) Matching numbers represent small increments of length within a given nomimal length. Belts will operate properly if the numbers are grouped within the limits given in Table 2.

TABLE 2. LIMITS OF BELT MATCHING NUMBERS.

Belt Length	Matching Limit
Up to 100	Use only 1 number
100 to 200	Within 2 consecutive numbers
200 to 300	Within 3 consecutive numbers
300 to 400	Within 4 consecutive numbers
400 to 500	Within 5 consecutive numbers
500 and Up	Within 6 consecutive numbers
Match No. 50 indicates a belt of standard nominal length. Nos. 51, 52 and 53 are successively longer belts, and Nos. 49, 48 and 47 are shorter ones.	

PULLEY SIZE

The relationship between pulley size and power is important. Pulley ratio (the ratio of the diameter of the large to the small pulley) should be 3:1 or less, in order that full power can be applied to a belt system. The use of manufacturers' specifications virtually assures the correct pulley ratio; however, when several different set-ups are possible, the energy technician should select the drive that will come closest to giving full power. When the diameter of one pulley is known, calculation of the most energy-efficient design for a system can be accomplished as shown in Example C.

EXAMPLE C: PULLEY SIZE CALCULATION.	
Given:	Large diameter pulley is 12".
Find:	Best diameter for small pulley.

Example C. Continued.

Solution:	$\frac{D}{d} = \frac{3}{1}$	Equation 3
	$\therefore d = \frac{D}{3} = \frac{12}{3} =$ 4" diameter minimum.	

Pulley size affects pulley speed. If two pulleys are the same size, they will rotate at the same speed; however, when the drive pulley is smaller than the driven pulley, the driven pulley will turn slower.

MAINTENANCE OF V-BELT DRIVES

A minimum of preventive maintenance will stop many of the more common energy losses associated with belt drives. Drives should be inspected regularly. CAUTION: Lock the on-off switch in "off" position when inspecting or repairing belt drives.

SHEAVE ALIGNMENT IN V-BELT DRIVES

Precise sheave alignment is required and is accomplished as follows: (1) Shafts upon which the sheaves are fitted must be aligned horizontally or in the same degree of angle. (2) Parallel shaft and groove alignment usually is accomplished simultaneously. Such alignment is illustrated in Figure 10a, in which a straight edge is used to provide an accurage alignment. (The straight edge itself, perhaps a board, must be straight and unwarped.) An alternate method, shown in Figure 10b, makes use of a line pulled taut. Even more precise alignment can be accomplished when the shafts are lengthy: measurements are made between the shafts at both ends.

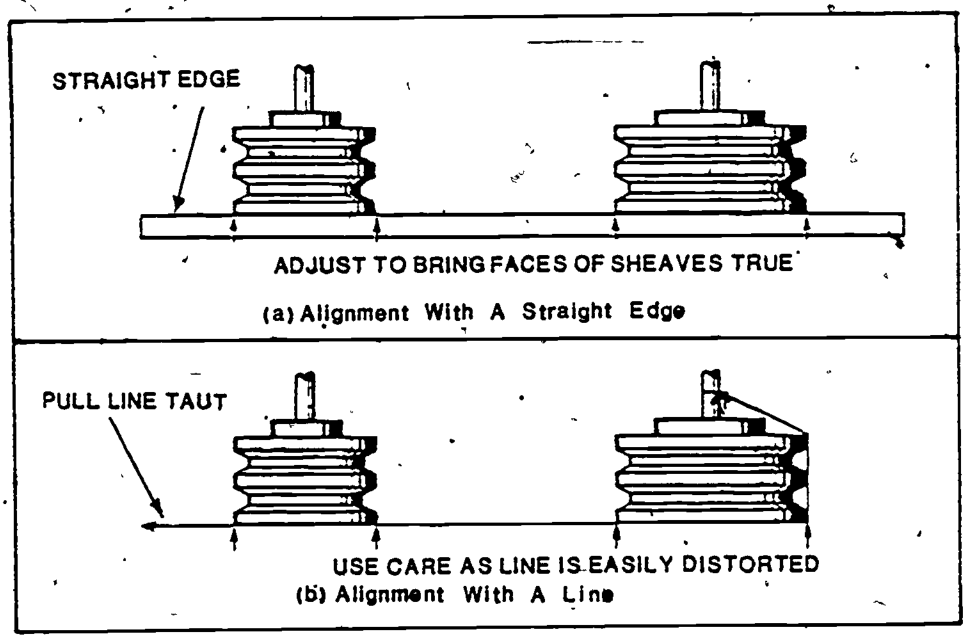


Figure 10. Alignment of Sheaves and Shafts.

V-BELT INSTALLATION

Belts should not be forced onto sheaves by so-called "rolling" action, which stretches them and breaks their fibers. Rather, the below step-by-step procedures should be followed:

- Loosen the adjustable tension mount.
- Slip the belt around the sheave grooves. When installing more than one V-belt on a multiple drive, make sure that all the belts are matched and that they all are slack on the same side (usually the top side).

- Adjust the mount to tighten the belt to approximately the correct tension.
- Start the unit, and allow the belt to "seat" in the sheave grooves.
- Stop the unit, and tighten belt to correct tension as follows:

BELT TENSION

Because belts tend to slip, when chains or gears do not, belt tension must be tested regularly to prevent excessive wear and reduction of mechanical energy. Since tension in a belt system is so important, some type of tensioning device, such as an idler pulley or a jacking screw, often is used. Whenever possible, the slack part of the belt should be at the top of the drive, to allow greater arc contact with the pulleys. Tension should be checked at specified inspection intervals. Because new belts stretch and "seat" into the sheave grooves, their tension should be checked after they have run 24 to 48 hours.

Belt tension often is determined by use of a pocket "Tensiometer" (Figure 11a), available from belt manufacturers.

The Tensiometer is used as follows: (1) The belt span length is measured (Figure 11b). (2) The large "O" ring on the Tensiometer is set for 1/64" for every inch of belt span. (3) The small "O" ring is set to zero. (4) The larger end of the Tensiometer is pressed downward at the center of the belt span (Figure 11c). On a single-belt drive, the Tensiometer is pressed until the large "O" ring is even with the bottom of a straight edge placed on the outside rims of the two pulleys; on a multiple-belt drive, it is pressed until the large "O" ring is even with the top of the adjoining belt (if taut itself). Each belt in the drive is measured, and the average reading is obtained. (5) The position of the small "O" ring now has changed to indicate the pounds required to deflect the belt. (6) Belt deflection tables from the belt manufacturer's catalog are checked for the proper tension in pounds.

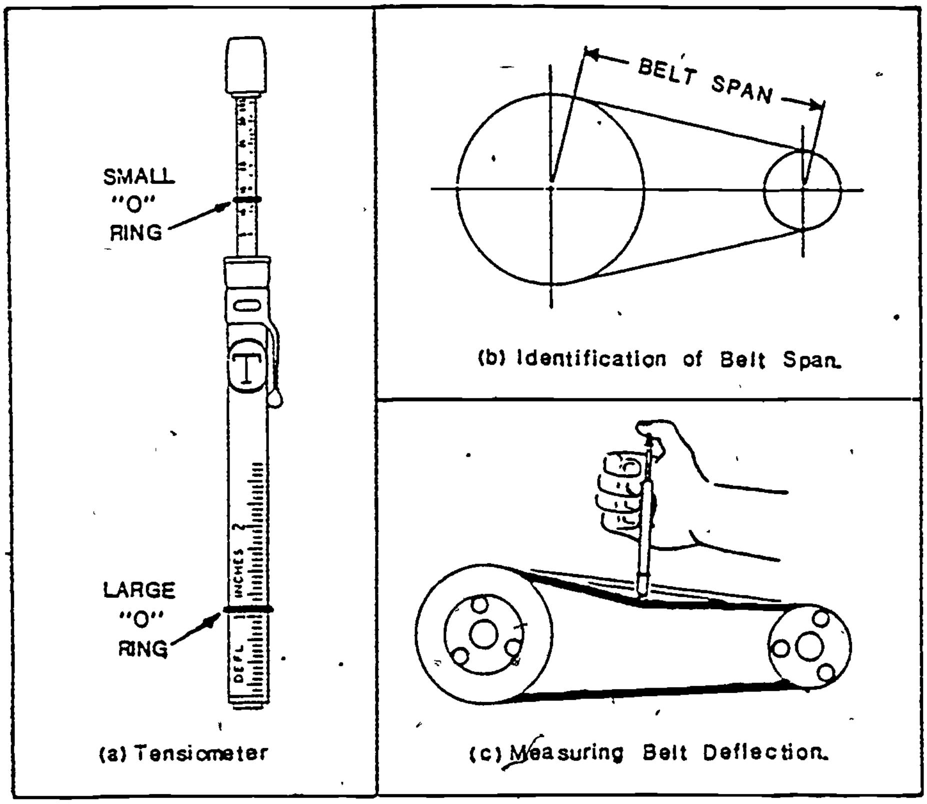


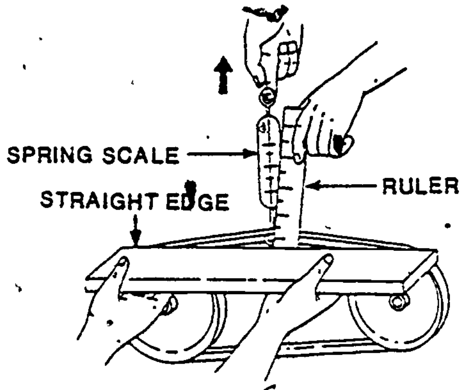
Figure 11. Use of the Belt Tensiometer.

A spring scale and a ruler also can be used to check tension, as explained in Example D.

EXAMPLE D: CHECKING BELT TENSION.

Given: A V-belt and pulley mechanical drive. Belt span is 32".

Find: Belt tension.



Solution:

- Hold a straightedge parallel to the belt, top surface, and place a ruler level and perpendicular to the straightedge.
- Use a spring scale, and apply a perpendicular force to the belt at the midpoint of the span.
- This force should be that required to deflect the belt 1/64 inch for every inch of span length; for example, a 32-inch belt should be deflected 1/64 x 32 or 1/2 inch.

NOTE: Belt manufacturers provide tables that list the recommended belt deflection force for their belts. These tables take into account such factors as sheave sizes, r/min, etc.

TROUBLESHOOTING OF V-BELTS

Table 3 provides extensive V-belt and sheave troubleshooting procedures that should be studied and discussed thoroughly.

TABLE 3. V-BELT TROUBLESHOOTING.

TROUBLE	CAUSE	CORRECTION
Belt Slipping	(a) Not enough tension (b) Drive overloaded (c) Oily drive	(a) Increase tension (b) Increase drive capacity (c) Correct oil or grease condition
Belts Squealing	(a) Drive overloaded (b) Heavy starting load (c) Not enough arc of contact	(a) Increase drive capacity (b) Increase tension (c) Lengthen center distance
Belts Turned Over	(a) Broken cords from running belts onto sheaves (b) Not enough tension (c) Impulse loads	(a) Reduce drive centers when installing belts on sheaves (b) Increase tension (c) Provide pivoted motor base or spring loaded idler
Repeated Belt Breakage	(a) Shock loads (b) Broken cords from running belts onto sheaves (c) Foreign objects	(a) Increase tension or increase drive capacity (b) Reduce drive centers when installing belts on sheaves (c) Provide protective guards

Table 3. Continued.

TROUBLE	CAUSE	CORRECTION
Rapid Wear	(a) Worn sheave grooves (b) Sheave dia. too small (c) Misalignment (d) Drive overloaded (e) Belts rubbing	(a) Replace sheave (b) Increase sheave diameters (c) Align drive (d) Increase drive capacity (e) Provide running clearance
Underside Cracked or Belt Hardened	(a) Excessive heat	(a) Provide ventilation for belt guard covering and/or correct slipping condition
Excessive Whipping	(a) Drive centers too long (b) Pulsating load	(a) Reduce drive centers or provide idler pulley(s) (b) Review flywheel requirements of drive
Hot Bearings	(a) Too much tension (b) Sheaves too small (c) Sheaves too far out on shaft (d) Belt slippage (e) Poor bearing condition	(a) Decrease tension (b) Use larger sheaves (c) Place sheaves as close as possible to bearings (d) Increase tension (e) Observe recommended design and maintenance
Some Belts on Multi-belt Drive Loose	(a) Belts not matched (b) Some grooves damaged (c) Loose belt internally damaged (d) Not enough tension	(a) Install matched set from one manufacturer (b) Remove burrs from or replace sheave (c) Replace belt (d) Increase tension
Tie Band Separating from Belts	(a) Worn sheaves (b) Sheave misalignment	(a) Replace sheaves (b) Align sheaves

Table 3. Continued.

TROUBLE	CAUSE	CORRECTION
Worn Belt Sides	(a) Normal wear (b) Misalignment, grit or dust	(a) Replace belt (b) Align sheaves; clean
Narrow Spots	Broken cords from prying or running belts into sheave grooves	Replace belt
Swollen, Spongy and/or Cover Stock Loose	Deterioration from exposure to oil, grease, or chemicals	Use better belt guards
Spot Wear or Burns	Slippage when starting or at peak loads	Increase tension or use system with more belts
Ply Separation	Belt running over too small a sheave	Use larger sheave
Belt Excessively Stretched	Broken internal cords and/or excessive tensioning	Replace belt, and reduce tension if necessary
Frayed or Gouged Belt Sides	(a) Misalignment (b) Rubbing (c) Damaged sheaves	(a) Align sheaves (b) Remove obstacle (c) Replace sheaves
Belt Rides Low in Grooves	(a) Worn belt (b) Worn grooves in sheave(s)	(a) Replace belt (b) Replace worn sheave(s) NOTE: Top of belt should ride 1/16" above top of sheave at rest.
Shiny Groove Bottoms	(a) Worn sheave (b) Worn belt	(a) Replace sheave (b) Replace belt
Worn Sheave Sides (check with template)	(a) Normal wear (b) Loose belt (c) Dusty conditions	(a) Replace sheave (b) Tighten belt (c) Eliminate dust if possible

V-BELT DRIVE SELECTION

The selection of the proper V-belt drive for a particular application can be simplified by the use of manufacturers' tables. While it is possible to calculate requirements for a "non-standard V-belt" by using formulas and performing stress analyses found in engineering textbooks, such calculations normally are unnecessary. The use of such manufacturers' tables will allow the technician to select a system and to compare costs of alternative systems immediately. The process of selection also permits the technician to take advantage of the data manufacturers have gathered over the years.

The tables also provide a quick and easy way to perform an energy-advantage analysis of existing systems. Using them, the technician can select several systems to meet the same need and compare their relative costs.

EXERCISES

1. A 3" wide belt, 250" long, is used to drive a pump from an electric motor. The motor and pump sheaves are 9" and 24" diameter. Calculate how far apart the shafts must be to use fully the belt length.
2. A 3 inch diameter flat-belt pulley rotates at 1100 r/min. What is the belt velocity?
3. A mechanical drive system has a driver pulley 9 1/2" diameter and driven pulley 21" diameter. If the recommended drive ratio is 3:1, calculate a new diameter for the driver pulley. What happens to the drive as the drive ratio increases?

LABORATORY MATERIALS

1 – Belt drive, consisting of a motor, sheaves (preferably with at least two grooves), and belts. The belt drive may be a special one constructed for the laboratory, or may consist of an available piece of equipment such as an air compressor similar to that shown in Figure 12.
2 – 0 to 48 oz spring scales.
2 – straightedges.
2 – 12" steel rules.

CAUTION! Do not adjust equipment while it is running. Observe all safety rules. Replace guards after equipment is adjusted.

LABORATORY PROCEDURES

1. Motor and drive are set up by instructor as illustrated in Figure 12. This belt drive may have one or more of the following defects:

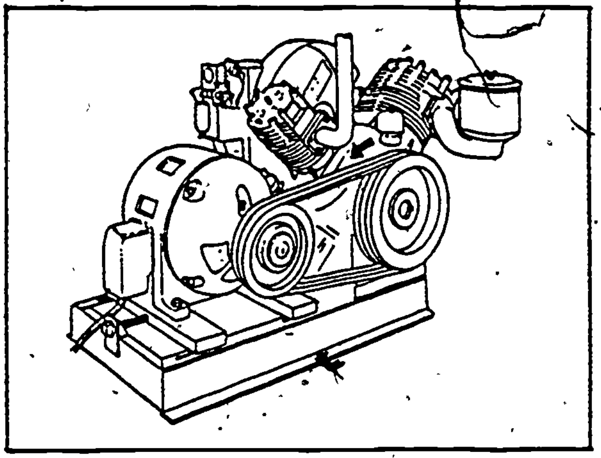


Figure 12. Typical Belt-drive Setup.

- Pulley misalignment.
- Incorrect V-belt size.
- Defective belt(s).
- Incorrectly-tensioned belt(s).
- Improperly matched belts (if the system is a multi-belt drive).
- Defective sheaves.

2. Instructor starts drive. Observe drive in operation, and note all symptoms of possible defects. Complete items 1 – 4 of Data Table 1.
3. Instructor stops drive. Inspect drive as follows:
   a. Complete Data Table 2.
   b. Inspect belt for signs of abnormal wear. Complete items 5 – 11 of Data Table 1.
   c. Check belt tension. Use procedures outlined below:
      - Measure belt span (Figure 13); record in Data Table 2.
      - Use a spring scale, and apply a perpendicular force to the belt at the midpoint of the span.
      - The force should be that required to deflect the belt 1/64 inch for every inch of span length. (A 32 inch belt, for example, should

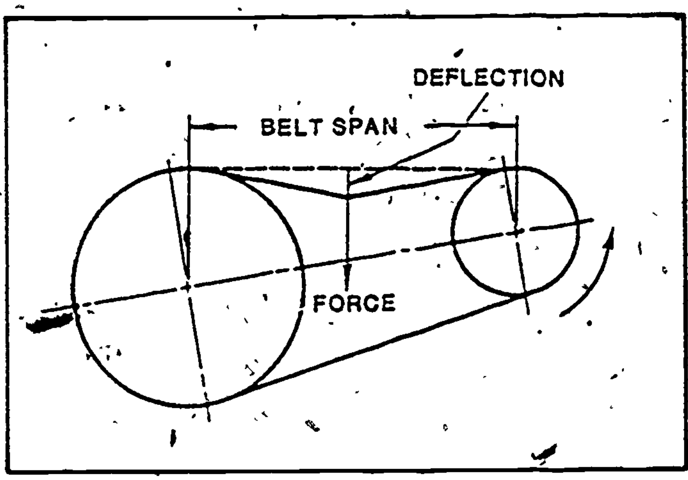


Figure 13. Belt Span.

be deflected 1/64 x 32 or 1/2 inch.) Record belt deflection and deflection force in Data Table 2.

- If a "Belt Deflection Table" for these belts is available, compare the measured reading with that in the Table.

d. Check pulley alignment.
   - Position straightedge against pulley.
   - Rotate pulleys, and note whether or not contact of either pulley with straightedge is disturbed.
   - Complete items 13 – 16 of Data Table 1.

e. Inspect pulleys. Complete Section E.

f. Review Sections A through E. Inspect drive for causes for all defects, and list possible causes in Data Table 1.

g. List the steps which should be followed to correct drive defects in Data Table 1.

DATA TABLES

DATA TABLE 1: TROUBLESHOOTING BELT DRIVES

TROUBLE	YES	NO	DESCRIBE	CAUSE	CORRECTION
1. Excessive Noise?					
2. Belt Squeak?					
3. Belt Squeal?					
4. Belt Slippage?					
5. Belt Fabric Rupture?					
6. Worn Belt Sides?					
7. Belt Base Cracking?					
8. Belt Cover Tear?					
9. Belt Burns?					
10. Belt Gouges?					
11. Correct Belt?					
12. Correct Belt Tension?					
13. Pulleys Aligned?					
14. New Belt 1/16 Inch Above Top Groove?					
15. Shiny Groove Bottoms?					
16. Pulleys Chipped, Bent or Cracked?					

DATA TABLE 2: SPECIFICATIONS AND MEASUREMENTS

Type Belt ______	No. of Belts
Manufacturer	
Nominal Length	
Matching Numbers	
Nominal Width	
Nominal Thickness	
Center Distance between Pulley Shafts (Belt Span)	
Belt Deflection (measured)	
Belt Deflection Force (measured)	

REFERENCES

Carmichael, C., ed. Kent's Mechanical Engineers Handbook. Design and Production. New York: John Wiley and Sons, Inc., 1975.

Drive Design. Akron, OH: B. F. Goodrich, Engineered Systems Division.

Fundamentals of Service: Belts and Chains. Moline, IL: Deere & Company, 1971.

Industrial Drives Catalogue. Cleveland, OH: Eaton Corporation, Industrial Drives Operations, 1978.

McDonald, William C., ed. Power Transmissions Handbook. Julian J. Jackson Publications, Inc., 1968.

Nelson, Carl A. Millwrights and Mechanics Guide. 2nd ed. Indianapolis: Theodore Audel & Co., 1972.

TEST

1. What are the three mechanical systems most often used to transmit rotary mechanical power?

2. Give at least one application of the following belts:
   a. Round belt ______________________________.
   b. Flat belt ______________________________.
   c. V-belt ______________________________.
   d. Double Angle V-belt ______________________________.
   e. Banded V-belt ______________________________.
   f. Linked V-belt ______________________________.
   g. Positive Drive belt ______________________________.
   h. V-ribbed belt ______________________________.
   i. Variable-speed belt ______________________________.

3. What are at least two advantages and disadvantages of these belts?
   a. Flat belts.

   b. V-belts.

   c. Linked V-belts.

   d. Positive Drive belts.

   e. V-ribbed belts.

   f. Cog and notch belts.

4. What are the design characteristics that distinguish the following pulleys?

   a. Round-belt pulleys.

   b. Flat-belt pulleys.

   c. V-belt pulleys.

5. What is the width and length of a C105 belt?

6. A flat-belt drive system consists of two pulleys, with diameters of 30" and 10"; the span between them is 61". What is the proper belt length for efficient operation? (Use Equation 1.)

7. Calculate the belt speed for a system in which a flat belt is riding upon two pulleys, one of which has a diameter of three feet and is rotating at five revolutions per second. (Use Equation 2.)

8. A drive system is being modernized. One pulley is almost new and is retained; it has a diameter of 34". What is the most energy-efficient size for the second pulley? (The second pulley is attached to the motor shaft.)

9. What are at least two ways through which an improperly-maintained belt drive can lose energy?

10. Give at least one possible cause for these V-belt malfunctions:
   a. Fabric rupture.
   b. Cover tear.
   c. Worn sides.
   d. Cross cracking.
   e. Burns.
   f. Gouges.

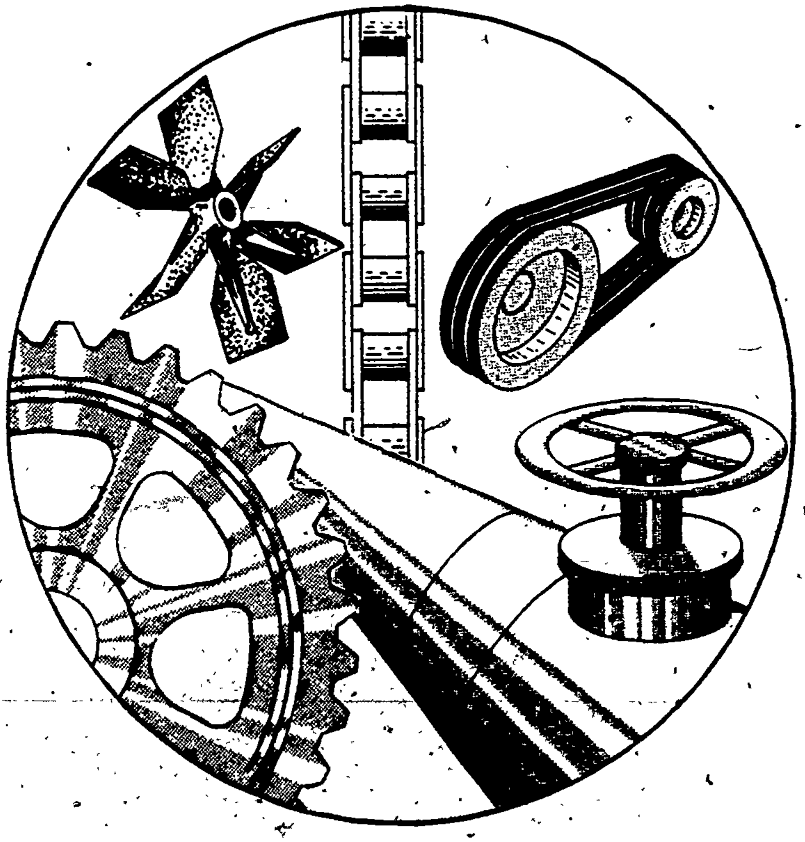
11. What is the correct procedure for installing V-belts?

12. Discuss how the belt drive examined in the laboratory procedure might have been better maintained.

ENERGY TECHNOLOGY

CONSERVATION AND USE

MECHANICAL DEVICES AND SYSTEMS



MODULE MS-02

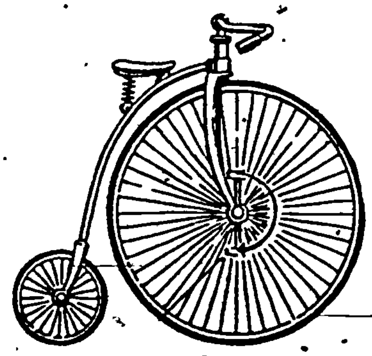
CHAIN DRIVES

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

A chain drive is a positive power-transmission system having zero slippage. The drive consists of a chain whose links mesh with toothed wheels called "sprockets." Such drives are utilized when (1) the distance between shafts is too great for economical gearing or when (2) no slippage, such as that exhibited by most belt drives, can be tolerated.

The first practical chain drive originated in about 1873 as a kind of detachable metallic belt, first used on agricultural machinery. Although the first bicycles operated by direct drive with no chains (Figure 1a), the development of the chain drive made possible the invention of the chain-drive bicycle (Figure 1b), which made use of a large drive sprocket and a smaller driven one for greater wheel speed and, thus, a smaller front wheel.


(a) Early High-Wheeled Bicycle (Direct Wheel Drive)

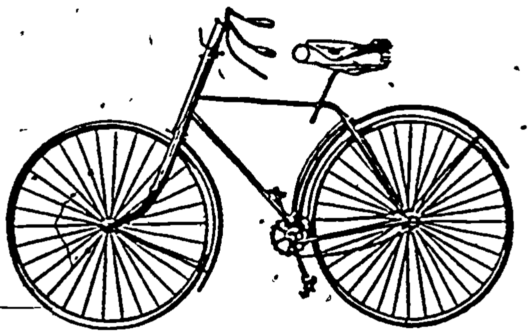

(b) Rover Safety Bicycle (Chain Wheel Drive)

Figure 1. Bicycle Designs.

Since then, the chain drive has been used in motorcycles, automobiles, snowmobiles, chain saws, and in a variety of industial machines.

This module discusses the design, use, installation and maintenance of drive chains and emphasizes the energy economics of these systems.

PREREQUISITES

The student should have completed the following Unified Technical Concepts Modules: Concept Modules 1-0, "Force," 2-0, "Work," 6-0, "Power," and 8-0, "Force Transformers"; and Application Module 8M3, "Drive Systems." One year of high school algebra also must have been completed.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Given sketch of the following types of chains, identify each chain correctly; and cite at least one specific application of each:
   a. Roller chain.
   b. Rollerless chain.
   c. Detachable link chain.
   d. Silent chain.
   e. Pintile chain.
2. Given an unlabeled sketch of parts of a roller chain, correctly label each part; and describe how the final chain link is assembled.

3. Given the number of teeth possessed by each sprocket of a chain drive, the center distance between them, and applicable formula, calculate proper chain length for that drive.
4. Given the diameter of a sprocket, r/min of the drive, and applicable formula, calculate sprocket speed.
5. Describe how increasing sprocket size, increasing the number of teeth on a sprocket, and decreasing the speed of a sprocket will affect energy balance and life of a chain-drive system.
6. Explain how sprockets are aligned by (1) parallel-shaft adjustment and by (2) axial adjustment.
7. Describe two ways in which tension can be adjusted on a chain drive.
8. Given the center distance between two sprockets and applicable formula, calculate chain slack.
9. Describe how proper lubrication of a chain drive increases its energy efficiency.

CHARACTERISTICS OF CHAIN DRIVES

Like belts, chains are used for power transmission, for conveyance, and for timing. Chain drives transmit power with higher efficiency and do not slip, or creep, like most belt drives. They are compact; easy to install; do not deteriorate due to oil, grease, or sunlight; and can operate at high temperatures. Since chains require more operating time to stretch and elongate, they require less frequent adjustment than belts; however, they are rather noisy and require frequent lubrication. Most chains will accept very little misalignment.

TYPES OF CHAINS

There are several different types of drive chains. Each type has its own special features and is well suited to its particular applications. A few of the common types of drive chains are illustrated in Figure 2.

The rollerless chain (Figure 2a) consists of a series of links and pins. This chain is used at low speeds when chain wear is not critical. It does not absorb friction well.

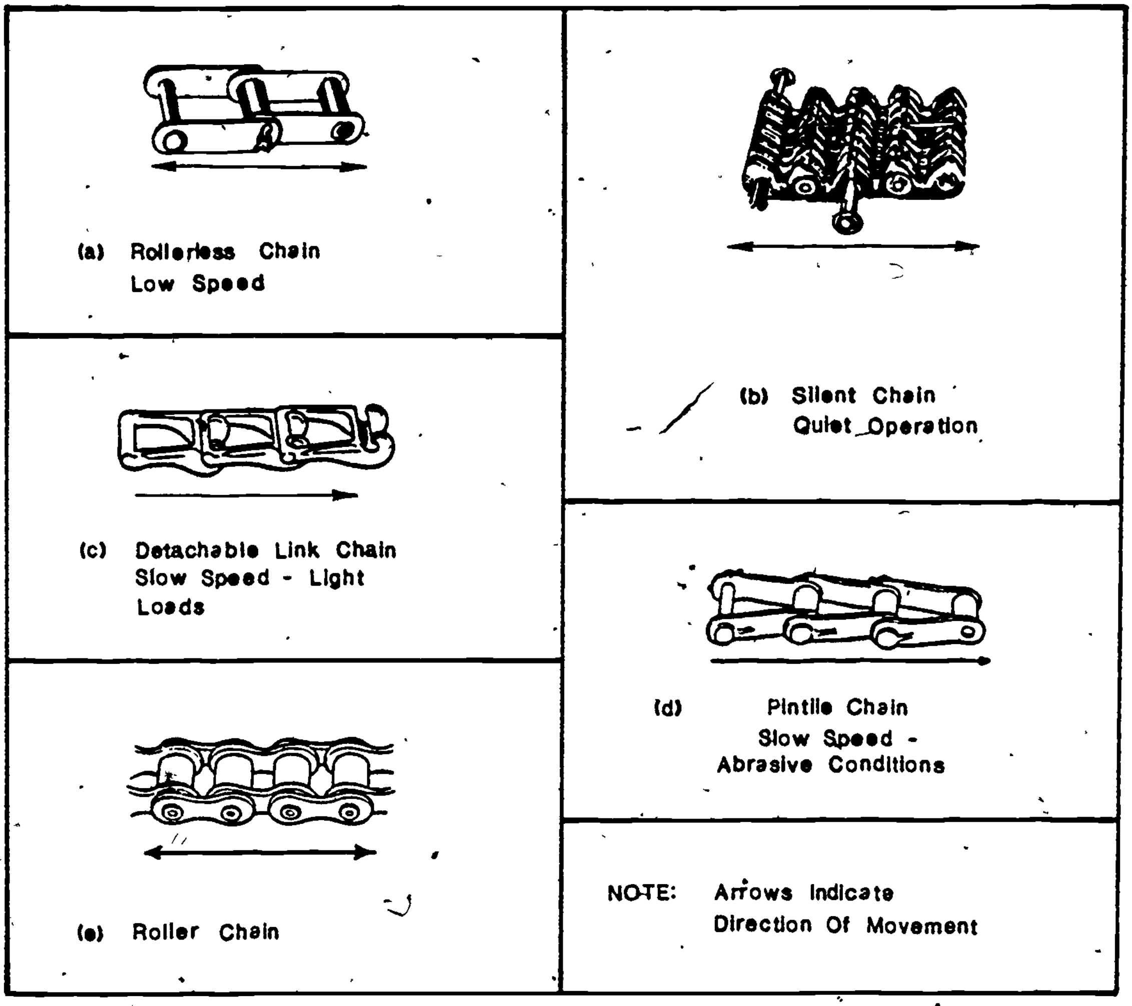


Figure 2. Five Types of Chains.

The silent chain (Figure 2b) is a series of flat links with teeth. The sprockets for this chain resemble spur gears. As the chain passes over the face of the sprocket, the teeth engage the gear-like surface; however, because the sprocket teeth do not project through the chain, the links enter and leave the sprocket smoothly and almost silently (Figure 3).

The links on the detachable link chain (Figure 2c) are replaced easily. This chain is inexpensive and is used for slow speeds and light loads.

The pintile chain (Figure 2d) is a series of iron links held together by a pin. It is used at low speeds — often outdoors, where it is exposed to the weather and to abrasive conditions.

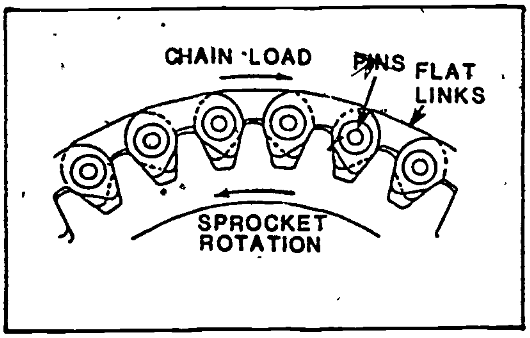


Figure 3. Silent Chain and Sprocket.

Roller chains are the most commonly-encountered chain drives. They can be used for virtually any application, from precision instruments to power transmission. These chains are constructed of alternate roller and pin links. Roller chain parts are illustrated in Figure 4; in assembly, the links are connected alternately, as in Figure 5.

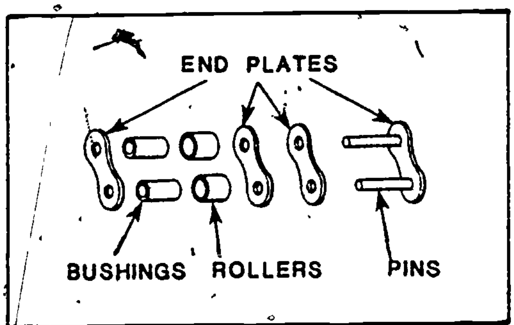


Figure 4. Roller Chain Parts.

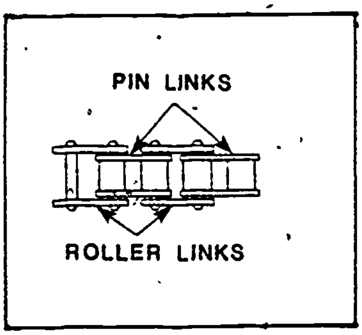


Figure 5. Roller Chain Assembly.

In operation, the pins turn inside the bushings, while the rollers turn outside the bushings. The roller contracts the sprocket teeth, guides the link into place, and absorbs most of the friction.

The ends of a roller chain usually are joined with a special link called a "master link" (Figure 6).

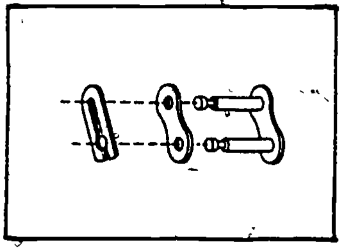


Figure 6. Roller Chain Master Link.

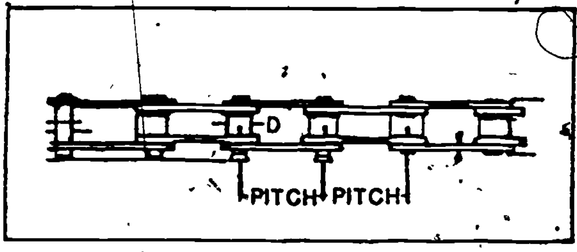


Figure 7. Roller Chain Pitch.

The "pitch" of a roller chain is the distance between the center of the rollers, or the space between the links (Figure 7). The pitch, the roller width, and the roller diameter have been standardized and are part of the American standard roller chain dimensions available in most mechanical engineering textbooks and handbooks. Roller chains are manufactured to meet the standards of the American National Standards Institute (ANSI).

CHAIN LENGTH

For chain to be properly tensioned, it must be the correct length. (Tensioning is explained under Maintenance.) Chain length can be calculated from Equation 1:

$$L_c = \frac{N_1 + N_2}{2} + \left(\frac{N_1 + N_2}{4\pi^2 \ell_c}\right)^2 + 2\ell_c \qquad \text{Equation 1}$$

where

L_c = chain length needed.

N_1 = number of teeth in large sprocket.

N_2 = number of teeth in small sprocket.

π = 3.14.

ℓ_c = sprocket center distance in inches.

Equation 1 is used to solve a problem in Example A.

EXAMPLE A: CALCULATION OF CHAIN LENGTH.	
Given:	Driving sprocket with 22 teeth. Driven sprocket with 36 teeth and a sprocket center distance of 1' - 0" = 12".
Find:	Length L_c of chain.
Solution:	Use Equation 1:

$$L_c = \frac{N_1 + N_2}{2} + \left(\frac{N_1 + N_2}{4\pi^2 \ell_c}\right)^2 + 2\ell_c$$

Substituting:

$$L_c = \left(\frac{36 + 22}{2}\right) + \frac{(36 + 22)^2}{4(3.14)^2 \times 12} + 2 \times 12$$

$$= \frac{58}{2} + \frac{3364}{473.7} + 24$$

$$= 29 + 7.1 + 24$$

$$L_c = 60.1"$$

The length then would have to be adjusted to the closest manufacturers standard chain length.

SPROCKETS

The toothed wheel through which power is transmitted is termed the "sprocket." In operation, the links of the chain mesh with the teeth of the sprocket to maintain a positive speed ratio between the Driver and the Driven sprockets.

If the chain has an even number of pitches, the sprockets have an odd number of teeth, and vice versa. This feature prevents a single link from contacting the same sprocket tooth each time the sprocket turns and prevents uneven wear and excessive vibration.

Sprockets connected to the same side of a chain revolve in the same direction; those connected to opposite sides revolve in opposite directions.

TYPES OF SPROCKETS

Sprockets are manufactured to standard dimensions for each type of chain. There are four basic types of sprockets, the choice of which depends upon cost, location, ease or access, and removal for maintenance (Figure 8).

Sprockets should have no fewer than 12 teeth because a small number of teeth increases the amount of impact of the chain seating on the sprocket. Impact will be reduced if the number of teeth of the sprocket is increased or if the speed is decreased. Chain pull also will be reduced as the sprocket size is increased. A larger sprocket allows the use of a lighter chain.

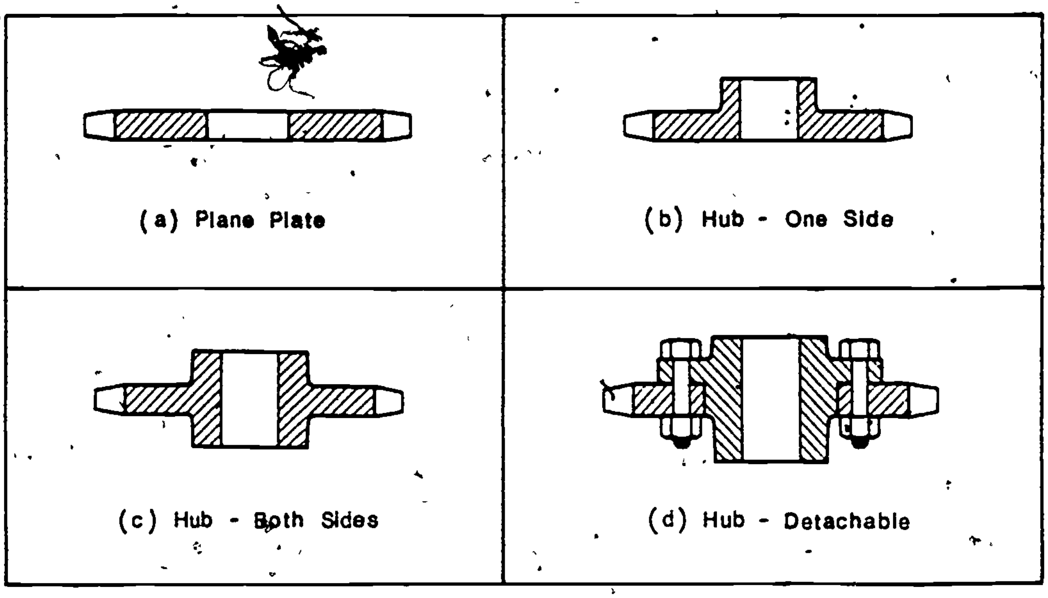


Figure 8. The Four Basic Types of Sprockets.

SPROCKET SPEED

When performing an energy- or economy-advantage analysis on a chain drive, the energy technician should determine the speed of the sprockets. When the diameter of the sprockets and the speed of the drive sprocket are known, the speed of the Driven sprocket can be calculated from Equation 2.

$$\frac{\text{r/min Driver}}{\text{r/min Drive}} = \frac{\text{Diameter Driver}}{\text{Diameter Driven}} \qquad \text{Equation 2}$$

Equation 2 is used to solve a typical problem in Example B.

EXAMPLE B: CALCULATION OF SPROCKET SPEED.	
Given:	Driver sprocket diameter = 12".
	Driven sprocket diameter = 24".
	r/min of drive = 1000 r/min.
Find:	r/min of Driven sprocket.
Solution:	Use Equation 2.

$$\frac{\text{r/min Driver}}{\text{r/min Driven}} = \frac{\text{Diameter Driver}}{\text{Diameter Driven}}$$

$$\therefore \text{r/min Driven} = \text{r/min Drive} \times \frac{\text{Diameter Driven}}{\text{Diameter Drive}}$$

$$= 1000 \times \frac{12}{24}$$

$$= 1000 \times .5 \text{ r/min}$$

$$\text{r/min Driven} = 500 \text{ r/min.}$$

Once the speed of the driven sprocket is known, the technician can determine if the speed of the drive can be reduced without loss of performance. The cost of increasing the sprocket size compared with the savings that could be realized by using a lighter chain should be examined. If a larger sprocket, with more teeth, and a lighter chain, operating at lower speeds, can be substituted for the old drive, considerable energy and monetary savings can be realized.

Using different types of sprockets and chains also can help save energy and materials; for example, the "hunting tooth" sprocket is designed for just this purpose (Figure 9). The arrangement of the teeth allows each tooth to contact the chain only once every second revolution; thus, chain and sprocket wear are reduced. This sprocket must be used with double-pitch chains.

Each tooth rests every other revolution. The double-pitch chain provides the required space for the extra set of teeth.

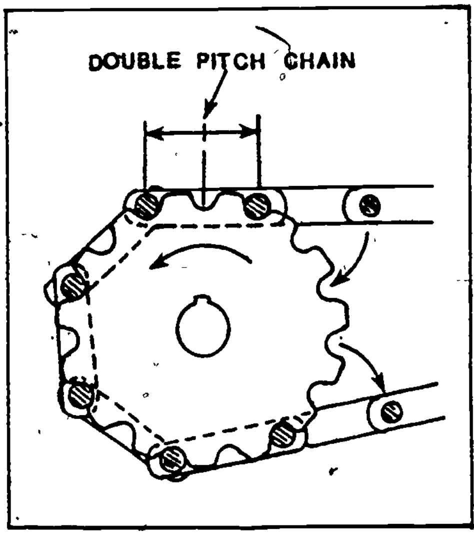


Figure 9. Hunting Tooth Sprocket.

SPROCKET POSITION

The position of the sprockets in the drive should be considered carefully because if arranged improperly, their life, and that of the chain will be shortened. Figure 10 displays some of the acceptable arrangements; however, a and particularly c should turn in the opposite direction indicated by the arrows if the sprockets were moved very close together.

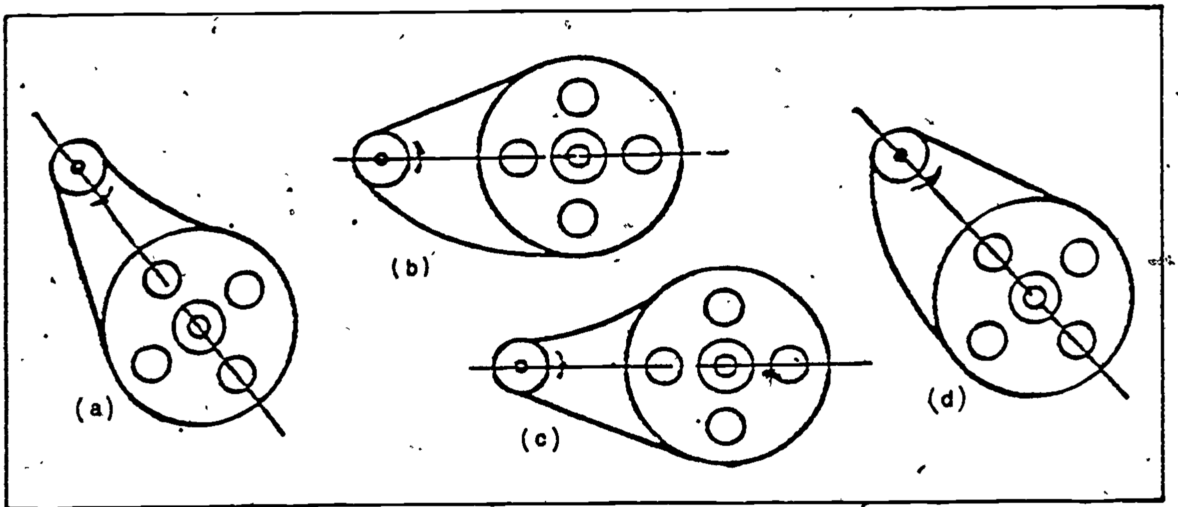


Figure 10. Sprocket Arrangements.

IDLER SPROCKETS

The small sprocket of a chain drive usually is the Driver sprocket, and the large sprocket is the Driven one. The chain should wrap around the small sprocket by at least 120°. The length of the chain is determined by the center distance between the sprockets.

As a minimum, the center distance must be greater than one-half the sum of the sprocket diameters, to prevent the teeth of the sprockets from interfering with one another. Long center distances between sprockets should be avoided, or the chain will whip.

Some chain drives have adjustable centers, which allow center distances to be adjusted by movement of the sprockets. If a drive has a fixed center, it may be equipped with an idler sprocket.

Idler sprockets should be no smaller than the Driver and should engage chains in the slack span (Figure 11).

When drives have fixed centers and when no idler sprockets are used, the exact center distance and chain length must be computed carefully.

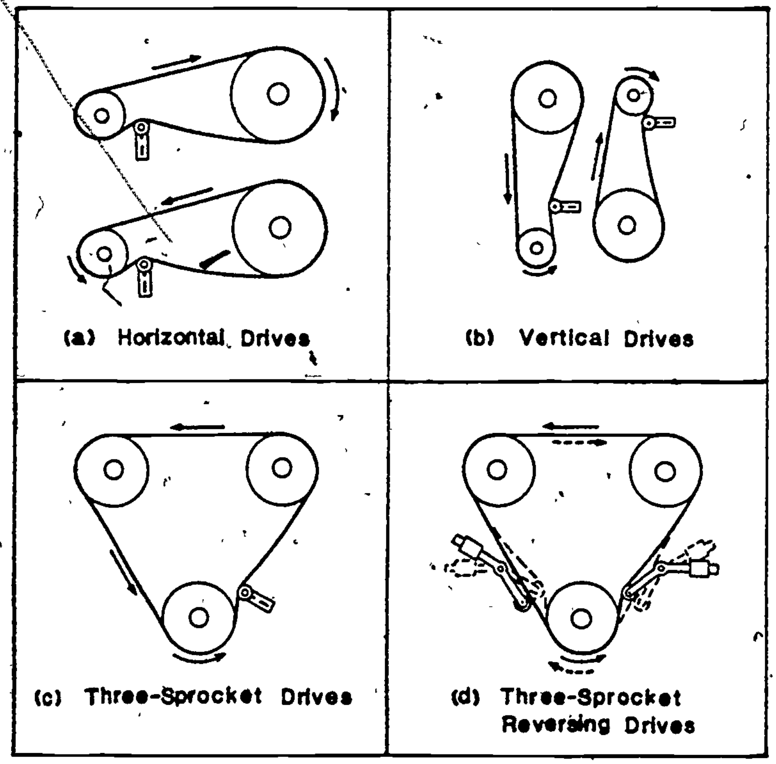


Figure 11. Proper Location of Idler Sprockets.

SELECTION OF CHAIN DRIVES

The easiest way to select the proper chain drive for a particular application is to use manufacturers' tables. Several systems can be designed quickly and their relative cost and energy benefits compared. As with belt drives, the technician simply follows an easily-understood step-by-step procedure.

MAINTENANCE

Proper maintenance of chain drives will result in considerable energy and monetary savings. The areas covered in this section include sprocket alignment, chain installation, chain tension, lubrication, troubleshooting, and storage.

ALIGNMENT

Alignment is important in belt-drive systems but is critical in chain-drive ones because metal chains are in direct contact with metal sprockets. Correct alignment is achieved when (1) the sprocket shafts are parallel and (2) when the sprockets themselves are positioned axially in such a manner that the rows of teeth on both sprockets are in the same plane.

To ensure that the shafts are parallel, align them horizontally with a machinist's level, and adjust them for parallel alignment with a feeler bar or measuring stick (Figure 12a). The distance between shafts on both sides of the sprockets must be equal. Once the shafts have been aligned properly, they must be bolted in place to maintain alignment during operation.

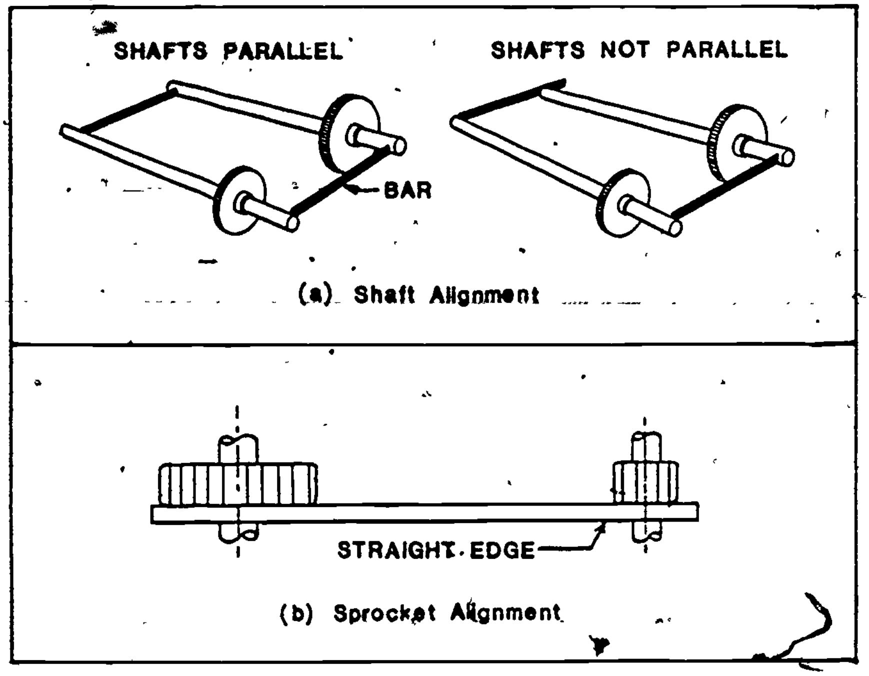


Figure 12. Shaft and Sprocket Alignment.

Sprockets are aligned axially with a straight edge pressed against them (Figure 12b). For long center distances, a wire stretched taut can be used instead.

When a shaft is subject to "end float" (the in-and-out movement exhibited, for example, by shafts of electric motors), the sprocket should be aligned for the normal running position. The running position can be determined by chalking the shaft and by then scribing a line in the chalk opposite a convenient fixed point. The shaft is stopped, and is blocked into its running position while the sprockets are being aligned.

CHAIN INSTALLATION

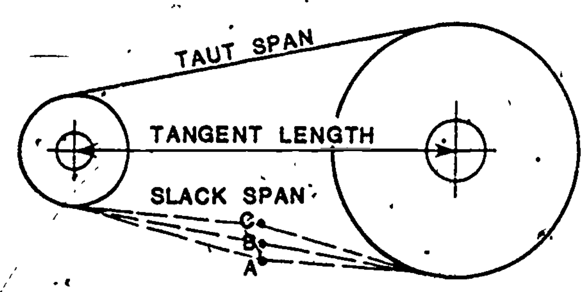
Chain installation is simplified when the following procedures are observed:

(1) Remove the chain pin or connecting link.
(2) Wrap middle of chain around one sprocket, and bring the two free ends together on the other sprocket.
(3) Insert the pin through the links of the chain ends.
(4) Install the free plate of the connecting link.
(5) Fasten the plate with the cotters or spring clip.
(6) Lightly tap the end of the connecting link opposite the free plate to bring the outside of the plate snug against the fastner. This procedure will ensure that the link is flexible and that the connecting link does not squeeze the sprocket teeth.

CHAIN TENSION AND SAG

Once the shafts and sprockets are aligned properly and a chain of the proper length has been installed, the chain tension must be adjusted to prevent equipment failure. Unlike belts, chains must not be tightened around the sprockets, but should have enough "mid-span movement," or "flex dimension" in the slack span to equal 2% to 3% the distance between sprocket centers for vertical drives. For horizontal drives, the movement should be between 4% and 6%.

The mid-span movement is measured between points A and C of Figure 13. When the measured value is obtained, it is



AC = Total Possible Mid-Span Movement
Depth of Free Sag = .866 AB, approximately

Figure 13. Slack Span.

compared to a table such as Table 1 to determine the proper mid-span movement.

TABLE 1. RECOMMENDED POSSIBLE MID-SPAN MOVEMENT AC.

Drive Center-Line	Tangent Length Between Sprockets								
	5"	10"	15"	20"	30"	40"	60"	80"	100"
Horizontal to 45°	.25"	.5"	.75"	1"	1.5"	2"	3"	4"	5"
Vertical to 45°	.12	.25	.38	.5	.75	1	1.5	2.	2.5

The most convenient method of measuring mid-point movement involves the measurement of sag, as illustrated in Figure 14. The chain is pulled taut on one side and a straightedge is placed on top of the chain at both sprockets and over the slack portion of the chain. A measuring stick is pressed against the chain at the mid-point to determine the sag distance from the chain at that point to the bottom of the straight edge. The measured sag distance is multiplied by two to obtain the mid-point movement (since mid-point movement is the total deflection on both the bottom and the top of the straightedge).

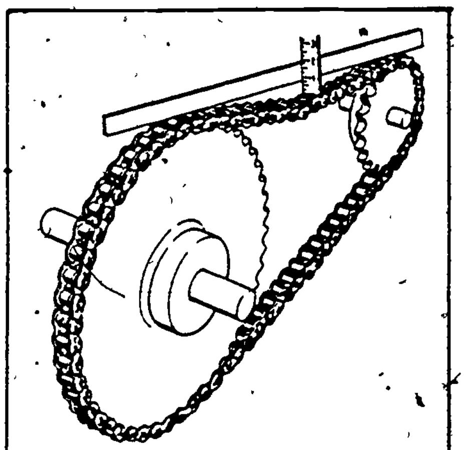


Figure 14. Sag Distance

Equation 3 can be used to determine the flex dimension.

$$f = 0.02\ \ell_c \qquad \text{Equation 3}$$

where

f = flexing dimensions.

0.02 = percent of center distance desired (in this case 2%).

ℓ_c = center distance (tangent length) between sprockets.

Equation 3 is employed to solve a problem in Example C.

EXAMPLE C: CHAIN TENSION.	
Given:	Chain/sprocket system center distance = 20".
Find:	Flexing dimension.
Solution:	From Equation 3: $f = 0.02\ \ell_c$ $= 0.02 \times 20$ $= 2.0 \times 10^{-1} \times 2 \times 10$ $f = 0.4"$, or approximately $\frac{13"}{32}$. Many manufacturers provide tables that can be used when checking tension. If these tables are used, proceed as follows: • Measure total possible mid-span movement of chain. • Measure distance between shafts ("tangent length," Figure 13), and locate flexing dimension in a table such as Table 1.

Chain drive tension should be checked after the initial 100 hours of operation due to chain stretch. Thereafter, it should be checked at 500-hour intervals. As chains wear and stretch, they do not mate properly with sprocket teeth. A badly-worn roller chain rides far out of the tooth pockets.

LUBRICATION

Although chain drives transmit energy more efficiently than most belt drives, they do possess one disadvantage: They require adequate lubrication. The rollers and bushings of roller chains are in constant movement as the rollers engage the sprocket teeth. Although both parts are made of hardened steel, wear will occur, and the chain will elongate. This elongation is normal but can be slowed down by proper lubrication. Lubrication also reduces friction, thereby saving energy and reducing excessive chain and sprocket wear.

Some chains can be lubricated manually; others require semi-automatic or automatic lubrication, as illustrated in Figure 15.

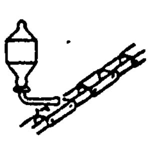
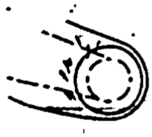
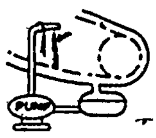
METHOD OF LUBRICATION	SEMI-AUTOMATIC	AUTOMATIC		
APPLICATION OF LUBRICANT	Drip Cup	Oil Bath	Oil Disk	Oil Stream
	Contact brush, direct dip	Chain dips into oil	Oil disk throws lube up on chain	Pump sprays oil on chain
				
KIND OF EQUIPMENT	Conveyors and Elevators. Drives in low horsepower and speed range	Drives—low to moderate horsepower and speed	Drives—moderate to high horsepower and speed	Drives—high horsepower and speed

Figure 15. Chain Lubrication
Semi-automatic and Automatic.

Table 2 illustrates the relationship of chain speed to the method of lubrication.

TABLE 2. CHAIN SPEED AND LUBRICATION METHOD.	
Chain Speed Ft/Min	Lubrication Method*
Less than 600 ft/min	A
600 to 1500 ft/min	B
Over 1500 ft/min	C

*Method A – 5-12 drops/min, shallow pan or manual application brush or oil can.
Method B – 20 drops/min or greater, immersion oil pan.
Method C – Continuous oil supply using pump.

Consult manufacturers manuals for correct type of lubricant to use.

SPROCKET INSPECTION

Sprockets should be replaced when wear causes the teeth to have a hooked appearance (Figure 16). A special gauge can be used to check wear on a roller chain. Another, less-convenient, method is to measure the length of the chain and to compare that measurement to the specified wear limit. Chain manufacturers have established tables of maximum length. When a chain stretches to its limit, it should be replaced.

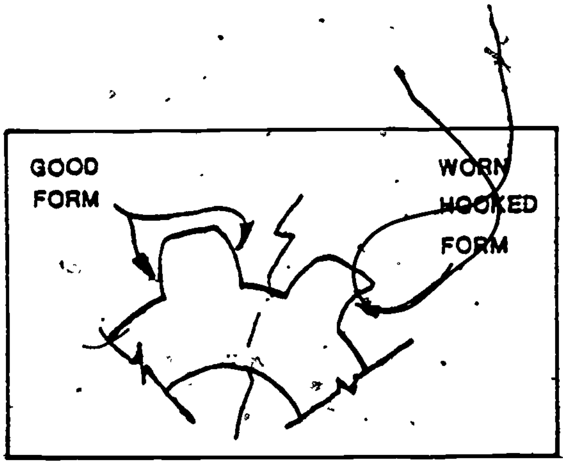


Figure 16. Worn Sprocket.

A new chain will be ruined if operated with a badly-worn sprocket; therefore, both the sprocket and the chain should be replaced at the same time. By the same token, a stretched or worn chain will ruin new sprockets.

TROUBLESHOOTING OF CHAIN DRIVES

Table 3 provides extensive roller chain and sprocket troubleshooting procedures that should be studied and discussed thoroughly.

TABLE 3. ROLLER CHAIN TROUBLESHOOTING.

TROUBLE	CAUSE	CORRECTION
Excessive Noise	(a) Sprockets not aligned (b) Improper slack (c) Inadequate lubrication (d) Loose casings or bearings (e) Chain or sprocket badly worn (f) Chain pitch too large	(a) Align sprockets (b) Adjust tension (c) Lubricate properly (d) Tighten bolts; brace casings (e) Replace (f) Replace chain
Wear on Chain Sides and Sides of Sprocket Teeth	Sprockets not aligned, or shafts not parallel	Remove chain, and align sprockets and shafts

Table 3. Continued.

TROUBLE	CAUSE	CORRECTION
Chain Climbs Sprockets	(a) Chain does not fit sprocket (b) Worn chain (c) Not enough chain wrap (d) Excessive chain wrap (e) Material build-up on sprocket teeth	(a) Ensure the sprocket bottoms are small enough (b) Replace chain (and usually the sprockets) (c) Increase wrap: replace with new system or use idlers to give more wrap (d) Adjust centers, take-up, or idlers (e) Remove build-up
Broken Pins, Bushings, or Rollers	(a) Chain speed too high for sprocket and pitch size (b) Heavy shock or sudden loads (c) Material build-up in sprocket teeth (d) Inadequate lubrication (e) Corrosion of chain or sprockets (f) Sprockets poorly fitted	(a) Use sprocket with more teeth and chain with shorter pitch (b) Reduce shock load (c) Clean sprockets (d) Lubricate properly (e) Protect from substances causing it (f) Check for wear
Chain Sticks to Sprockets	(a) Worn sprockets (b) Lubricants too heavy (c) Material build-up on sprocket teeth	(a) Replace (b) Lubricate properly (c) Clean sprockets
Chain Whips	(a) Excessive slack (b) Pulsating load (c) Stiff links (d) Chain wear	(a) Adjust idlers, take-up, or centers (b) Reduce load or increase chain drive with stronger one (c) Remove stiff links or lubricate them (d) Replace chain

Table 3. Continued.

TROUBLE	CAUSE	CORRECTION
Stiff Chain	(a) Improper lubrication (b) Chain corroded (c) Excessive loads (d) Material build-up on joints (e) Side plates peel (f) Misalignment	(a) Clean and lubricate (b) Protect from corrosion (c) Reduce loads (d) Enclose chain; lubricate often (e) Prevent chain from rubbing (f) Align properly
Broken Sprocket Teeth	(a) Foreign material (b) Chain or sprocket rubbing (c) High shock loads (d) Chain climbing sprocket teeth	(a) Remove material (b) Check clearances (c) Reduce loads or use sprockets (d) (See under "Chain Climbs Sprockets.")
Cotters Fall Out	(a) Excessive vibration (b) Cotters striking obstructions (c) Cotters improperly installed	(a) Reduce vibration (b) Eliminate obstruction or use riveted chain (c) Install cotters properly
Chain Drive Becomes Overheated	(a) Excessive speed (b) Improper lubricant (c) Insufficient lubrication (d) Chain too deep in oil bath (of bath-lubricated drive) (e) Chain too fast for bath system (f) Chains, sprockets, or shafts rubbing against obstruction	(a) Reduce speed (b) Use proper lubricant (c) Increase frequency of lubrication (d) Set oil level to recommended height (e) Use oil stream system (f) Remove obstruction

CHAIN STORAGE

Chains should be stored indoors and away from heat and moisture. If they must be stored on equipment, observe the following procedure:

- Remove chain from equipment.
- Wash chain in diesel fuel.
- Drain diesel fuel from chain.
- Mount chain on equipment, and apply a coating of heavy grease to chain and sprockets.
- Remove storage grease and dust; relubricate, and reset chain before returning equipment to operation.

EXERCISES

1. A 4-inch diameter sprocket is driven by a motor rotating at 1100 r/min. What is the speed of the sprocket?

2. A chain drive has two sprockets with diameters of 2 1/2 and 4 inches respectively. What is the minimum center distance for the sprockets in this drive?

3. The two sprockets of a chain drive have 20 and 60 teeth respectively. Center distance is 3 feet. What is the proper chain length for the drive?

4. Two drive shafts are connected by a chain drive system, 67" apart. Calculate the permissible chain slack.

5. Describe at least 3 methods of lubricating a chain-drive system, and list their specific applications.

LABORATORY MATERIALS

1 - 110V a.c. motor.
Sprockets and chain.
2 - straightedges.
2 - 12" steel rules.
1 - level.
1 - yardstick.

CAUTION! Do not adjust equipment while it is running. Observe all safety rules. Replace guards after equipment is adjusted.

LABORATORY PROCEDURES

1. Motor and drive are set up by instructor as illustrated in Figure 17. Chain drive may have one or more of the following defects:
   a. Defective pins, bushings, or rollers.
   b. Defective chain.
   c. Defective sprocket.
   d. Incorrect chain tension.
   e. Inadequate lubrication.
2. Instructor starts drive. Observe the drive in

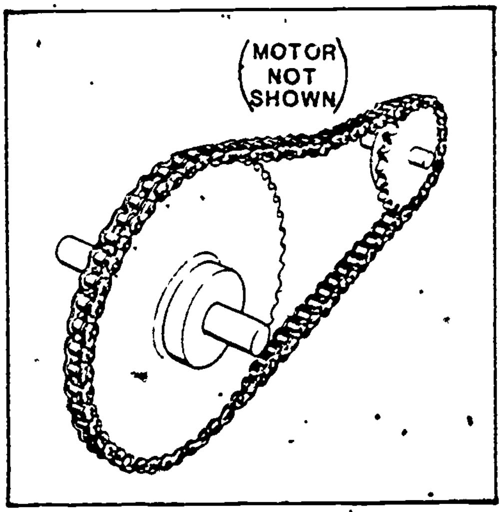


Figure 17. Typical Chain-Drive Setup for Laboratory.

operation, and note all symptoms of possible defects. Complete items 1-4 of Data Table 1.

3. Instructor stops drive. Inspect drive.
   a. Complete items 1-9 of Data Table 2.
   b. Inspect chain, chain parts, and sprockets for signs of abnormal wear or breakage. Use Data Table 1, items 5-12, as a checklist.
   c. Check chain tension.
      • Measure total possible mid-span movement of chain (Figure 18). Record in Data Table 2, item 10.

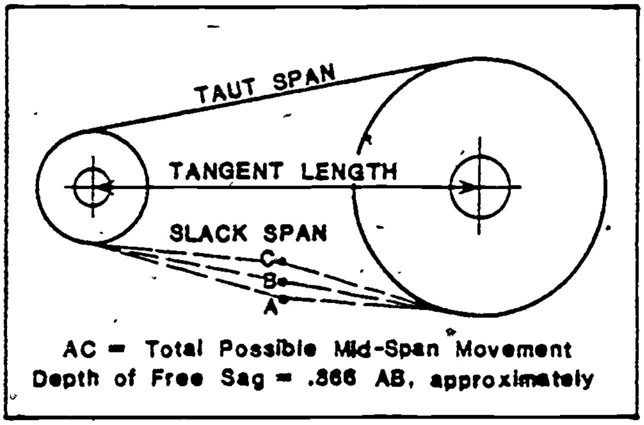


Figure 18. Total Possible Mid-span Movement.

      • Measure tangent length between sprockets; record in Data Table 2, item 11.
      • Compare reading to recommended mid-span movement:

Drive Center-Line	Tangent Length Between Sprockets								
	5"	10"	15"	20"	30"	40"	60"	80"	100"
Horizontal to 45°	.25"	.5"	.75"	1"	1.5"	2"	3"	4"	5"
Vertical to 45°	.12	.25	.38	.5	.75	1	1.5	2	2.5

- Complete item 13 of Data Table 1.

d. Check sprocket alignment.

- Measure distance between shafts on both sides of sprockets to check parallel alignment. Ensure that both shafts are level.
- Place straightedge adjacent to the sprocket hubs and touching the sprocket; rotate sprockets and check whether contact of either sprocket with straightedge is disturbed.
- Complete item 14 of Data Table 1.

DATA TABLES

DATA TABLE 1: TROUBLESHOOTING CHAIN DRIVES

TROUBLESHOOTING — SYMPTOMS AND DIAGNOSIS — CHAIN DRIVES					
	YES	NO	DESCRIBE	CAUSE	CORRECTION
1. Excessive Noise?					
2. Chain Whipping?					
3. Chain Climbing Sprocket?					
4. Chain Clinging to Sprocket?					
5. Worn or Broken Pins?					
6. Worn or Broken Bushings?					
7. Chain Worn?					
8. Chain Stiff?					
9. Chain Corroded?					
10. Foreign Material on Chain Parts?					

7

DATA TABLE 1. Continued.

11. Chain Adequately Lubricated?					
12. Chain Sticking?					
13. Correct Chain Tension?					
14. Sprockets Aligned?					
15. Sprocket Teeth Broken or Worn?					
16. Sprockets Have Correct Numbet of Teeth for Drive?					

DATA TABLE 2: SPECIFICATIONS AND MEASUREMENTS

1. Type Chain (no of chains) ______________________
   Manufacturer ______________________
2. Nominal Length (obtain from mfg. table) ______________________
3. Nominal Width ______________________
4. Driver Sprocket Size ______________________
5. Driven Sprocket Size ______________________
6. Driven Shaft Diameter ______________________
7. Lubrication Method ______________________
8. Chain Tensioning Method ______________________
9. Idlers Provided Pulley Rotation facing end of Motor Shaft ______________________
10. Mid-Span Movement of Chain (measured) ______________________
11. Tangent Length Between Sprockets ______________________
12. Recommended Mid-Span Movement (from table) ______________________

REFERENCES

Carmichael, C. Kent's Mechanical Engineers Handbook. Design and Production. New York: John Wiley & Sons, Inc., 1975.

Diamond Catalogue #1135. Indianapolis: Diamond Chain Company, 1977.

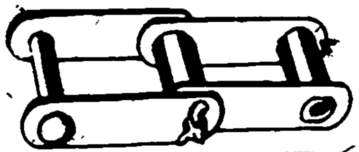
Link-Belt Chains and Sprockets for Drives, Conveyors and Elevators. Indianapolis: FMC Corporation, Chain Division, 1976.

McDonald, William C., ed. Power Transmission Handbook. Julian J. Jackson Publications, Inc., 1968.

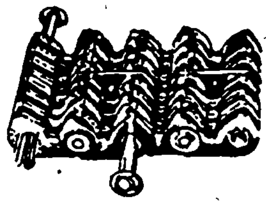
Nelson, Carl A. Millwrights and Mechanics Guide. 2nd ed. Indianapolis: Theordore Audel & Co., 1972.

"The Installation, Operation and Maintenance of Drive Chains." Bulletin #59126R, Milwaukee: Rexnord, Inc.

1. Identify each type of chain sketched below and label them in the appropriate spaces. List at least one specific application for each type.



Chain type ________________
Specific application ____
____
____



Chain type ________________
Specific application ____
____
____

Chain type ________________
Specific application ____
____
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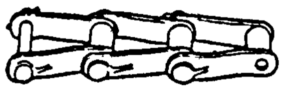
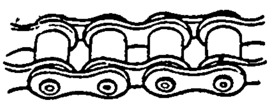
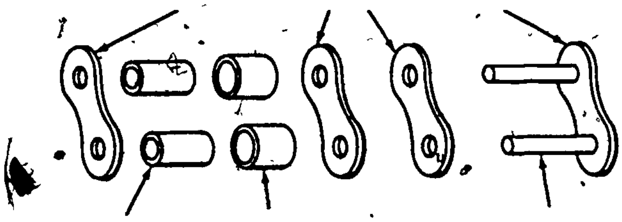


Chain type ________________
Specific application ____
____
____



Chain type ________________
Specific application ____
____

2. Label the parts of the roller chain sketched below, and describe how the final link will be assembled.



3. Given: Driver sprocket with 24 teeth, Driven sprocket with 48 teeth, and a sprocket center distance of 2'.

Find: Length of chain L_c.

Use: $L_c = \frac{N_1 + N_2}{2} + \left(\frac{N_1 + N_2}{4\pi^2 \ell_c}\right)^2 + 2\ \ell_c$.

4. Given: Driver sprocket diameter = 15".

Driven sprocket diameter = 24".

r/min of drive = 1200.

Find: r/min of Driven.

Use: $\text{r/min of Driven} = \text{r/min Drive} \times \frac{\text{Diameter Driven}}{\text{Diameter Drive}}$

5. How will increasing sprocket size, increasing the number of teeth on the sprocket, and decreasing the speed of the sprocket affect the energy balance and life of a chain drive system?

6. Explain how sprockets are aligned by (1) parallel-shaft adjustment and by (2) axial adjustment.

7. Describe two ways in which tension can be adjusted on a chain-drive system.

8. Given: Chain/sprocket system center distance = 40".
Find: Permissible chain slack.
Use: $f = 0.02\ \ell_c$.

9. How will proper lubrication increase the energy efficiency of a chain drive?

ENERGY TECHNOLOGY

CONSERVATION AND USE

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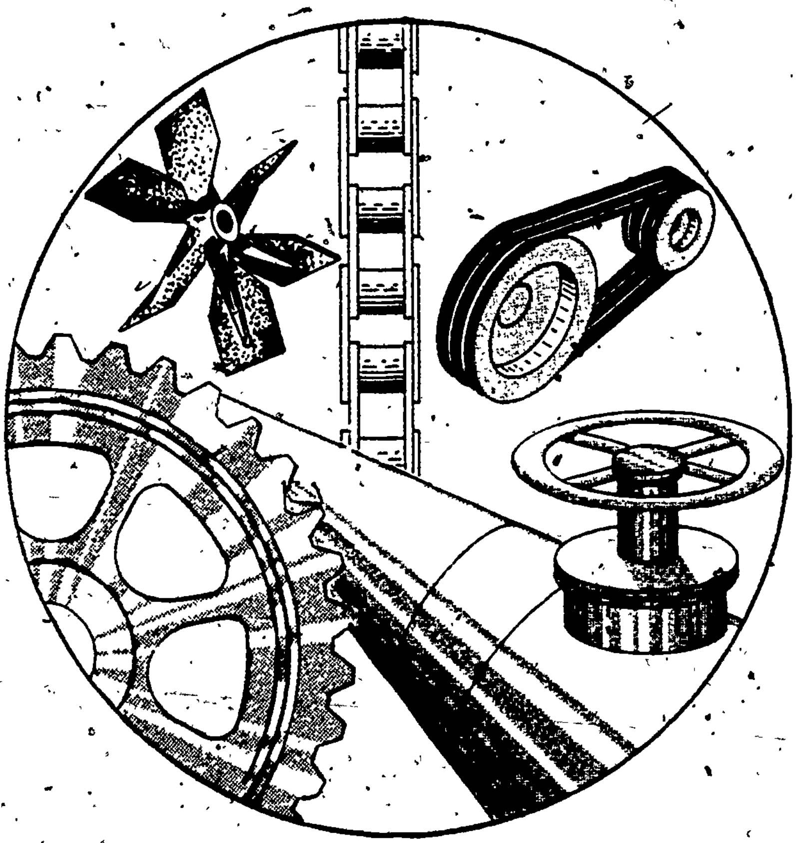
MECHANICAL DEVICES AND SYSTEMS



MODULE MS-03

GEAR DRIVES

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

In this module, gearing terminology is discussed, and actual physical characteristics and everyday applications are detailed. Only those calculations necessary to an understanding of why gears actually work the way they do are introduced. A limited description of gear maintenance and lubrication is included. Energy economics is emphasized wherever possible. Most importantly, the technician is introduced to gear-drive characteristics.

PREREQUISITES

The student should have completed the following Unified Technical Concepts Modules: Concept Module 8-0, "Force Transformers"; and Application Modules 8M3, "Drive Systems," and 8M4, "Gear Trains."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the below terms:
   a. Force.
   b. Work.
   c. Power.
   d. Horsepower.
   e. Mechanical advantage.
   f. Torque.
   g. Pitch circle.
   h. Pitch diameter.
   i. Addendum.

j. Clearance.
k. Diametral pitch.
l. Pinion.
m. Face of gear.
n. Face of tooth.
o. Flank of tooth.
p. Involute curve.
q. Pressure angle.
r. Backlash.
s. Gear ratio.
t. Excessive backlash.
u. Helix angle.

2. Given all variables, use applicable formulas to calculate any or all of the following quantities:
   a. Work.
   b. Power.
   c. Horsepower.
   d. Torque.
   e. Mechanical advantage.
   f. Gear ratio.
3. List five conditions in which gear drives should be used instead of belt or chain drives.
4. List three uses for gear drives.
5. Given unlabeled sketches of any or all of the following gear types, identify each; briefly describe its distinguishing characteristics; and give at least one application, advantage, or disadvantage:
   a. Straight spur.
   b. Helical spur.
   c. Herringbone.
   d. Plain bevel.
   e. Spiral bevel.
   f. Zerol.

g. Crossed axis helical.

h. Hypoid.

i. Worm.

j. Rack and pinion.

6. Cite distinguishing characteristics of (1) simple, (2) compound, (3) reverted, and (4) planetary gear trains.

7. Describe how a planetary gear train can be used to give different speeds to a shaft.

8. Describe operation of a mechanical differential.

9. Cite two general reasons for failure of a gear system.

10. Describe gear lubrication, and state why it is necessary.

The gear principle is simple; probably this simplicity lead to its early invention and use. A gear is merely a wheel with teeth cut into its circumference. These teeth maintain a precise angular relationship between two shafts while transmitting motion from one shaft to another.

The gear is a definite improvement over the simple friction drive created when two wheels are placed on parallel shafts touching each other and when the wheels touch each other in the manner illustrated in Figure 1.

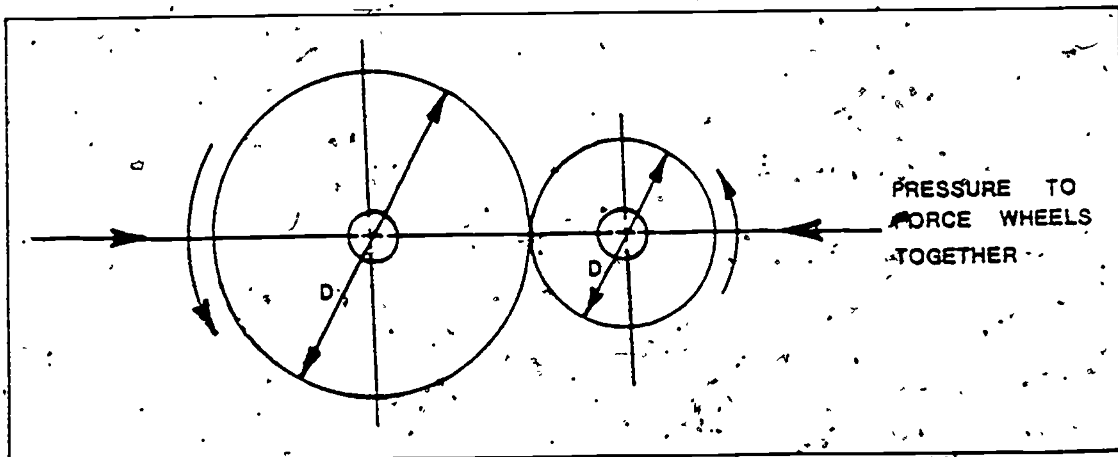


Figure 1. Friction Drive.

In this friction-drive system, the shafts turn at different speeds; and unless the ratio of the angular velocity between them remains the same, energy losses and slippage occurs. The problems of energy loss and slippage can be solved if each cylinder is provided with gear teeth that ensure a more positive ratio between the gears than possible by friction alone. Gears can maintain both the ratio of the angular velocity and a constant speed ratio between shafts. These abilities give them their reputation as being the most efficient mechanical drive.

Figure 2 illustrates a simple gear drive that consists of two gears.

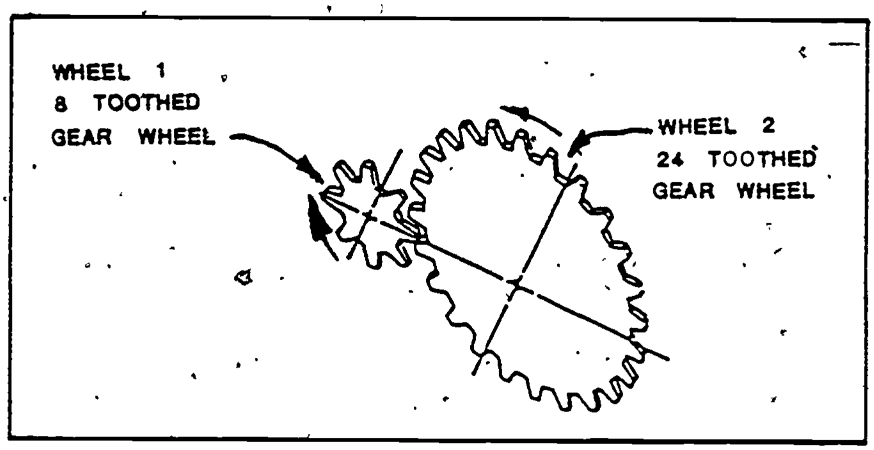


Figure 2. Gear Drive.

MECHANICAL BASICS

Before gears and gear drives can be discussed in depth, certain mechanical concepts must be presented, especially the concepts of force, work, power, horsepower, mechanical advantage, and torque:

- A force causes a change in the motion of an object.
- Work is the measure of change that force produces when it acts upon something; this change sometimes is referred to as "displacement." Work is the product of force and displacement.
- Power, the rate at which work is done, is equal to work divided by time.
- "Horsepower" is the term used in mechanical systems to measure power, and one horsepower is equal to —

$$\frac{550\ \text{ft}\cdot\text{pounds}}{\text{sec}} \quad \text{or} \quad \frac{33{,}000\ \text{ft}\cdot\text{pounds}}{\text{min}}$$

- In most mechanical systems, the smaller force is used to move the larger force. The use of a crowbar as a lever, for example, enables a man to "overcome" the force of gravity and to lift an automobile. The crowbar is said to have a "mechanical advantage."
- Torque is a force applied in a way that produces rotary movement; for instance, a hand twisting a screwdriver applies a rotary force, or a torque, to the screwdriver.

Force can be expressed in pounds; displacement, in feet. Because work is the product of force and displacement, it can be expressed in foot·pounds. Power and horsepower, measurements of the rate at which work is done, can be expressed in so many foot·pounds per unit of time. The following equations depict these relationships:

$$\text{Work} = \text{Force} \times \text{Displacement} \qquad \text{Equation 1}$$

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \qquad \text{Equation 2}$$

$$\text{Horsepower} = \frac{\text{Work}}{\text{Time} \times 33{,}000} \quad \text{(Time in minutes)} \qquad \text{Equation 3}$$

or

$$\text{Horsepower} = \frac{\text{Work}}{\text{Time} \times 550} \quad \text{(Time in seconds)} \qquad \text{Equation 4}$$

$$\text{Torque} = \text{Force} \times \text{Rotational Distance} \qquad \text{Equation 5}$$

$$\text{Horsepower} = \frac{\text{Torque} \times \text{r/min}}{5252^*} \quad \text{(When torque is expressed in ft·lbs)} \qquad \text{Equation 6}$$

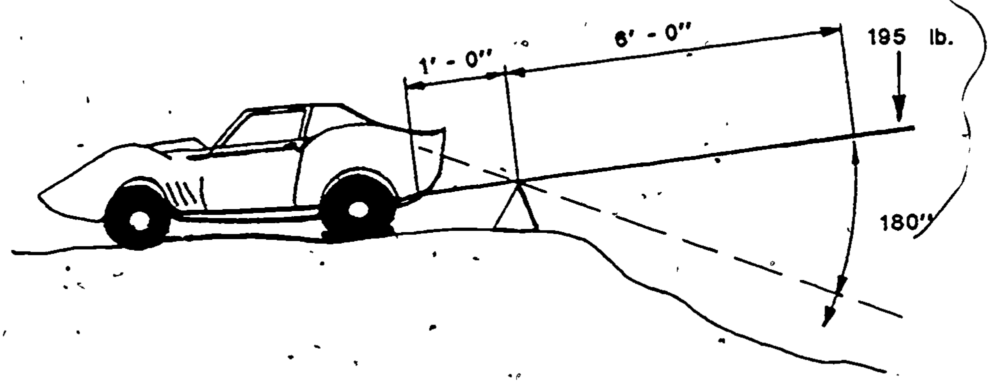
$$\text{Torque} = \frac{\text{Horsepower} \times 5252^*}{\text{r/min}} \qquad \text{Equation 7}$$

$$\text{Mechanical Advantage} = \frac{\text{Larger Force}}{\text{Smaller Force}} \geq 1.0 \qquad \text{Equation 8}$$

* The quantity 5252 is merely a constant used to convert torque to horsepower.

Examples A and B demonstrate how these concepts are used in typical problems.

EXAMPLE A: FORCE, WORK, POWER, AND HORSEPOWER.	
Given:	A man who weighs 195 pounds uses a lever in a mechanical system to raise his automobile 36 inches off the ground in 10 seconds.
Find:	Force, work done in ft•lbs (foot pounds), power used, horsepower (hp) exerted, and torque used.



Solution:

Force = 195 lbs.

$$\text{Work} = 195 \times \frac{180''}{12} = 2925 \text{ ft·lbs.}$$

$$\text{Power} = \frac{195 \times 180}{10 \times 12} = 292.5 \text{ ft·lbs/sec.}$$

$$\text{Horsepower} = \frac{195 \times 180}{10 \times 550 \times 12} = 0.53 \text{ hp.}$$

Torque = 195 x 6 = 1170 ft•lbs.

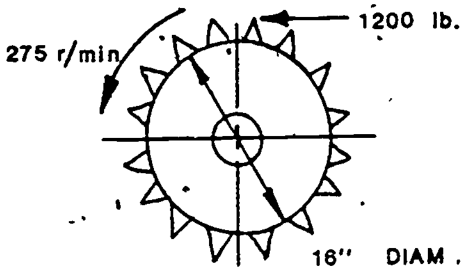
If the car weighs 1170 pounds, the mechanical advantage of this system is $\frac{1170}{195} = 6.0$.

EXAMPLE B: HORSEPOWER.

Given: A gear drive 16 inches in diameter, rotates at 275 r/min because of a force of 1200 pounds.

Find: Horsepower of the system.

Solution:



Work per revolution = Force x distance.

$= 1200 \times \pi \times D \times r/min$

$= 1200 \times \pi \times (\frac{16}{12}) \times 275$

Work per revolution = 1,382,300 ft·lbs

$\text{Horsepower} = \frac{\text{Torque} \times r/min}{33{,}000}$

r/min = 275

Torque = F x d

$= 1200 \times \frac{16}{2} \times \frac{1}{12}$

Torque = 800 ft·lbs.

Substituting:

$hp = \frac{800 \times 275}{33{,}000}$

$= \frac{8.0 \times 10^2 \times 2.75 \times 10^2}{3.3 \times 10^4}$

hp = 6.6.

GEAR BASICS

Gears normally are used to transmit torque from one shaft to another. These shafts may operate in line, parallel, or at an angle to each other.

Gears should be used when

- Center distances between shafts are relatively small.
- Constant, accurate speed ratios between shafts must be maintained.
- Shaft speeds are not appropriate for belt drives.
- Relatively high torque must be transmitted.
- The direction of motion from one shaft to another must be changed.

When an even number of gears rotate, direction is reversed (Figure 3a). Rotation in the same direction results when an odd number of gears are used (Figure 3b).

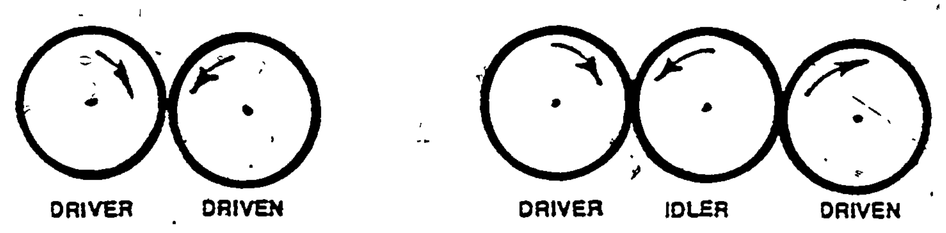


Figure 3. Gear Rotation.

TERMINOLOGY

Gearing terminology (Figure 4) is highly specialized, and a basic knowledge of terms is required of the technician. Several of these terms are important, as are those terms in Figure 5:

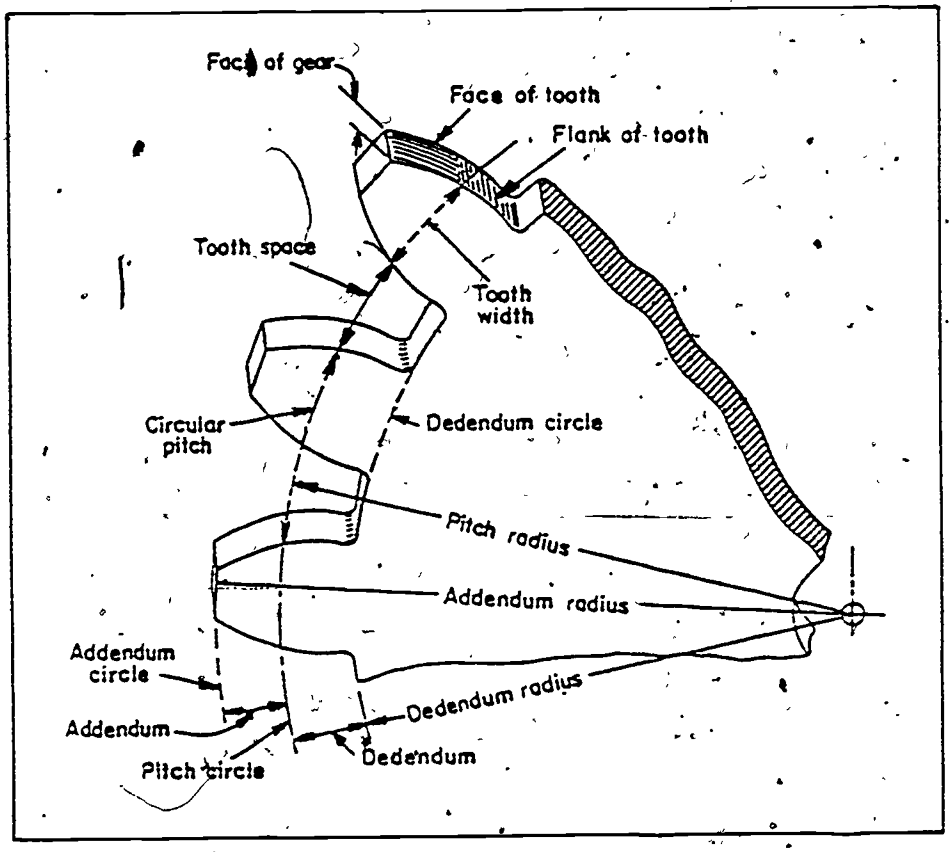


Figure 4. Gear Terminology.

- Between the "addendum circle" and the "dedendum circle" is the "pitch circle," which is important because it is the effective size of the gear. To understand better the significance of this circle, consider two meshed gears (Figure 5). When the teeth of the two gears mesh, they overlap each other; consequently, each gear has an effective diameter of a little less than its outside diameter. This lesser diameter is the "pitch diameter," which may have to be determined when a replacement is ordered.
- "Addendum": Radial distance from the pitch circle to outside circle of gear.

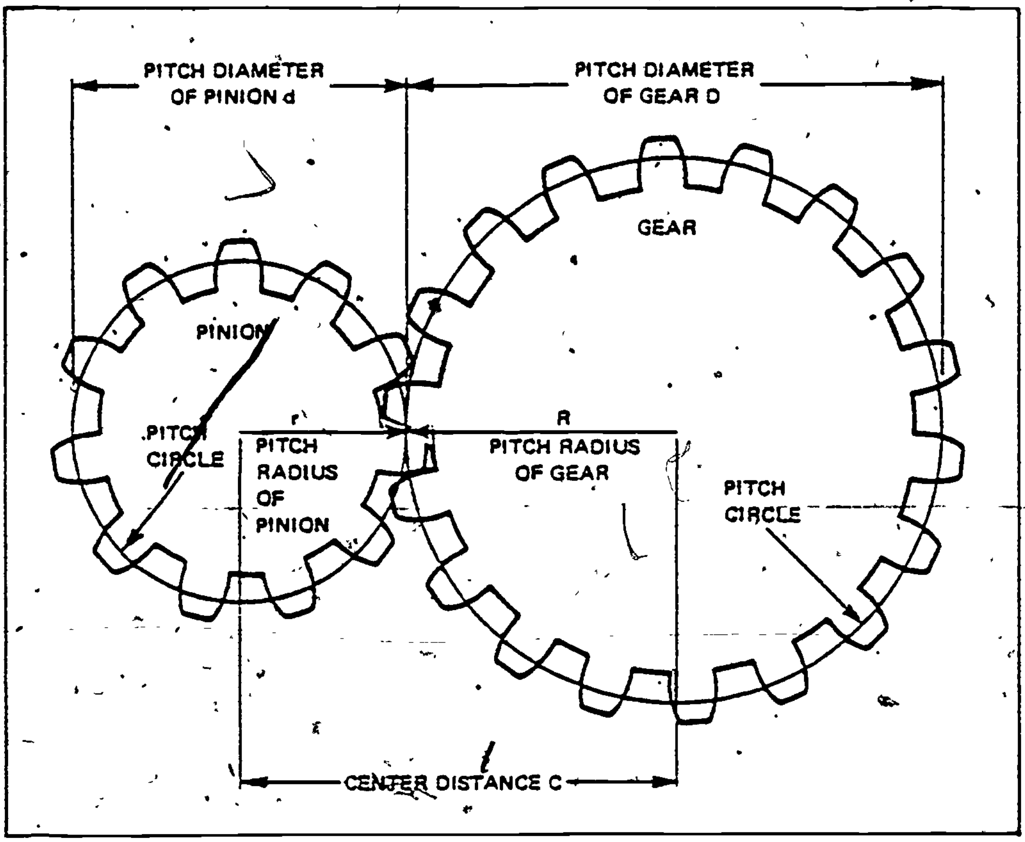


Figure 5. Meshed Gears.

- "Dedendum": Radial distance from pitch circle to bottom of space between teeth. When two gears are meshed, the attendum of one protrudes into the dedendum of the other.
- "Clearance": The difference between the addendum and dedendum. Clearance should be computed carefully to ensure that gear rides on pitch circle and does not "bottom out."
- "Diametral pitch": Number of teeth on a gear, divided by its pitch diameter. The diametral pitch of a gear is used to indicate the relative size of its teeth. It is a convenient number in gear calculations but is not an actual dimension. Diametral pitch can be calculated from

Equation 9; pitch diameter from Equation 10; and number of gear teeth from Equation 11:

$$P = \frac{N}{D} \qquad \text{Equation 9}$$

$$D = \frac{N}{P} \qquad \text{Equation 10}$$

$$N = DP \qquad \text{Equation 11}$$

where

P = diametral pitch.
N = number of teeth.
D = pitch diameter.

- "Pinion": When two gears mesh, the smaller gear is called the "pinion."
- "Face of gear": Thickness of gear measured parallel to the axis of rotation.
- "Face of tooth": Contacting surface of tooth from pitch circle to addendum circle.
- "Flank of tooth": Contacting surface of tooth from pitch circle to dedendum circle.

The teeth of nearly all standard gears are "involute" (Figure 6) in shape. An involute-shaped tooth results in a contact point that rolls with little slippage. The involute is a geometrical curve formed by the unwinding of a string around a cylinder. Each tooth of a gear wheel is involute on each of its two faces. The point of

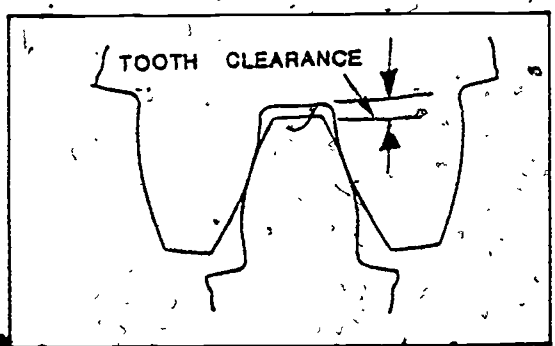


Figure 6. Typical Involute Tooth Form.

the involute is cut off to provide clearance for the meshing gear teeth. The involute tooth has the following advantages:

- Contacting tooth surfaces are always at constant speed ratios.
- The tooth is strong and rigid.
- The shape of the tooth permits easy entry and exit of mating tooth.
- Tooth-cutting methods are economical and universally available.
- Permits gears to mesh in both forward and reverse directions.

The "pressure angle" of a tooth is the angle between a tooth profile and the line normal to a pitch surface (Figure 7a). The pressure angles most often used are 14.5 and 20 degrees. Gears with different pressure angles (Figure 7b) will not mesh.

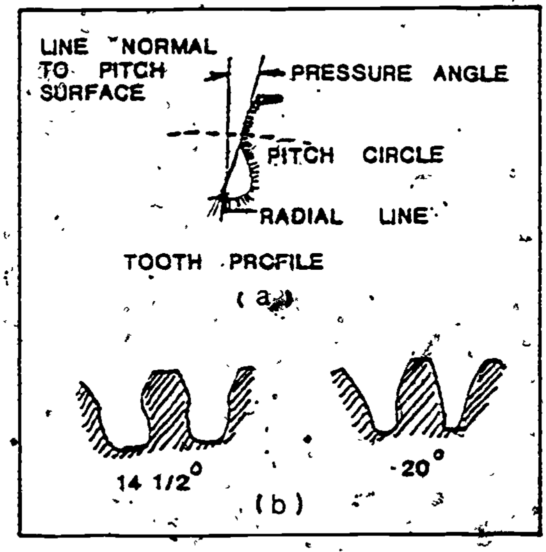


Figure 7. Pressure Angles.

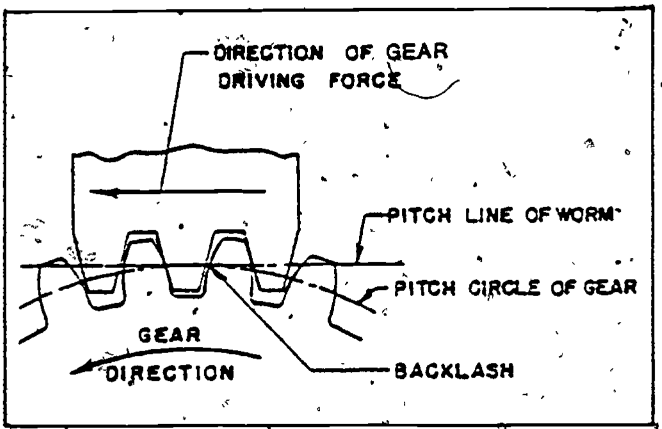


Figure 8. Backlash Clearance.

When two properly-cut gear teeth are meshed, there should be a space between the non-driving side of the tooth of the

Driver gear and the Driven gear tooth behind it (Figure 8). This space is called the "backlash" of the gear.

Backlash is cut into a set of gears to ensure proper meshing clearance and to provide adequate lubrication space between the gear teeth. Backlash should be kept to a minimum in order that gears properly mesh and transmit power with maximum efficiency.

"Gear ratio" is the relationship of the number of teeth of one gear to the number of teeth of the other meshing gears. As there is a definite relationship between the number of teeth on a gear and its pitch diameter, the gear ratio also can be expressed as the ratio of the pitch diameter of two gears (Equation 12).

$$\text{Gear Ratio} = \frac{\text{Number of Driven Teeth}}{\text{Number of Driver Teeth}} \qquad \text{Equation 12}$$

Equation 12 is used to calculate gear ratio in Example C.

EXAMPLE C: CALCULATING GEAR RATIO.	
Given:	A driven gear having 60 teeth meshes with a driver gear having 30 teeth.
Find:	Gear ratio of the system.
Solution:	Use Equation 12.
	$\text{Ratio} = \frac{\text{Number of Driven Teeth}}{\text{Number of Driver Teeth}} = \frac{60}{30}$
	Ratio = 2:1.

TYPES OF GEARS

PARALLEL-AXES GEARS

There are three types of parallel-axes gears (Figure 9):

- Spur.
- Helical.
- Herringbone.

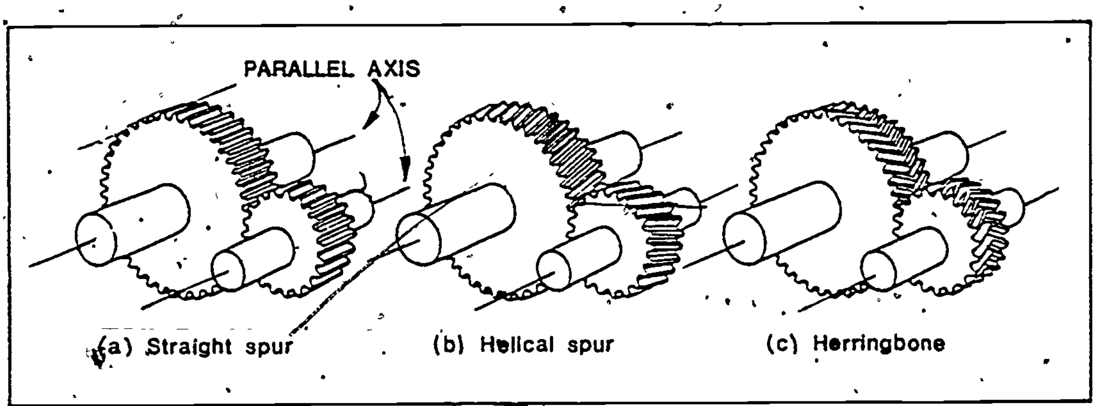


Figure 9. Parallel-Axes Gears.

In all these systems, the shafts are parallel to one another. Parallel-axes gears frequently are used to change the speed/torque ratio of a turning shaft.

Spur gears contain straight teeth, cut parallel to the gear's axis of rotation (Figure 9a). Since only one or two teeth of mating gears mesh at a time, these gears are rather noisy, have high vibration levels, and often are used in slow-speed operations. Spur gears, especially those with high pressure angles (20° or higher), can be used to transmit heavy loads.

The helical gear (Figure 9b) is a spur gear having its teeth set on a helical curve. Because, at any given time, the teeth of two meshed helical gears are in various stages of load bearing (rather than being suddenly loaded and unloaded, as are straight-cut gears), they operate more quietly and smoothly. The helical cut also makes the gear less subject to stress damage. Helical gears often are used in high-speed applications and in many machine transmissions.

The herringbone gear (Figure 9c) is easily identifiable because the pattern of its teeth looks like the spine of a fish. These gears really are double helical gears having teeth angles reversed on opposite sides. This arrangement causes the thrust produced on one side to be counterbalanced by the thrust produced on the other side. Herringbone gears are used for quiet, high-speed, heavy-load applications, such as turbines, generators, and ship and submarine transmissions.

INTERSECTING-AXES GEARS

An intersecting-axes gear can be used to change the direction of rotation of a shaft or to permit power to be transmitted "around a corner" (Figure 10). Shafts on which these gears are mounted intersect at right angles.

Plain bevel teeth are cut parallel to the axis (Figure 10a). The two gears are called the "ring gear" (larger, driven gear) and pinion gear (smaller, driving gear). The plain bevel is used in low-speed applications not subject to high loads.

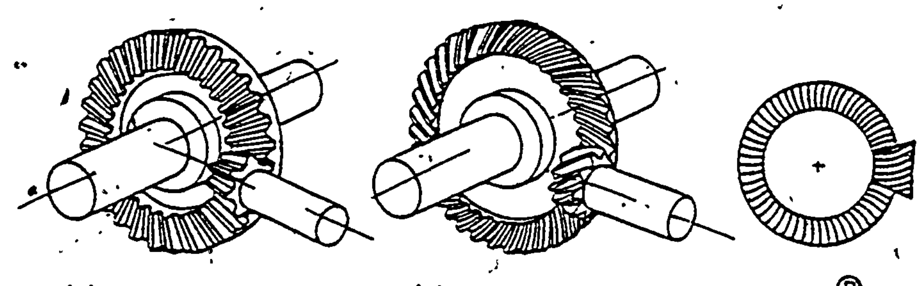


Figure 10. Intersecting-Axes Gears.

Spiral bevel gear teeth are curved and have more engagement overlap than plain bevel gears when they mesh (Figure 10b). They run more smoothly than plain bevel gears and can bear higher loads. Unfortunately, they impart more axial thrust than plain bevel gears.

Zerol® gears (Figure 10c) possess all the advantages of spiral bevel gears but none of their disadvantages: They are counterbalanced, run quietly, and can carry somewhat larger loads than plain bevel gears.

NON-INTERSECTING, NONPARALLEL-AXES GEARS

This family of gears is used to transmit power between shafts whose axes do not meet and are not parallel to each other (Figure 11).

Crossed-axes helical gears (Figure 11a) are the simplest of this family and the easiest to manufacture. They also can be mounted easily because small misalignments of shaft angle or of center distance are not critical. The load-carrying

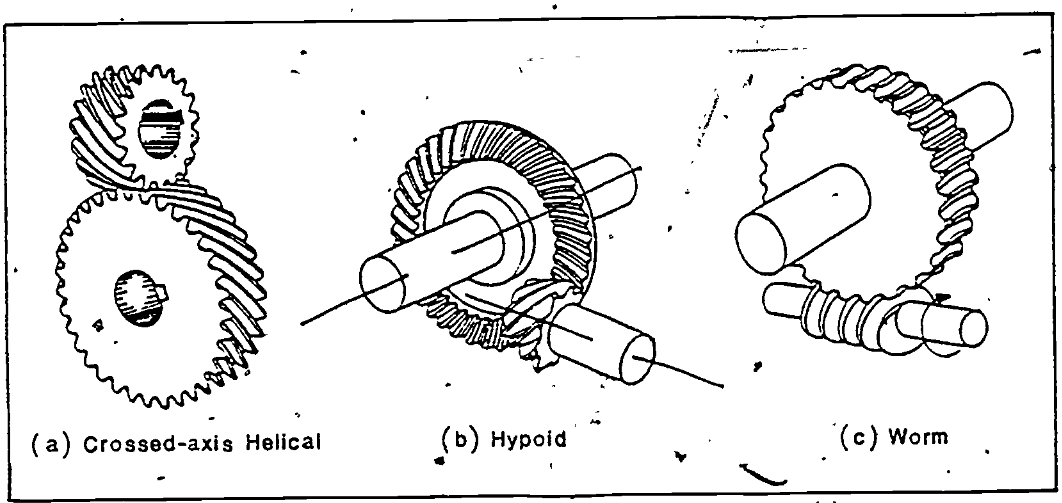


Figure 11. Non-Intersecting, Nonparallel-Axes Gears.

capacity of these gears is limited because of the small meshing area of their teeth.

The hypoid gear is similar to the spiral bevel gear, except that its pinion axis is offset above or below the ring-gear axis (Figure 11b). These gears are smoother and quieter than bevel gears, but are not as efficient, due to the sliding action of the teeth.

The worm gear actually is a screw, in which the power source normally operates at a high speed and the output at a slow speed with high torque (Figure 12). Because of its design, a worm gear reduces speed and increases torque (Figure 12). Since the driven gear, called the "wheel," cannot turn the worm gear, the worm can be used to prevent the wheel from reversing. Worm gears are employed in a variety of industrial "speed reducers."

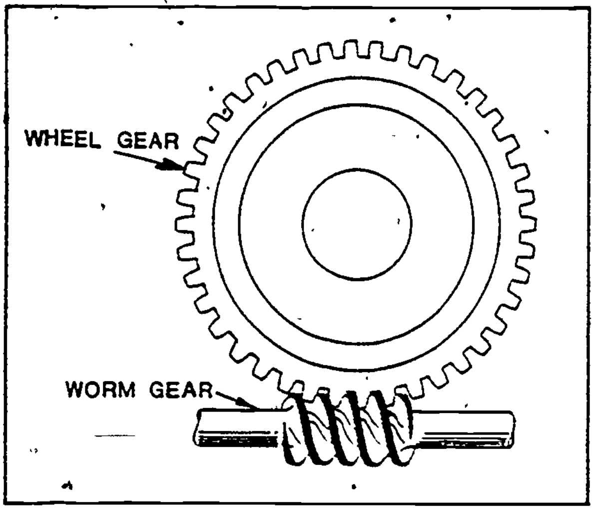


Figure 12. A Worm-Gear Drive.

Standard worm gears may have 1, 2, 3, or 4 threads. The number of threads on a worm can be obtained by counting the number of starts at the end of the worm. They are available with left- or right-hand threads.

The speed ratio of a worm-gear system is the ratio of the number of gear teeth to the number of worm threads.

MOVING-AXES GEARS

Many practical applications of mechanics require that rotary motion be converted to linear motion. One of the mechanisms used to make this conversion is the rack-and-pinion gear arrangement (Figure 13). A rack consists of a straight bar having involute gear teeth cut into one surface. It normally is meshed with a pinion, as depicted in Figure 13.

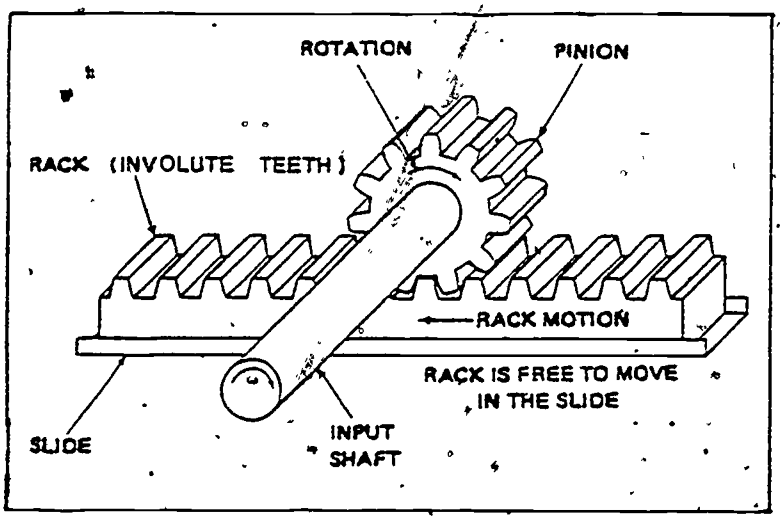


Figure 13. A Rack-and-Pinion Gear Arrangement.

The rotary motion of the pinion causes the rack to move on the "slide." Frictional losses between the rack and the slide can be a very serious problem. Consequently, rack slides require careful lubrication.

GEAR TRAINS

An arrangement of two or more gears in a series is called a "gear train." The simplest gear train is the familiar pinion and gear arrangement (previously illustrated in Figure 5). The simple gear train always has fixed centers and only one gear per shaft.

A compound gear train (Figure 14) has a fixed center, but more than one gear per shaft.

A "reverted" gear train is used when input and output shafts must have the same axis (Figure 15).

In a planetary gear train, which has at least one unfixed center of rotation, the outer ring has internal teeth that mesh with teeth on the smaller planet gears. The planet gears mesh with a "center," or "sun," gear (Figure 16).

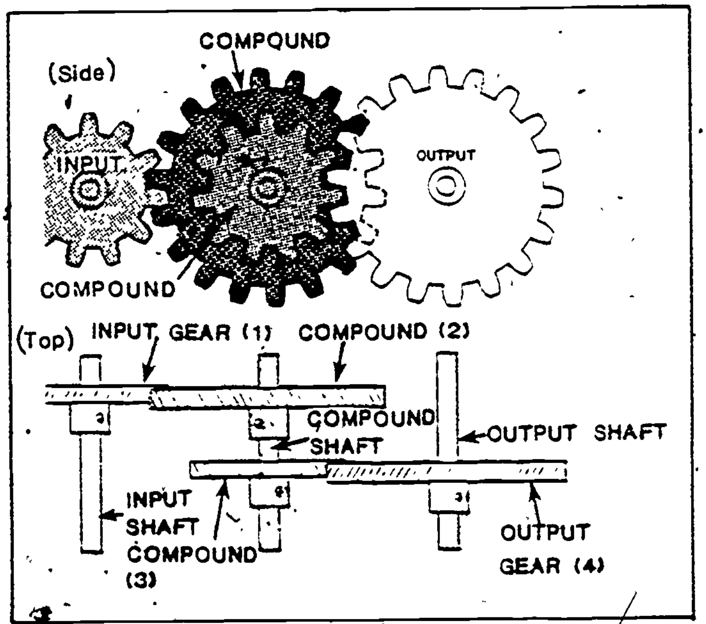


Figure 14. A Compound Gear Train.

When power is applied to one member of the planetary system, and a "brake" is applied to restrain a second member from turning, the third member will become a power output source, or, for example, in the following cases:

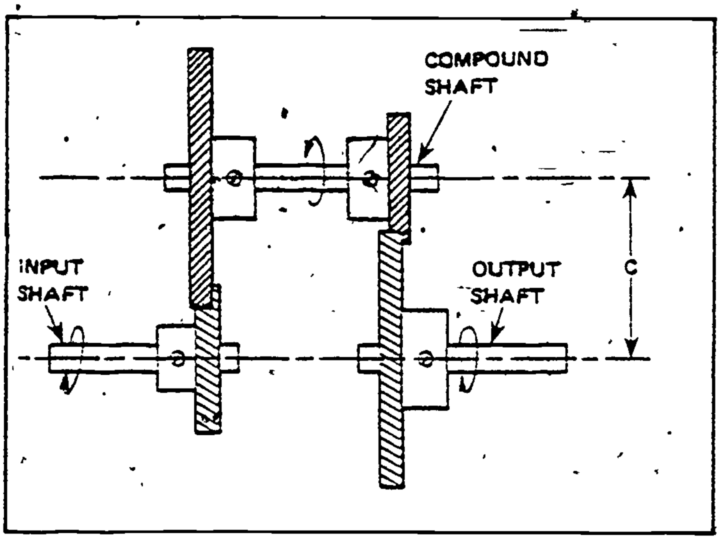


Figure 15. A Reverted Gear Train.

- If the sun gear is driven, and if a brake applied to the ring gear, the planet gears rotate around the ring gear, forcing the planet carrier to rotate in the same direction as the sun gear, but at a slower speed.
- If the planet gear carrier is driven, and if a brake is applied to the ring gear, the planet gears rotate around the ring gear, forcing the sun gear to rotate in the same direction, but at a faster speed.

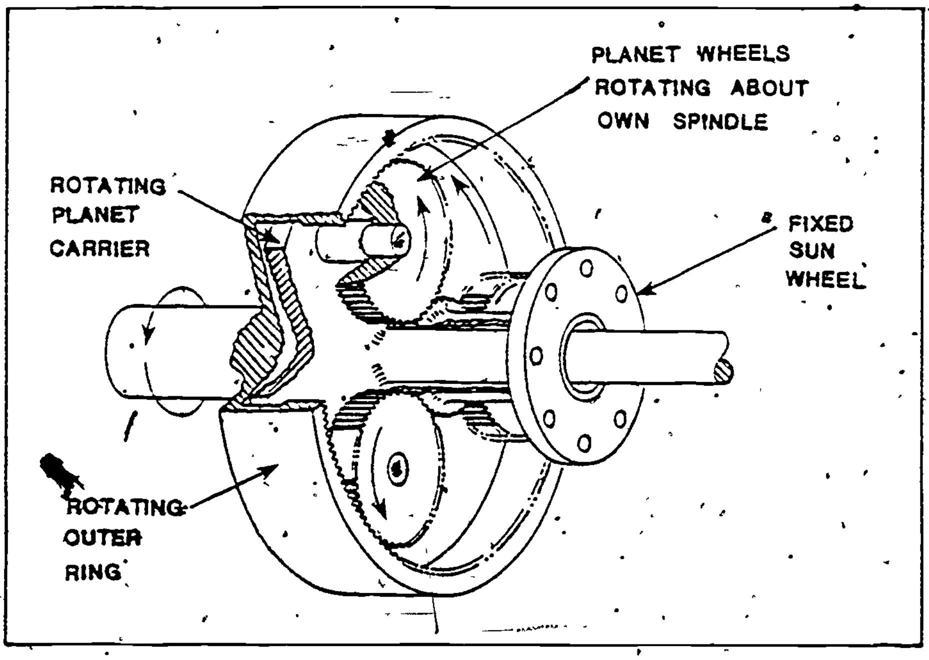


Figure 16. A Planetary Gear Train.

Depending upon which member is the driver and which is the braked, the planetary rotates at different speeds. This characteristic makes it especially useful in automobile transmissions.

The differential (Figure 17) is a gear train that produces an output proportional to the difference between two inputs. In automobiles, it is used to transmit power around a corner to the drive axles and to allow each wheel to rotate at different speeds and still propel its own load. There are dozens of various differential arrangements.

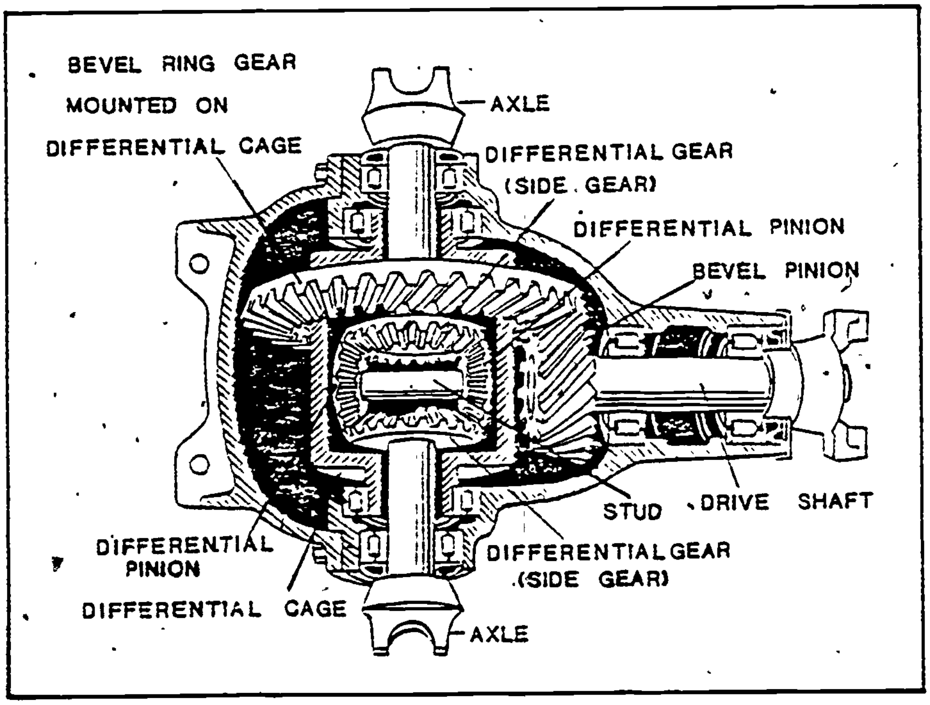


Figure 17. An Automobile Differential.

MAINTENANCE

LUBRICATION

Gear drives require careful and frequent lubrication to reduce gear wear and to keep the drive operating at peak efficiency.

Gear lubricants range from mineral oils to complicated formulas containing many ingredients. In small, simple gear units, simple oils are used. Special gear arrangements, or gears operating under special or unusual conditions, require special lubricants. These special oils usually contain anti-friction and "extreme-pressure" additives.

Oils in modern power transmissions must have special qualities, as, for example, the ones below:

- Must be free of sediment and water, to prevent sludge and rust.
- Must be foam-resistant, to prevent oil from foaming when it is agitated.
- Must be chemically stable, to withstand heat and agitation.
- Must act as a coolant.
- Must provide a protective film.
- Must have enough fluidity to coat surfaces of all load-bearing parts.

Both the Society of Automotive Engineers (SAE) and the American Petroleum Institute (API) have established standards and classification systems for gear oils. Selection of the proper gear lubricant is important, and manufacturers specification always should be followed.

The consequences of improper lubrication are serious:

- Gear-tooth pitting (Figure 18), usually is caused by contaminated oil or the incorrect type of oil, but also can be caused by the running of gear trains under excessive loads for long periods of time.

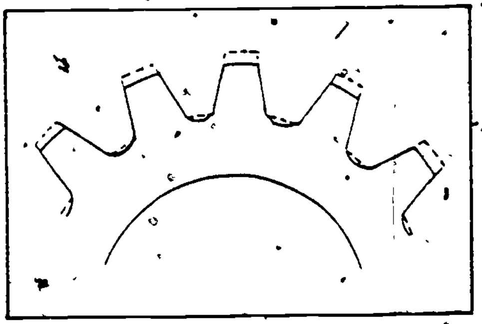


Figure 18. Gear Tooth Pitting.

- Gear-tooth scoring and galling is caused by metal-to-metal contact of mating gear teeth (Figure 19). High temperature produced by friction softens the metal, causing the teeth of one mating gear to tear particles of metal from the teeth of the other gear.

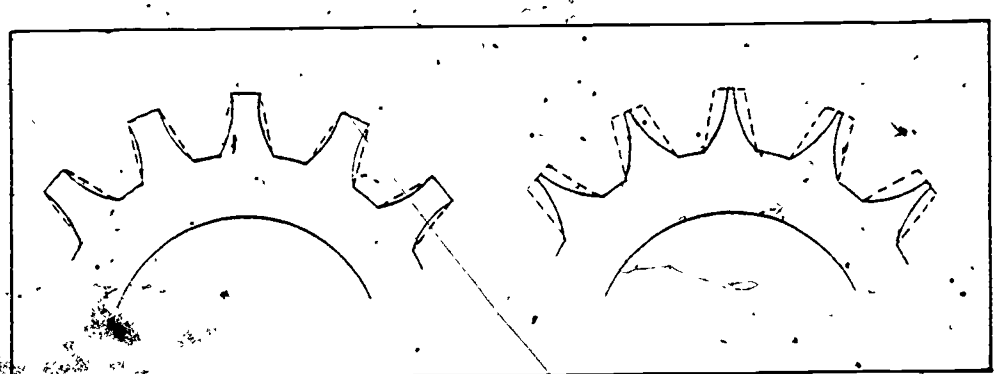


Figure 19. Scoring and Galling.

- Abrasive wear is caused by contaminants such as abrasive dust.

Generally, most gear drives fail because they are lubricated improperly. Occasionally, incorrect installation and excessive load cause the problem.

ADJUSTMENT

Gear trains must be adjusted when installed. Three kinds of adjustments are required:

- Clearance, or play between gears (backlash).
- End-to-end movement in a gear shaft.
- Gear alignment.

Excessive load also causes gear-tooth wear and breakage. Also, sudden shock load may break gear teeth.

INSPECTION AND TROUBLESHOOTING

Manufacturers usually supply specific troubleshooting instructions for the equipment they manufacture. There are, however, a few general procedures that should be followed in the inspection and troubleshooting of gears:

Inspection.

- Check for proper lubrication and for impurities in oil.
- Inspect gears for signs of wear or breakage.
  - Gear-tooth pitting, caused by contaminated oil, too little oil, or excessive loads.
  - Gear-tooth scoring and galling, caused by poor-quality oil or lack of lubrication.
  - Abrasions or fine tooth scratches, caused by dirt, grit, or metal particles in gears.

- Broken or cracked gear teeth, usually caused by too much backlash or by excessive overloading.

- If inspection reveals tooth damage or wear, follow the troubleshooting procedures listed below.

Troubleshooting.

- Gather information on history of operation of unit by questioning the operator; obtain information on maintenance and lubrication procedures, past failures, and hours of use.
- Disassemble unit.
  - Keep oil sample in order that it can be checked for impurities.
  - During disassembly, check for incorrectly-installed or aligned parts and missing parts.
  - Clean and inspect each part closely; determine type of failure.
- Consult manufacturer's troubleshooting guideline to determine causes and corrections.

SELECTION OF GEAR DRIVES

Gear and gear train makers provide all the information the technician needs to select an energy-efficient and economical drive. The technician would consult manufacturers' manuals and follow the procedures there outlined. These procedures, usually simple and straightforward, involve only the most basic of calculations. Several different systems meet the need; therefore, costs and energy-efficiencies of these systems should be compared and the final selection carefully made.

EXERCISES

1. The Driver gear of a simple gear train has 60 teeth; the Driven gear has 20 teeth. What is the system's ratio?

2. A gear 16-inch in diameter rotates at 315 r/min because of a force of 900 lbs. What is the system's horsepower?

LABORATORY MATERIALS

Miscellaneous gears: Spur; Helical; Spiral Bevel; Herring-bone; Worm; Rack-and-Pinion.
Spur gear large enough to allow instructor to label its parts. (Refer to Step 3.)
Spur and worm-gear set.
Auto, truck, or tractor gear box having cutaway sections; with manufacturer's manual. (Refer to Step 5.)
Miscellaneous gears with evidence of excessive wear, tooth breakage, rubbing, etc.
Rules, vernier gages, and calipers.

LABORATORY PROCEDURES

1. From a set of gears provided by the instructor, identify the following gears, and list them in Data Table 1.
   a. Straight spur.
   b. Helical spur.
   c. Herringbone.
   d. Plain bevel.
   e. Spiral bevel.

f. Zerol®.
g. Crossed-axes helical.
h. Hypoid.
i. Worm.
j. Rack-and-pinion.

2. After all gears have been identified, list (in appropriate spaces in Data Table 1) distinguishing characteristics of each gear and as many specific applications, advantages, and disadvantages of each as possible.
3. Each of the following parts of a spur gear have a number labeled on it; use Data Table 2 to match number with proper terms:
   a. Addendum.
   b. Dedendum.
   c. Face of gear.
   d. Face of tooth.
   e. Flank of tooth.
   f. Pitch circle.
4. Measure pitch diameter, and count number of teeth in spur gear; calculate diametral pitch from Equation 9; enter results in Data Table 2.
5. Perform the following procedures, using a truck, tractor, or auto transmission box having sections cut out of front, middle, and rear casing to expose internal gears:
   a. Identify gears in gear box; list them in Data Table 3.
   b. Inspect gears, using lower portion of Data Table 3 as a checklist.
   c. Determine from manufacturer's manual which lubricant is recommended for this transmission.
   d. Trace power flow from input shaft to output shaft for all forward gears.

DATA TABLE 1

Gear	Distinguishing Characteristics	Specific Applications, Advantages, and Disadvantages
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

DATA TABLE 2

Part Number	Part
1.	
2.	
3.	
4.	
5.	
6.	

Pitch Diameter ____________

Number of teeth ____________

Diametral pitch ____________

DATA TABLE 3

Types of Gears in Transmission:

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________
6. ____________

	Yes	No	Possible Cause
Gear tooth pitting?			
Gear tooth scoring or galling?			
Abrasive wear?			
Tooth breakage or cracking?			

REFERENCES

Beiser, Arthur. Modern Technical Physics. 3rd ed. Menlo Park, CA: The Benjamin/Cummings Publishing Company, Inc., 1979.

Dudley, D. W. Gear Handbook. New York: McGraw-Hill Book Company, 1962.

Carmichael, C. Kents Mechanical Engineers Handbook. New York: John Wiley & Sons, 1976.

Lent, D. Analysis and Design of Mechanisms. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1970.

Tinnell, Richard W. and TERC staff. Mechanisms: Drives. Electromechanical Technology Series. Albany, NY: Delmar Publishers, 1971.

1. Define the following terms:
   a. Force.
   b. Work.
   c. Power.
   d. Horsepower.
   e. Mechanical advantage.
   f. Torque.
   g. Pitch circle.
   h. Pitch diameter.
   i. Addendum.
   j. Clearance.
   k. Diametral pitch.
   l. Pinion.
   m. Face of gear.
   n. Face of tooth.
   o. Flank of tooth.
   p. Involute curve.

q. Pressure angle.

r. Backlash.

s. Gear ratio.

t. Excessive backlash.

u. Helix angle.

2. Given: A gear drive 18 inches in diameter that rotates at 360 r/min due to a force of 800 lbs.
Find: Horsepower of system.

3. List five conditions in which gear drives should be used instead of belts or chain drives:

a.

b.

c.

d.

e.

4. List three uses for gear drives:

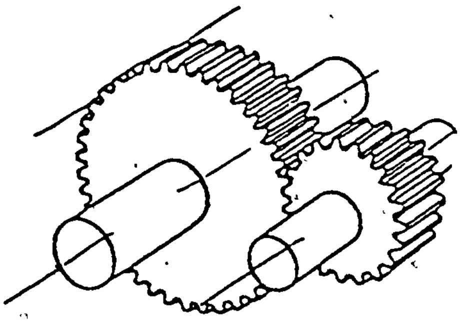
a.

b.

c.

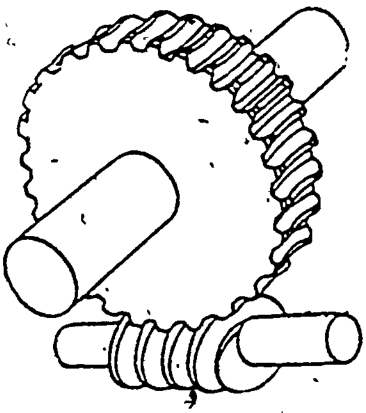
5. Identify parts on each of the unlabeled sketches; briefly describe each gear's distinguishing characteristics; and list at least one application and one advantage or one disadvantage of each:

a.



Type ______________________
Characteristics ______________________
____
____
Applications ______________________
Advantages ______________________
Disadvantages ______________________

b.



Type ______________________
Characteristics ______________________
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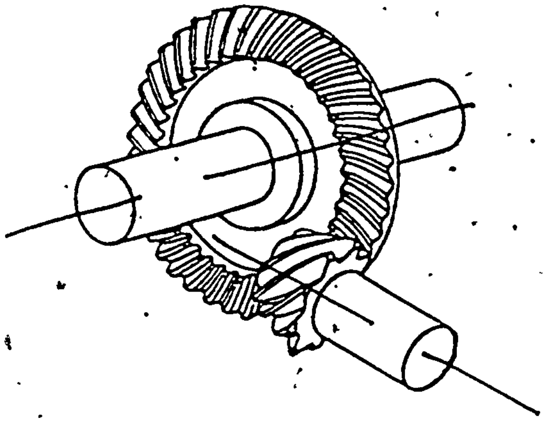
Applications ______________________
Advantages ______________________
Disadvantages ______________________

c.



Type ______________________

Characteristics ______________

____

____

Applications ________________

Advantages __________________

Disadvantages _______________

6. Cite the distinguishing characteristics of the simple, compound, reverted, and planetary gear trains.

7. Describe how a planetary gear train can be used to give different speeds to a shaft.

8. Describe the operation of a mechanical differential.

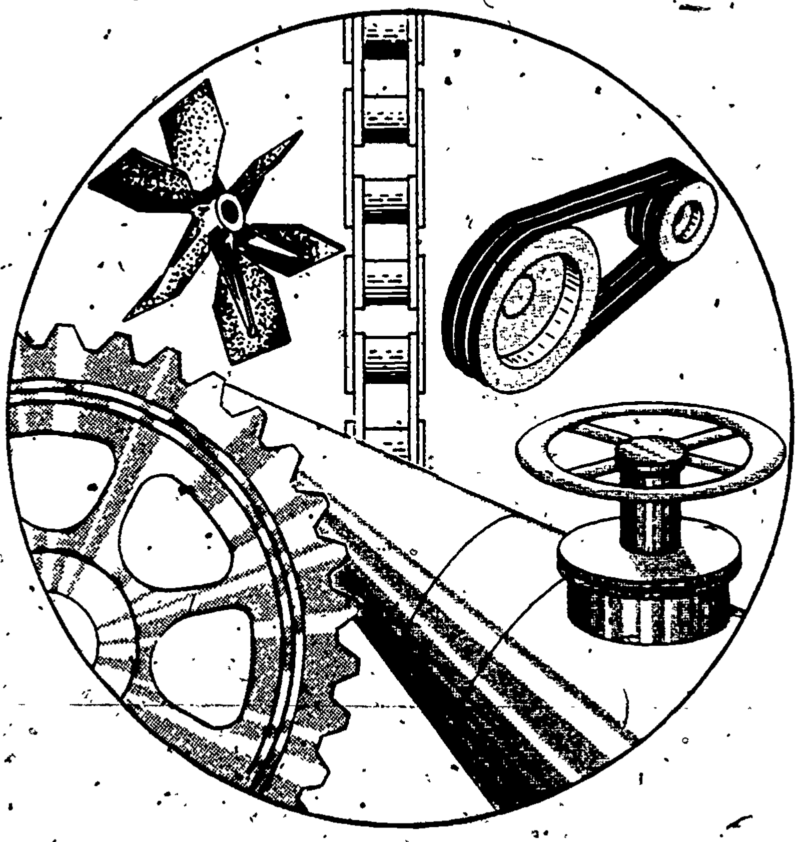
9. Cite two general reasons for failure of a gear system.

10. Describe gear lubrication and why it is necessary.

ENERGY TECHNOLOGY

CONSERVATION AND USE

MECHANICAL DEVICES AND SYSTEMS



MODULE MS-04

DRIVE TRAIN COMPONENTS I

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

The three basic drive systems — which, remember, are the belt drive, the chain drive, and the gear drive — depend upon drive train components for their operation. Two of the more important components are shafts and bearings, both of which are the subjects of this manual.

This manual also discusses shaft keys, key seats in shafts, and keyways in pulleys and other components. The different types of bearing housings are described and their importance explained.

Proper maintenance of shafts and bearings can result in very substantial energy and monetary savings. A knowledge of the necessary maintenance procedures is a requirement for the energy technician because of the frequency of attention demanded by these components.

PREREQUISITES

The student should have completed one year of high school algebra.

OBJECTIVES

1. Match the following terms and definitions:

_______ Shaft.	A. A shaft enlarged under the pulley.
_______ Metalizing.	B. Axial and parallel.
_______ Bossed shaft.	C. Piece of metal that locks shaft and pulley together.
_______ Shaft expansion.	
_______ Shaft alignment.	

_______ Keyway and keyseat.
_______ Shaft key.

D. Key groove in pulley; key groove in shaft.
E. Process for adding metal to shaft.
F. Effect of temperature change.
G. Transmits power.

2. Explain the uses of these plain bearings:
   a. Journal.
   b. Stave.
   c. Split (used with shim).
   d. Solid.
   e. Thrust.
   f. Flanged thrust.
   g. Grooved split.
   h. Spherical plain.
3. Identify and describe the two types of friction and which type is experienced by plain and antifriction bearings.
4. Define these terms for antifriction bearings:
   a. Radial.
   b. Thrust.
   c. Combination.
   d. Expansion.
   e. Roller.
   f. Self-aligning.
5. Given unlabeled sketches of various bearing mounts, identify each type and discuss the use of each.
6. Describe three ways in which bearings can be damaged and how such damage can be prevented.
7. List the advantages of oil lubrication and of grease lubrication.
8. Identify where pulleys or couplings should be located on a shaft relative to the bearings.

SHAFTS

The shaft forms an intrical part of almost all power transmission equipment. Its basic function is to transmit power from the power source to driven components such as pulleys, sprockets, gears, and couplings (Figure 1).

Some shafts are the components of motors and are called "motor shafts." Others are connected to motors by other drive components and range in length from very short to many feet in length. Figure 1 depicts such a "line shaft."

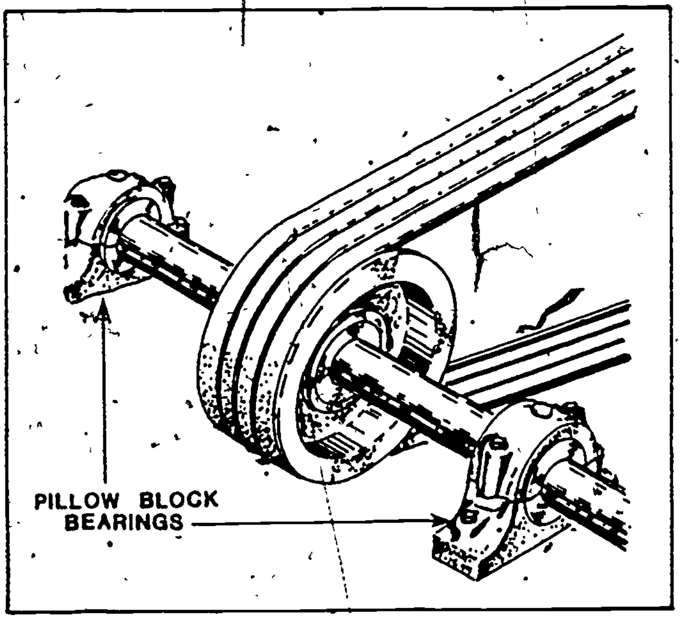


Figure 1. Shaft in Belt Drive.

SHAFT SPACING

Line shafting normally is spaced on centers of about 8 feet. Pulleys, sprockets, clutches, or rigid couplings should be positioned near bearings to prevent shaft bending, deflection, and vibration. High-speed shafts require shorter centers.

BOSSED AND TURNED-DOWN SHAFTING

Heavily-loaded pulleys often are fitted to bossed shafts — those having an enlarged section under the pulleys but turned to a smaller diameter at the bearings to allow for smaller, more economical bearings.

FLEXIBLE SHAFTS

Some power drive and remote control operations are well suited for use with flexible shafts, which exhibit the following advantages: freedom of locating power source and driven components; replaces universal joints, couplings, and shields; accuracy of alignment; and low cost.

SHAFT EXPANSION

Heat often transfers through a high-temperature process to the shafting, which expands. The longer the shaft, the greater the expansion. Unless "expansion," or "floating," bearing units are utilized, some of the bearings will be damaged by the end pressure exerted by the expanding shaft. Except for the anchor bearing, all bearings on a shaft subject to expansion should be of the expansion type (discussed under bearings).

ALIGNMENT

Two or more shafts transmitting power from one to the other must be aligned as follows:

- They must be parallel. Ensure that the distance is the same between the shafts at the ends.
- They must be on the same axis if end-to-end.

Shafts often must be realigned because of settling foundations, the effects of heat, vibration, worn bearings, etc. Although some bearings and couplings will handle limited misalignment, precise alignment reduces wear.

METALIZING OF SHAFTS

Shafts often develop irregular areas at the points at which they contact the bearings. These irregularities are caused by wear, misalignment with bearings, and other reasons. They can be removed if the worn area is metalized and refinished on a lathe or other means. The process of metalizing is the technique of spraying a metal coating on a metal object. Aluminum or zinc in the form of wire is fed into a spray gun, where it is melted by a flame and sprayed or deposited on the surface. Another process is called "vacuum evaporation." (Some pulleys can be repaired by metalization.)

BENT SHAFTS

Bent shafts wear out bearings and cause excessive vibration. They should be replaced, although some of them can be straightened in an emergency. They should be removed for straightening, as bearings will be damaged if they are hammered on the equipment.

SHAFT SELECTION

Shaft size normally is selected when the equipment is designed, although modifications sometimes are necessary, especially to accommodate thrust loads (loads at the ends of a shaft or at the sides of pulleys and other components connected to it). Should a larger shaft be required, the technician can extract adequate information on proper size from manufacturers' catalogs and manuals. Some of the factors in selection are the distance between shaft supports, the torsional moment (twisting action) in the drive, and the degree of shock load upon equipment startup.

SHAFT KEYS AND KEYSEATS

Shaft keys fit into grooved "keyseats" in the shaft and into grooved "keyways" in the component attached to the shaft (Figure 2).

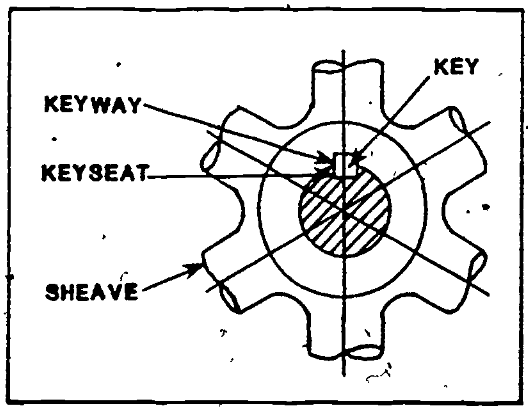


Figure 2. Square Shaft Key.

The purpose of the key is to lock the shaft and its drive member firmly together (Figure 2) in such a manner as to prevent slippage between the two.

The square key (Figure 2 and Figure 3a) is, perhaps, the most widely-used type. The flat key (Figure 3b) is a popular type, as well. The set screws in the hub should be tightened on the key to prevent it from tipping under load.

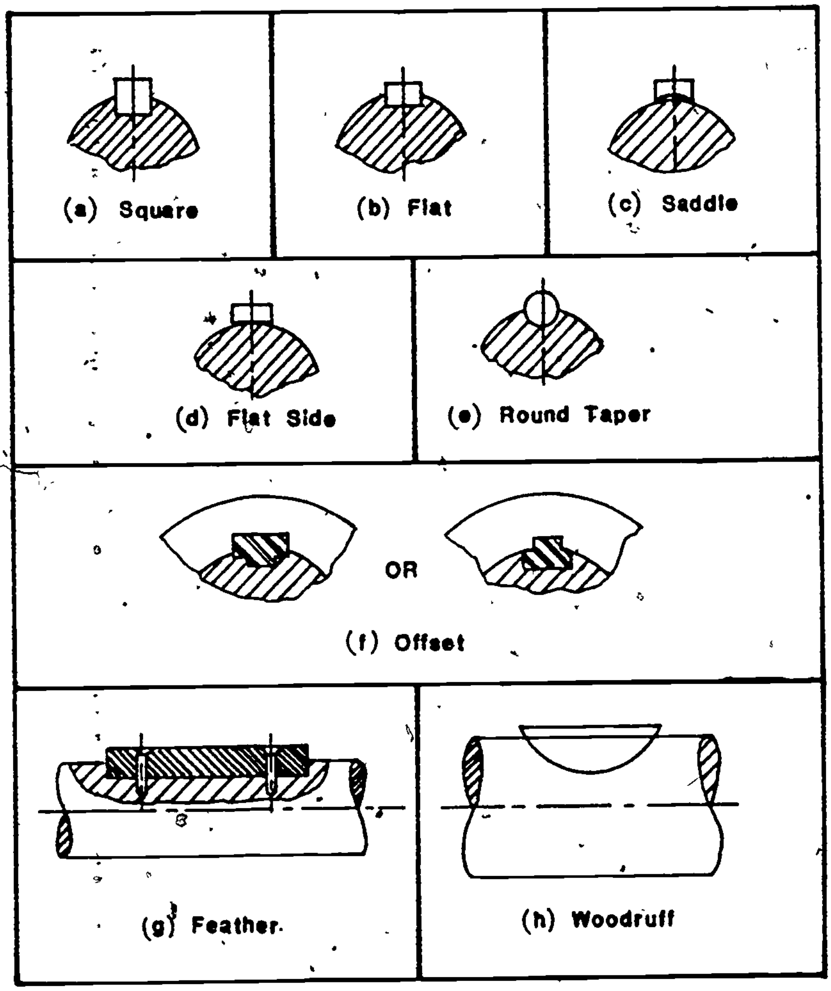


Figure 3. Shaft Keys and Keyseats.

When shaft grooves are not used with a hub, the saddle key (Figure 3c) is acceptable for light duty.

The flat key illustrated in Figure 3d is not used with a keyseat, but with a shaft end flattened on one side. This key usually is tapered for a close fit. Similar to this key is the round taper key (Figure 3e); both types are for light duty.

Figure 3f depicts the offset key, which adjusts for a shaft groove of different width than the hub groove.

When a hub must be moved often for a very short distance along the shaft axis, the long Feather key is attached by screws into the shaft keyseat (Figure 3g).

Figure 3h illustrates the Woodruff key, which is both flat and circular to adjust for tapered shafts. This design minimizes the tendency of keys to tip when load is applied. These features are responsible for its wide use in light duty applications, such as machine-tool construction.

Some key material, especially the flat type, is manufactured in blanks several inches in length. This material is termed "key stock"; it can be cut to the desired length.

BEARINGS

The proper maintenance of bearings can result in substantial savings of equipment and down time. The two principal types of bearings are plain and antifriction. A bearing is a device that supports in or on it a part that rotates, slides, or oscillates. Shafts are the most common devices that rotate within a bearing. (Sometimes the shaft is stationary and a housing rotates around it, as with a front automobile wheel.)

PLAIN BEARINGS

Plain bearings (Figure 4) contain no rolling elements; that is, the solid bearing surfaces contact the shafts directly, separated only by a thin film of lubricant. Plain bearings are constructed of materials softer than the shaft material. These softer materials often are impregnated with oil or dry lubricant.

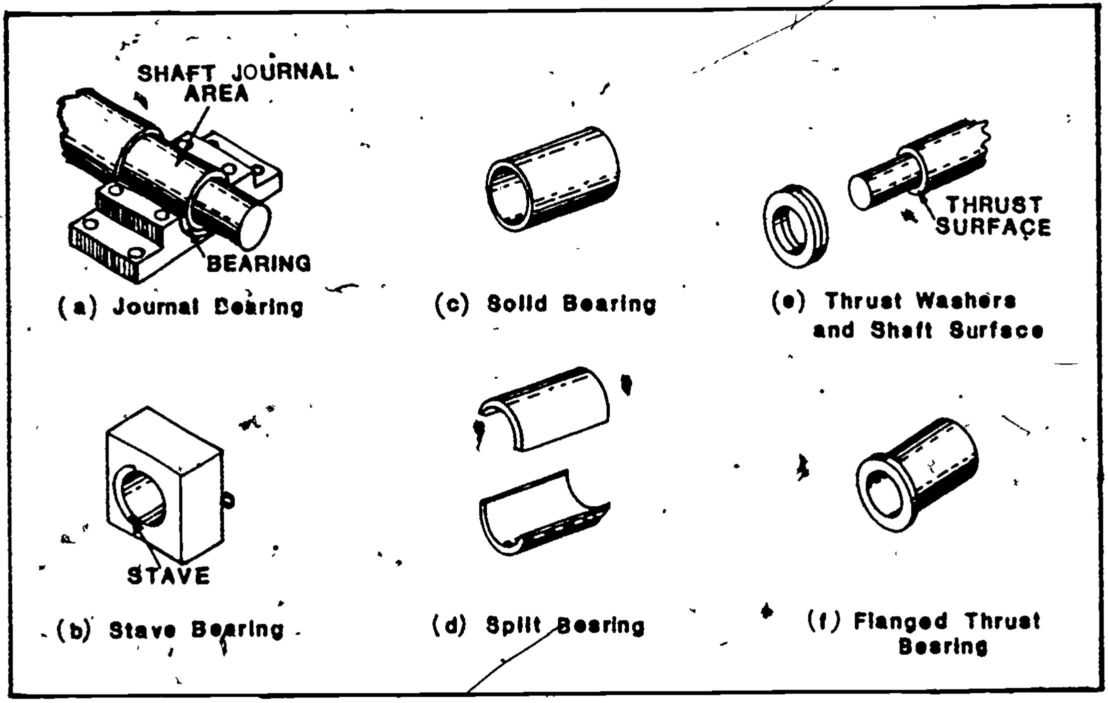


Figure 4. Plain Bearings.

The journal bearing supports radial loads, or loads exerted radially from the shaft. It is positioned on the shaft as illustrated in Figure 4a. The journal bearing may be only half a bearing (Figure 4b), used when the load is only upon that part of the bearing. This "part bearing" is not to be confused with the split bearing (Figure 4d) that is split in two for ease of installation on continuous shafts and easy shaft removal.

Split bearings have the added advantage of being easily repaired. High spots on the inner surface can be scraped off with a half-round scraper or a three-cornered one. The high spots are identified by use of Prussian blue or Red lead, which is placed on the shaft surface in the bearing area and which transfers to the high spots of the bearing when the bearing is placed on the shaft.

Split bearings (Figure 5) must be tightened to achieve a proper "running fit." (This expression is not to be taken in the sense, "He had a running fit.") A running fit is a snug, but not tight, grip of the bearing halves on the shaft. Metal shims often must be used, as illustrated in Figure 5. The shims must not touch the shaft because they would interfere with proper lubrication and cause shaft wear.

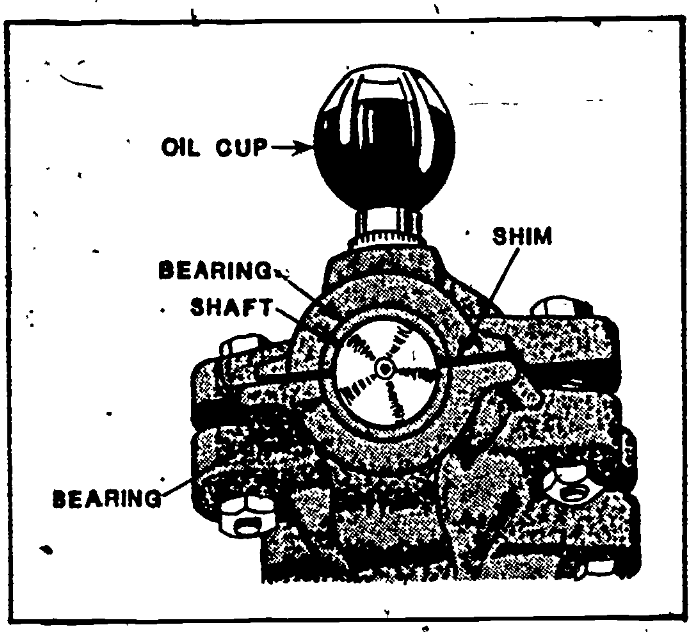


Figure 5. Shaft Running in a Split Bearing.

The thrust washers illustrated in Figure 4e accept force applied at their sides. The flanged thrust bearing supports thrust loads at the end of a journal bearing that also supports radial loads.

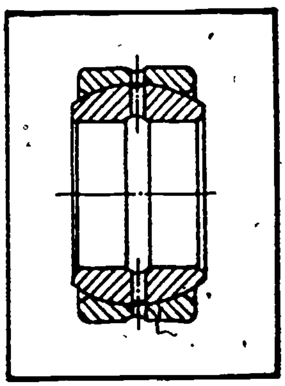


Figure 6. Spherical Plain Bearing.

The spherical plain bearing (Figure 6) performs like a ball joint. Its primary value lies in its capacity to accommodate large degrees of misalignment. Other features include high capacity, ability to handle low-frequency shaft oscillations, and easy installation.

Mounted Plain Bearings

Plain bearings often are mounted in pillow blocks, flanges, and other housings similar to those in which antifriction units are mounted. (Antifriction mounts are discussed later and are illustrated in Figure 10.)

Lubrication

Most plain bearings are lubricated through an oil inlet at the top or, sometimes, the side (Figure 7). The groove allows the lubricant to spread along the entire journal surface. Circled or crossed grooves do not seem to be as effective in most instances as straight grooves. Bearings over seven or eight inches in length should be equipped with more than one oil inlet.

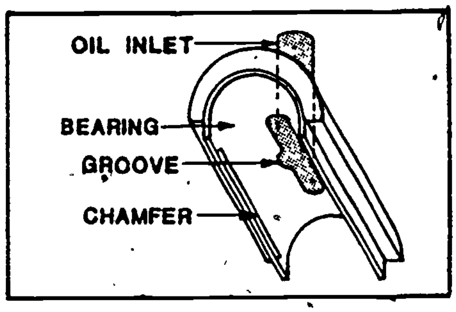


Figure 7. Oil Groove in Split Bearing.

Split bearings must be chamfered, or beveled, at the inside joints (on both halves) to allow proper distribution of lubricants (Figure 7).

Bearings manufactured to exacting specifications normally perform well if the shafts upon which they ride are in good condition. Those bearings prepared in the plant of Babbot's material (an alloy of copper, tin, and altimony) may have irregular surfaces that cause overheating and other problems if not carefully prepared.

Table 1 lists the major troubleshooting procedures for plain bearings.

TABLE 1. TROUBLESHOOTING OF PLAIN BEARINGS.

TROUBLE	CAUSE	CORRECTION
Bearing Overheated and/or Wears out too Quickly	(a) Out of oil or wrong grade	(a) Increase oil flow and use correct grade
	(b) Dirt in oil	(b) Replace oil
	(c) Bearing not aligned with shaft	(c) Align
	(d) Uneven bearing surface	(d) Replace bearing or scrape inner surface
	(e) Bearing too tight	(e) Loosen bearing; use thicker shim
	(f) Wrong grooving	(f) Replace bearing
	(g) Excessive operating temperatures	(g) Increase water flow if water-cooled unit is used; if not, consider the use of one
	(h) Wrong bearing material	(h) Try other material
	(i) Uneven shaft surface	(i) Metalize shaft
	(j) Hot shaft from process	(j) Use heat discs on shaft to dissipate heat
CAUTION: Never pour cold water on a hot bearing or shaft; this procedure may break a housing or warp components.		

ANTIFRICTION BEARINGS

Antifriction bearings experience less friction and maintain closer tolerances than plain bearings, which must withstand sliding friction. The "rolling friction" exhibited by antifriction bearings is comparatively small because there is little relative motion between the bearing surfaces and the ring surfaces. The more important terms used with ball bearings are given in Figure 8a; and the terms used with roller bearings, in Figure 8b.

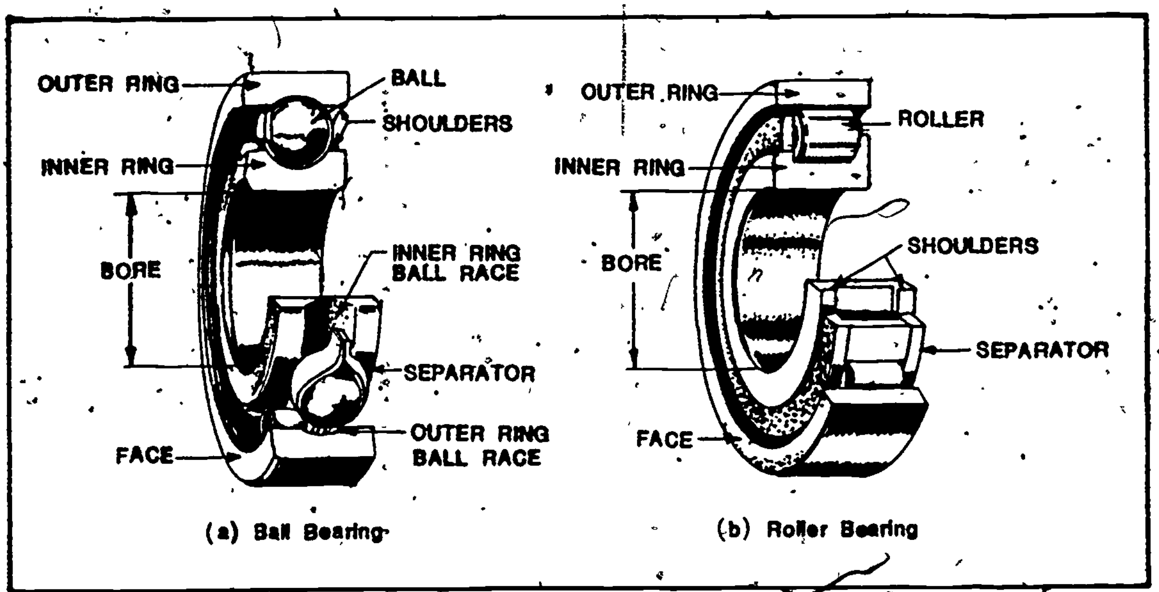


Figure 8. Bearing Terminology.

All antifriction bearings can be categorized according to their functions: radial, thrust, or combination.

Radial bearings (Figures 8 and 9) radiate out from a common center and bear loads applied radially, or perpendicular to the axis. Thrust bearings take axial loads, or those applied to the bearing sides (Figure 10a). Combination bearings bear a combination of radial and thrust loads.

Radial Bearings

Figure 9a displays the most popular radial bearing — the double-groove type — which exhibits excellent contact between the balls and the deep grooves in which they ride.

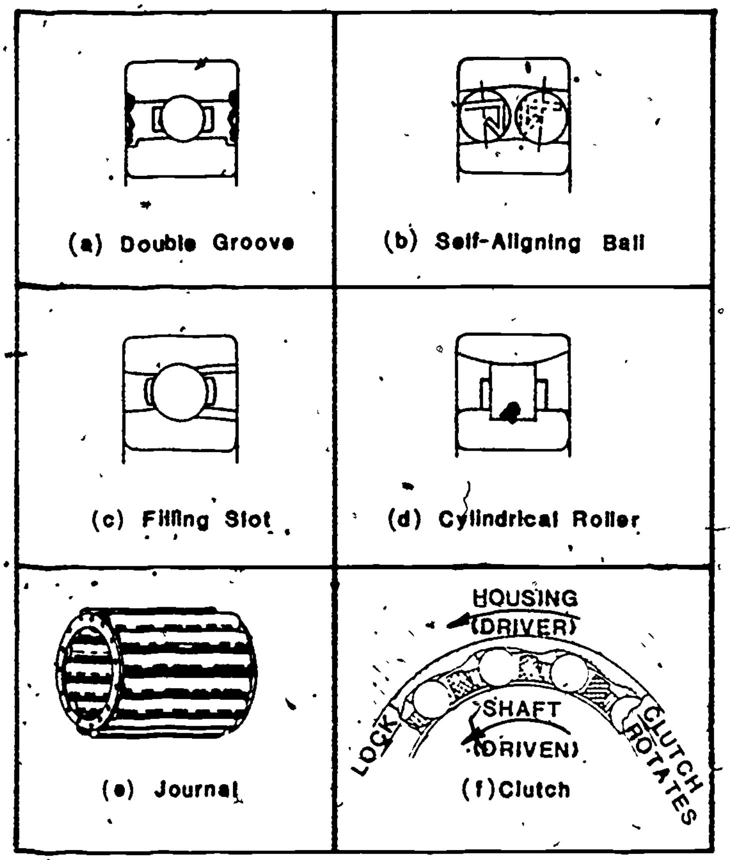


Figure 9. Radial Bearings.

This bearing can accept considerable thrust load, but must be precisely aligned between shaft and housing.

Such precise alignment is not required with the self-aligning ball bearing (Figure 9b), which has two rows of balls that ride on a spherical surface, over which the balls can rotate side-to-side. This free action allows for slight angular misalignment.

The filling-slot bearing (Figure 9c) contains rather large balls for maximum radial load but will handle light thrust forces, as well.

The cylindrical roller bearing (Figure 9d) contains cylinder-shaped rollers capable of bearing much greater loads than ball bearings. (Balls make contact at small points; whereas, rolling cylinders make contact along their entire length.) Some designs contain two rows of rollers for very close tolerances.

The journal bearing, as illustrated in Figure 9e, is constructed of long rollers of small diameter, which often ride directly on a shaft. The journal bearing is used when space is limited, and when a moderate load is applied at a low-to-medium speed. This bearing will overheat at high speeds.

One of the most interesting bearings is the clutch type (Figure 9f), which allows rotation in only one direction and allows free "overrun" in that direction. When the housing or shaft move in an opposite direction from the overrun positions, the bearings are wedged between tapered slots in the outside race to lock the housing and shaft. These bearings are used in bikes, conveyor rollers, motors (as backstops), rack indexing drives, etc.

Needle bearings contain long, small-diameter rollers. These units can be used when there are close tolerances between small shafts and housings.

Antifriction ball screws ride upon specially-threaded shafts to provide linear motion. The balls ride in the grooves to provide free motion. Antifriction "way bearings" also provide for linear motion and friction-free positioning of machine parts or of objects being handled by machinery.

Thrust Bearings

The ball thrust bearing depicted in Figure 10a rides in the grooves of two races, or "washers." This bearing supports force applied to its sides, but must be run only at slow and medium speeds because high speed causes excessive loading, by centrifugal force, at the outer portions of the washers.

The cylindrical roller bearing (Figure 10b) is capable of bearing even greater thrust loads, but not at high speeds. When high speeds must be accommodated, the spherical roller thrust bearing (Figure 10c) is an excellent choice. Its lower friction (than the straight roller) and steep angular position allow it to operate at high speeds; to accommodate

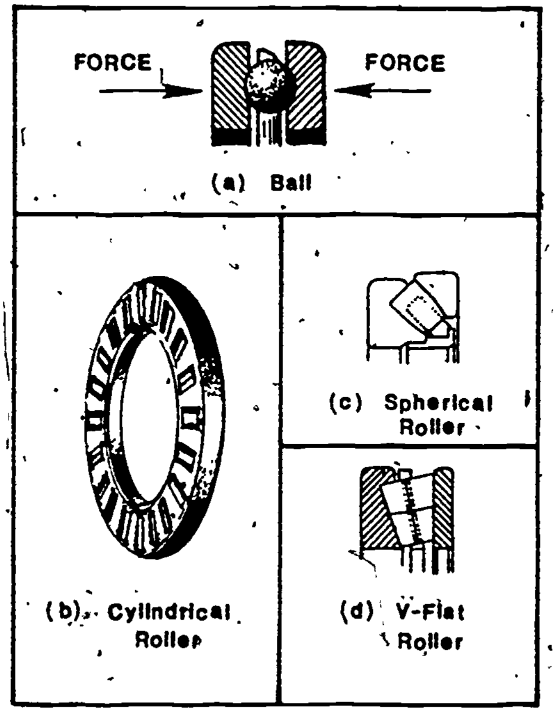


Figure 10. Thrust Bearings.

high thrust loads and even moderate radial loads; and to maintain alignment (or to adjust for some misalignment).

For extreme load conditions, the V-flat thrust bearing (Figure 10d) is the ideal choice, either for new installations or for replacement. This design achieves true rolling motion between the tapered rollers and both races; there is no sliding at any point. The one flat race permits some radial displacement.

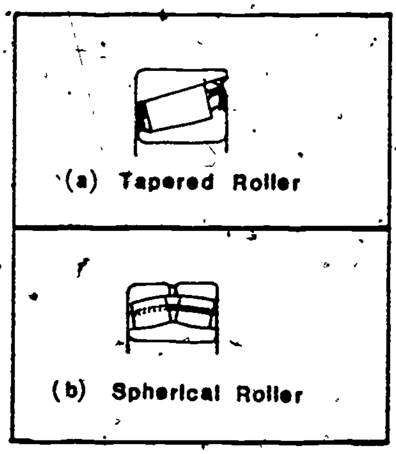


Figure 11.
Combination Bearings.

Combination Bearings

Although some of the radial and thrust bearings will accommodate a combination load, there are two principal types of basic combination bearings. These types are the tapered roller (Figure 11a) and the spherical roller (Figure 11b).

The tapered roller bearing consists of slightly tapered, slightly cone-shaped rollers that rotate between tapered raceways. This bearing is widely used to carry radial and axial loads that act simultaneously. The radial load normally is greater than the axial. One of the more desirable features of this bearing is its capacity to be adjusted for close or loose tolerance. (The front wheel bearing of the automobile is a good example.)

The spherical roller bearing (Figure 11b) contains arc-shaped outside surfaces that ride in race grooves that match. This design allows the bearing to pivot and, therefore, to operate when the shaft is displaced angularly. This capacity to accept misalignment is the reason the bearing is termed "self-aligning." It is a heavy-duty unit designed for large radial loads and small thrust loads. As the thrust load increases, the speed must be decreased if this bearing is to be used. Another desirable feature of this bearing is its capacity to operate well under greater vibration than most other bearings.

Mounted Bearings

Mounted bearings (Figure 12) are those mounted in housings that can be attached to support surfaces. Housings often are fitted with "expansion" bearings — those bearings which can move axially a certain distance to avoid the thrusting of bearings on opposite ends of a shaft that floats or expands when heated. Most mounted bearings are of the self-aligning type to accommodate some misalignment.

The pillow block (Figure 12a) is the most popular bearing mount because of its adaptability. It may be mounted in the middle of a shaft or at the end; if at the end, the end closure unit (Figure 12b) often is used because the shaft

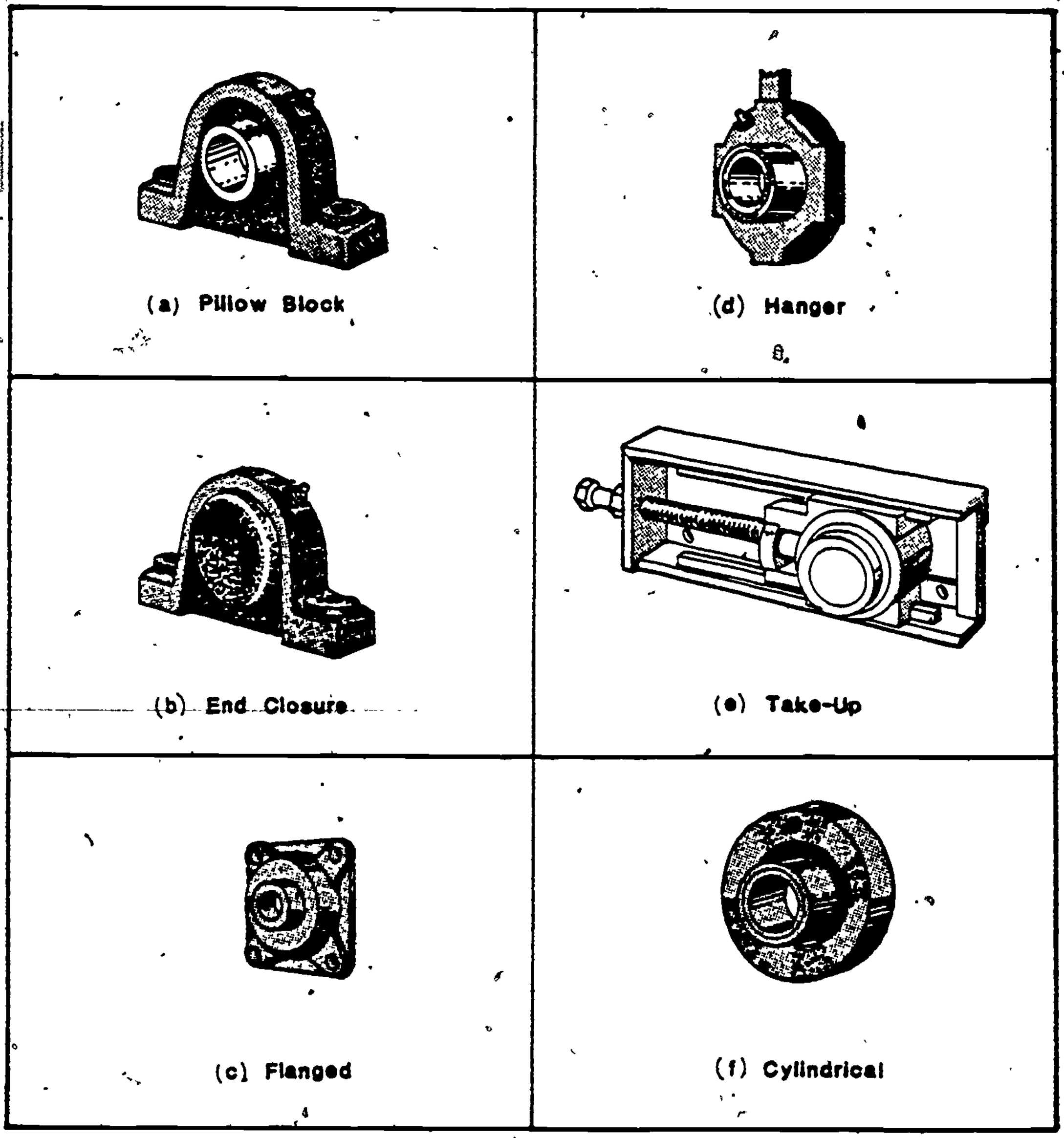


Figure 12. Mounted Bearings.

end is covered for safety reasons or to prevent foreign matter from contacting the shaft end or bearing. The pillow block is designed to be bolted to surfaces parallel to the shaft.

The flange bearing (Figure 12c) mounts to surfaces perpendicular to the shaft.

Although most housed bearings are mounted by bolts, the hanger unit (Figure 12d) is suspended at the end of a vertical pipe or rod. It is utilized in some conveyors and in other equipment in which shaft movement is permissable or desired.

Take-up units such as the one illustrated in Figure 12e are employed as belt-tightening and shaft-adjustment devices. The housing slides in a metal frame when an adjusting screw, to which the housing is attached, is turned.

The cylindrical bearing (Figure 12f) is used when suitable holes for it can be provided within the frame of the machine.

Bearings also are mounted in idler pulleys and sprockets.

Shaft Alignment

Linear shaft misalignment (Figure 13a) is extremely destructive to bearings. When shafts are coupled out of line, they exert added pressure on the bearings; the result is frequent bearing replacement. Angular misalignment, if not too great, can be handled by the proper coupling or by self-aligning bearings.

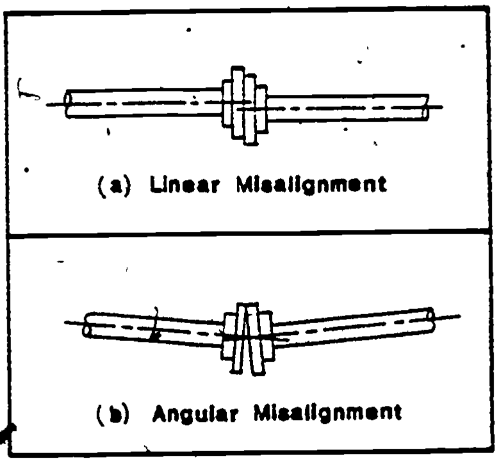


Figure 13. Misalignment.

Belt Tension

If belts are tensioned too tightly, they will fail; and, perhaps more importantly, such excessive tension results in rapid bearing wear and, thus, more down time.

Shock Loads

Heavy-duty drives having large shock loads at start-up should be equipped with the appropriate clutch or shock coupling, in order to avoid the tremendous pressures exerted upon bearings, shafts, and other components.

Bearing Installation

Bearings should be installed carefully as follows:

- Clean shafts and bearing housings thoroughly.
- Clean dirt out of keyways, splines, and grooves.
- Remove burrs and slivers.
- Clean and oil bearing seats.
- Press bearing on straight and square.
- Press only on the ring that takes the tight fit.
- Press bearings until they are seated against the shaft or housing shoulder.

Bearings should not be struck directly during installation. If possible, they should be pressed on the shaft by an arbor press or other special unit. If, however, they must be tapped onto the shaft, the bearing should be started on the shaft, which then is placed into a close-fitting pipe. The pipe is then tapped (with some insulating material between it and the hammer) to force the bearing into place. Heavy blows must not be applied.

If a bearing is difficult to force onto a shaft when cold, it can be heated evenly and moderately to 200–250°F to expand the inner ring. Another method is to cool the shaft in dry ice.

Similarly, bearings must not be struck directly during removal. When possible, special tools should be used.

Vibration

Bearing damage can result if they are vibrated excessively while not turning. Some means should be found to reduce such vibration; flexible couplings or clutches can provide relief in many instances.

Current Through Bearings

Electric current that arcs through bearings will produce burn damage. This current may originate from stray magnetic fields in the machinery or from the process of welding when the ground must pass through the bearing. All motors should be grounded properly and maintained properly.

Lubricants

The type and amount of lubrication required depends upon the bearing design, the load it must support, and the speed of operation. Much of the required information is available in the catalogs of the manufacturers.

The three principal lubricants are oils, greases, and solids of which have certain advantages. In general, grease is utilized in heavy-duty operations, since it is confined to housings easily, offers better bearing protection, and requires less frequent re-lubrication than oils. Overlubrication can be as damaging to bearings as underlubrication. When using a grease gun, open plug at bottom of most housings to allow excess grease to drain off when machine runs a few minutes. Then replace plug.

In high-temperature conditions shafts can be equipped with cooling discs that dissipate heat. Some pillow blocks are equipped with cooling coils through which water is passed.

Lubrication Systems

The simplest oil supply system is the oil bath, in which oil is contained in the bottom of a bearing housing at a level just high enough to enter the bearing. This method is suitable for low or moderate speeds.

Circulating oil systems are ideal for large drives that operate under severe conditions such as high ambient temperatures and high power and speed inputs. Oil temperature often is controlled automatically.

The spray, splash, or mist systems are excellent for high speeds and for vertical operation.

The wick system is suitable for very high speeds because the wick supplies a small quantity of filtered oil to the bearing. Wicks must be cleaned occasionally, dried, and resaturated before further use.

Grease systems are important components in all plants. Confusion sometimes arises about prelubricated bearings that have no provision for re-lubrication. These units are designed to operate over a specific period or life in equipment that does not experience extensive, heavy-duty operation.

Even when heavily sealed, commercial bearings require re-lubrication, although good seals prevent over-greasing and dust contamination. A bearing housing such as a pillow block should be filled only one-third to one-half full. More lubricant than this will be churned and will break down, causing the bearing to fail. If the housing has a bottom drain plug, excess grease can be forced out, as described under "Lubricants." A few housings are equipped with grease quantity regulators, which are overflow chambers for excess grease.

The grease that comes in a new bearing may last a year or two in light and medium service and at average temperature. Most bearings, however, should be cleaned of the old grease about once a year; new grease then should be worked by hand into the clean bearings. All grit and dust must be avoided. A convenient time for such an operation is during the annual maintenance shutdown of most plants.

Accurate records should be maintained for the lubrication intervals of the bearings on each machine. Remember that some bearings will require more frequent lubrication than others.

Troubleshooting

Table 2 provides bearing troubleshooting procedures that should be studied and discussed thoroughly.

TABLE 2. TROUBLESHOOTING OF ANTIFRICTION BEARINGS.

TROUBLE	CAUSE	CORRECTION
Bearing Overheated and/or Wears out too Quickly	(a) Wrong grease (b) Oil level low (c) Too little grease (d) Too much grease (e) Not enough internal bearing clearance (f) Bearing housing out of round or too small	(a) Use correct grease (b) Add oil (c) Add grease (d) Reduce amount (e) Replace with proper bearing (f) File housing to allow clearance or replace it

Table 2. Continued.

TROUBLE	CAUSE	CORRECTION
	(g) Seals with too much spring tension; worn seals	(g) Replace seals
	(h) Seals rubbing against parts	(h) Re-align
	(i) Load unbalanced	(i) Balance equipment
	(j) Shafts not aligned	(j) Align shafts
	(k) Dirt or other matter in bearing	(k) Clean bearing and housing; replace seals
	(l) Acid, water, or other matter in bearing	(l) Add cover or "flinger" that throws off matter
	(m) Shaft diameter too small	(m) Metalize and regrind shaft to fit
	(n) Adapter too loose or too tight	(n) Adjust adapter
	(o) Bearing damaged when "hammered" on shaft during installation	(o) Replace bearing
	(p) Oil level cup too high or too low	(p) Reposition cup or replace with sight gage
	(q) Bent shafts	(q) Straighten; add supports if necessary
	(r) Excessive load during equipment start-up	(r) Consider use of clutch on motor to reduce startup load (and to conserve electrical power)
	(s) Misalignment of two or more coupled shafts with bearings	(s) Shim pillow blocks
	(t) Irregular shaft surface	(t) Metalize shaft
Excessive Vibration	(a) Any of the causes of wear already discussed	(a) Same as for corrections already discussed

Table 2. Continued.

TROUBLE	CAUSE	CORRECTION
	(b) Chips, dirt, etc., left in bearing when installed	(b) Clean bearing and housing; use new lubricant
	(c) Flat spots on roller or ball from fast starting	(c) Replace bearing; if necessary, use clutch on motor to reduce starting speed or reduce motor speed (if possible)
	(d) Machine vibration	(d) Balance machine
	(e) Excessive internal bearing clearance	(e) Replace with proper bearing
	(f) Wrong type of bearing	(f) Try spherical roller bearings
	(g) No coupling or one of wrong type	(g) Use vibration coupling

Selection of Antifriction Bearing

The selection of the proper bearings for a given application can be accomplished by reference to manufacturers' catalogs. Such data as seal information, load and capacities, applications, and lubrication for specific bearings is given in these catalogs.

EXERCISES

1. When should a shaft be metalized? Check one: (a)_____ when it is bent. (b)_____ when too long. (c) _____ when it contains surface irregularities.
2. Place a check beside each of the below bearings that can align itself automatically: (a) _____ spherical plain. (b) _____ self-aligning ball. (c) _____ spherical roller thrust. (d) _____ spherical roller.
3. What is the purpose of an expansion bearing? Check one: (a) _____ expands when heated. (b) _____ adjusts for linear shaft expansion. (c) _____ neither of these.

LABORATORY MATERIALS

Laboratory 1

1 – drive train assembly of auto, truck, or tractor (including rear axle, differential, and drive shaft).

1 – roll masking tape.

Rags, paper towels, or other material with which to clean grease from bearings.

Laboratory 2

1 – block of wood, 6" x 6" x 12".

1 – wood screw.

1 – plastic bucket.

1 lb of sand.

1 – lab scale or postage scale.

String.

Light oil.

6 – round plastic rollers, 1/4" dia. x 8" in length.

LABORATORY PROCEDURES

LABORATORY 1. BEARING IDENTIFICATION

1. Disassemble drive train assembly (rear axle, differential, and drive shaft). Place all parts, especially the bearings, on a clean surface.
2. Clean all bearings of external grease. Attach a piece of masking tape to each bearing and on the tape label each bearing with a different number.
3. List each bearing by number in Data Table 1. Beside each bearing listed, describe its type and the method used to lubricate it.
4. Discuss why each type was used and why other types were not used instead.

LABORATORY 2. BEARING LUBRICATION

1. Set up experiment as illustrated in Figure 14a.
2. With the wood block resting on dry table (Figure 14a), slowly pour sand into the pail to which block is attached by string, until block moves to edge of table. Weigh sand in bucket and record weight in Data Table 2.
3. Repeat Step 2, except place light oil slick on table under block (Figure 14b). Record sand weight required to move block.
4. Repeat Step 2 again, except place plastic rollers under cleaned block (Figure 14c). Record sand weight required to move block.

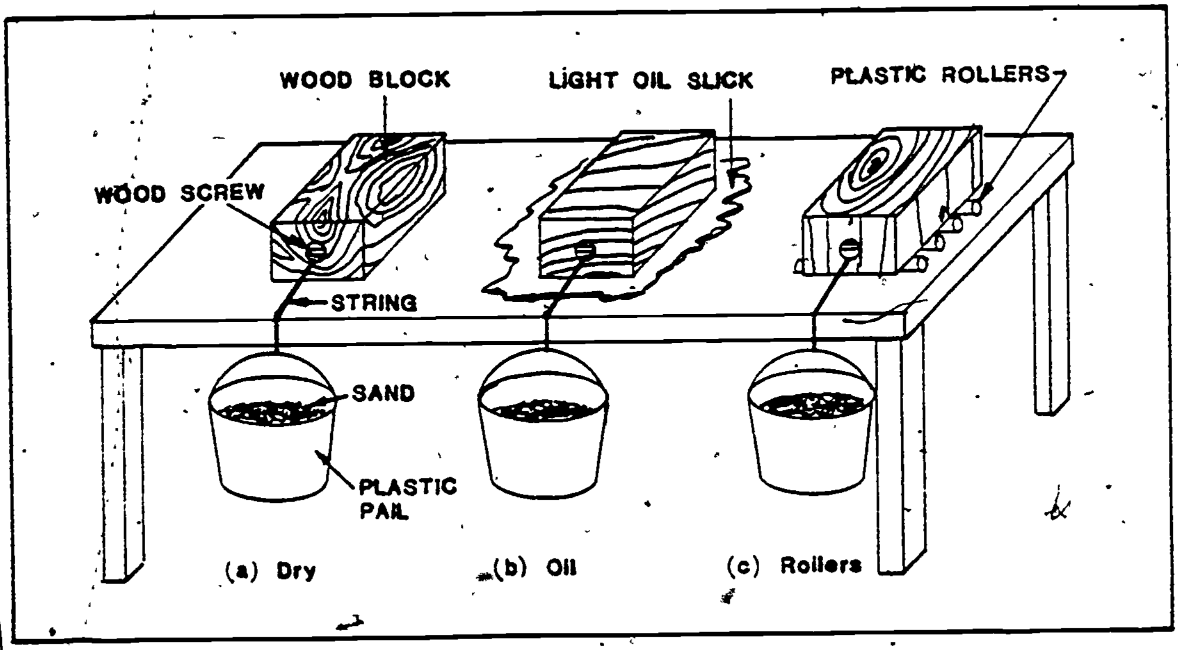


Figure 14. Sliding and Rolling Friction.

5. In which of the three tests did the block experience little or no relative motion between it and the table top?

DATA TABLES

DATA TABLE 1: BEARING IDENTIFICATION.

Bearing No.	Type	Location	Lubrication

Data Table 1. Continued.

Bearing No.	Type	Location	Lubrication

DATA TABLE 2: SLIDING AND ROLLING FRICTION.

WEIGHT OF SAND IN PAILS		
Dry Table	Oiled Table	Use of Rollers

REFERENCES

Bearing Technical Journal. 3rd ed. Indianapolis: FMC Corporation, Bearing Division, 1977.

Elonka, Stephen Michael. Standard Plant Operators' Manual. 2nd ed. New York: McGraw-Hill Book Company, 1975.

Fafnir Bearings: Ball Bearings, Power Transmission Units. Service Catalog No. 21. 3rd ed. New Britain, CT: Fafnir Bearing Division of Textron, Inc., 1966.

Nelson, Carl A. Millwrights and Mechanics Guide. 2nd ed. Indianapolis: Theodore Audel & Co., 1972.

SKF Industries, Inc., Advertising Department. Bearing Failures and Their Causes. Form 310M 10M-8-78 GP. New York: SKF Industries, Inc., 1978.

Timken Engineering Journal. (No city given): The Timken Company, 1972.

Torrington Bearings. Catalog 478. Torrington, CT: The Torrington Company, 1977.

1. Define the following terms:
   a. Shaft.

   b. Bossed shaft.

   c. Metalizing.

   d. Shaft expansion.

   e. Shaft alignment.

   f. Keyway and keyseat.

   g. Shaft key. (List seven types.)

2. Explain the uses of plain bearings; include the below types:
   a. Journal.
   b. Stave.
   c. Solid.
   d. Split (used with shim).
   e. Thrust.
   f. Flanged thrust.
   g. Grooved split.
   h. Spherical plain.

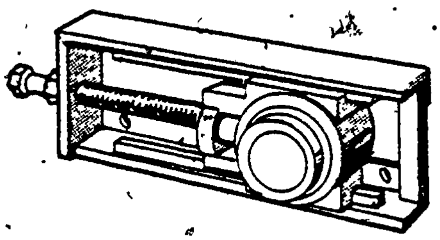
3. Name and describe the two types of friction and which is experienced by plain and antifriction bearings.

4. Match the following terms and definitions for antifriction bearings:

________	Radial.	A.	Bearings containing these features: spherical rollers or balls on spherical races.
________	Thrust.	B.	Bears thrust and radial loads.
________	Combination.	C.	Allows for axial shaft displacement.
________	Expansion.	D.	Bears loads applied at right angles to the shaft.
________	Roller.	E.	Bears loads applied at sides of bearing.
________	Self-aligning bearings.		

5. Label the bearing mounts illustrated, and discuss the purpose of each:

____



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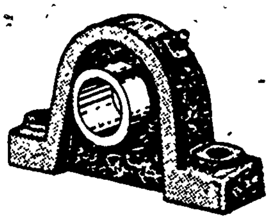

____

6. Antifriction bearings can be damaged in a variety of ways. For each of the causes listed, describe how damage can result and how it can be prevented.

   a. Faulty installation.

   b. Vibration.

   c. Electrical current.

7. What are the advantages of oil lubrication and of grease lubrication?

8. Where should couplings and pulleys be located? Check one: (a) _____ near the center of the shaft; (b) _____ near the end of the shaft; or (c) _____ near bearings.

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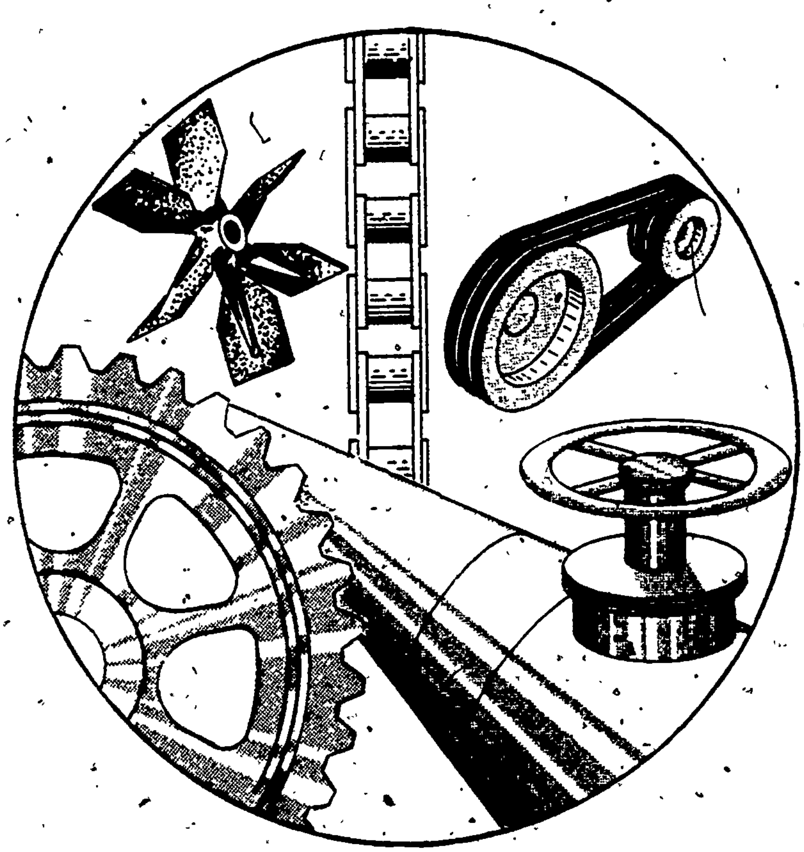

MODULE MS-05

DRIVE TRAIN COMPONENTS II

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

This module analyzes the following drive train components: (1) seals, (2) couplings, and (3) clutches. These components are important, not only for the proper operation of equipment, but also for its protection. Seals, for example, retain vital lubricants and other fluids; flexible couplings protect equipment from vibration and limited misalignment; and clutches protect against the great stresses placed upon heavy industrial equipment when suddenly turned on or when a heavy load is placed abruptly upon it. Some clutches reduce motor power consumption and wear of drive components.

PREREQUISITES

One year of high school algebra.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe, with the aid of appropriate sketches, how a gasket seals.
2. List and describe the four types of gasket joints. (Use sketches whenever possible.)
3. Describe at least four types of non-metallic and metallic gasket materials and two types of combination gasket materials.
4. Select a gasket from a given table to suit a particular temperature and fluid application.
5. Describe, with the aid of sketches, how an O-Ring seals; and list four types of O-Ring materials.

6. List at least three types of packing that can be used on a dynamic seal.
7. Describe a mechanical seal, and list two different types.
8. Describe, sketch, and list the design characteristics of three types of rigid couplings and six types of flexible couplings.
9. Describe four types of clutches, and list their design characteristics.
10. Explain how a "dry-fluid" clutch saves energy and protects equipment.

SEALS

A seal is a device used to control the movement of fluids or gases through a joint or opening. The wide range of operating conditions and the numerous assembly problems of modern machines have necessitated many varieties of seals. Seals may be classified into one of two general categories: Static or dynamic. The static seal provides a seal between two stationary surfaces and the dynamic seal between moving surfaces.

STATIC SEALS - GASKETS AND O-RINGS

A gasket is a static seal constructed of such materials as rubber, asbestos and metal. A gasket (Figure 1) is designed to provide a pressure-tight seal between two mating surfaces. The soft gasket material is placed between the hard flanges of the gasket joint and deforms and fills the joint when pressure is applied to the surfaces. Pressure applied to squeeze the gasket must exceed the pressure on the gasket, or the fluid will escape (Figure 1b).

There are four general types of gasket joints:

- Contained gasket joint.
- Gasket between flat faces.
- Partially contained gasket.
- Self loading gasket.

The contained gasket joint (Figure 2) is the most suitable joint for high-pressure applications. The gasket is contained in a groove and pressure is applied when the flange joints are tightened. The gasket cannot be blown out by high-pressure fluids.

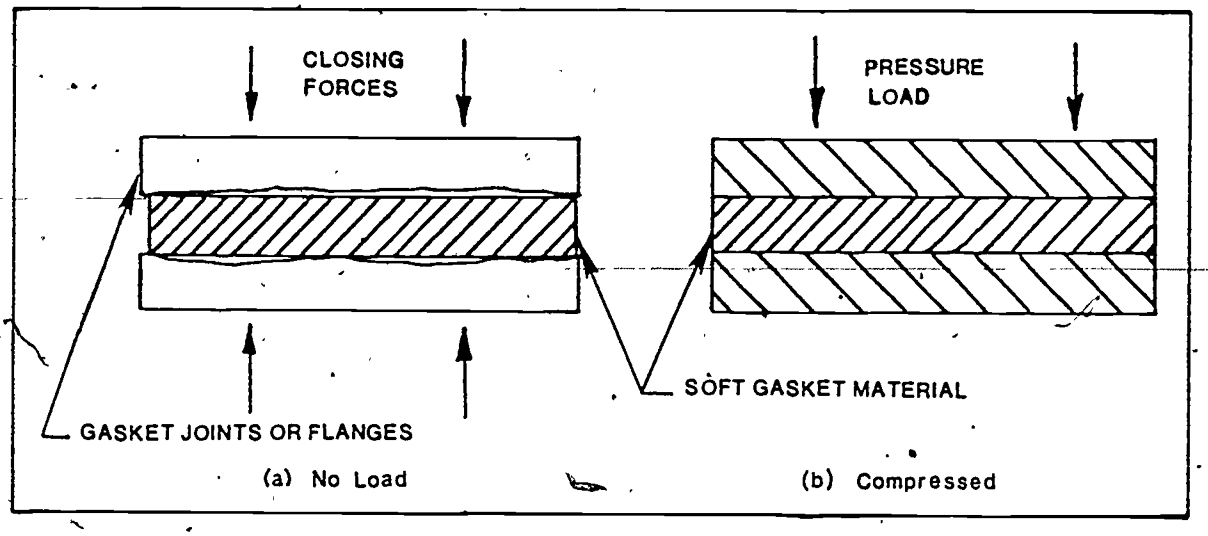

Figure 1. Gasket Operation.

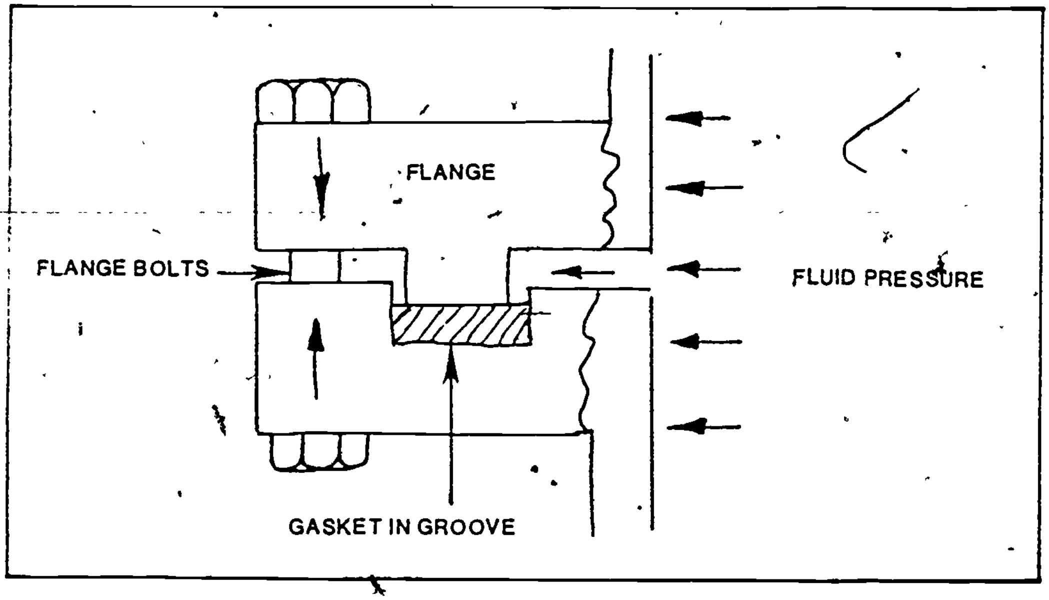

Figure 2. Contained Gasket Joint.

Figure 3 shows the gasket joint between flat surfaces. The gasket is not contained in a groove, but is squeezed between two flat flange faces. The gasket can be blown if the bolts are not tight. Some gasket manufacturers provide metallic inserts to secure the gasket and to prevent it from being blown.

The partially-contained gasket joint (Figure 4) is intended to provide the advantages of the first two gasket joints. It is confined in a groove on its outer edge.

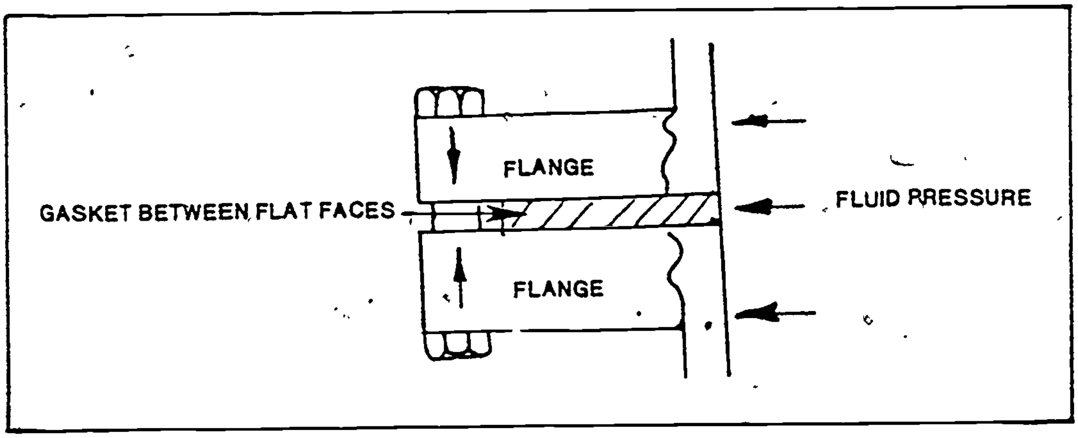

Figure 3. Gasket Between Flat Faces.

The self-loading gasket joint (Figure 5) is used extensively in the power, oil, and gas industries for handhole and manhole closures. The gasket is sealed by the internal pressure of the fluid on the cover. The bolt is utilized to tighten the gasket during increase in vessel pressure.

When a gasket is selected for a particular application, the type of service it must provide and the conditions it must withstand must be considered. Table 1 is a typical gasket selection chart. Gaskets are manufactured to meet American Standards Association specifications.

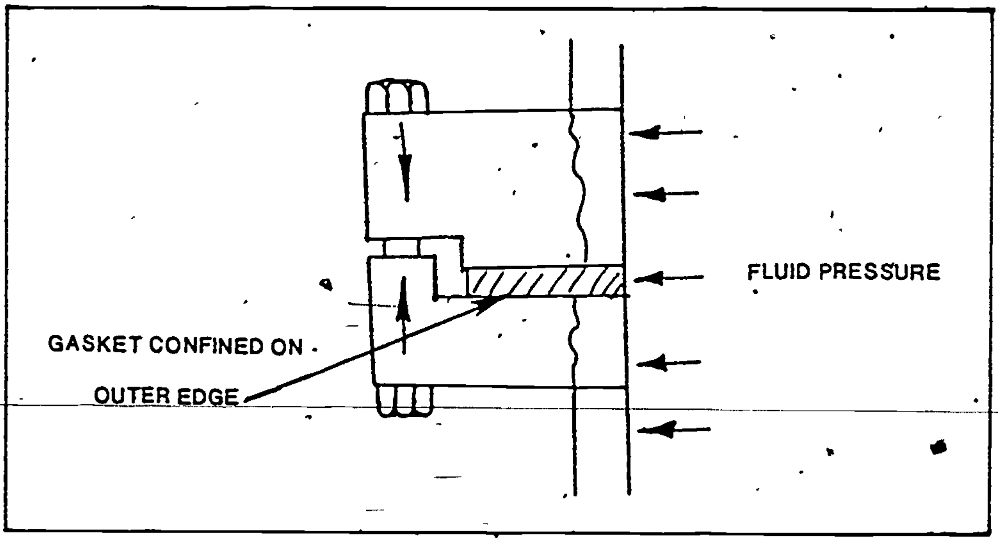

Figure 4. Partially Contained Gasket.

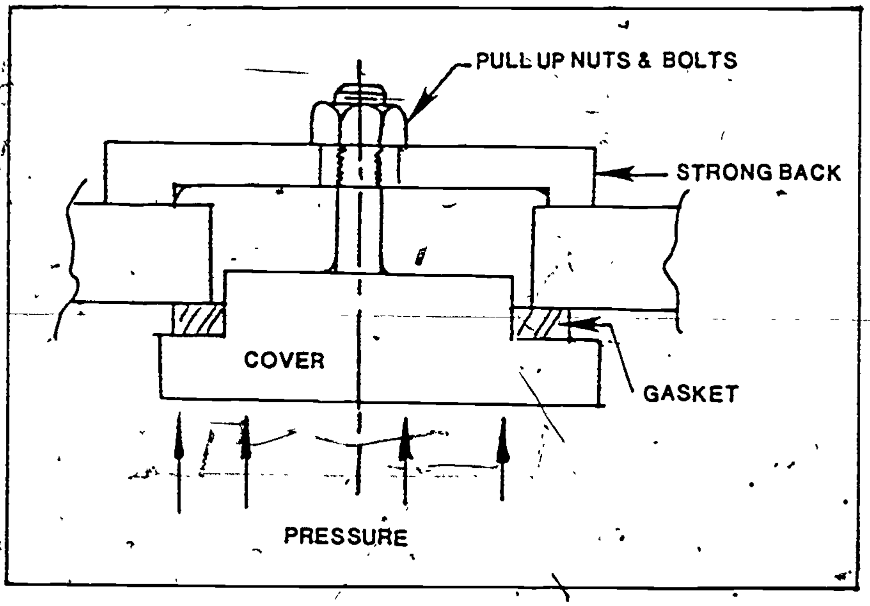

Figure 5. Self-loading Gasket Joint.

TABLE 1. GASKET MATERIALS FOR DIFFERENT SERVICES.

Fluid	Application	Gasket Material
Steam (high pressure)......	Temp up to 1000°F	Spiral-wound comp. asbestos
	Temp up to 1000°F	Steel, corrugated or plain
	Temp up to 1000°F	Monel, corrugated or plain
	Temp up to 1000°F	Hydrogen-annealed iron
	Temp up to 1000°F	Stainless steel 12 to 14% chromium, corrugated
	Temp up to 1000°F	Ingot iron, special ring-type joint
	Temp up to 750°F	Comp. asbestos, spiral-wound
	Temp up to 600°F	Woven asbestos, metal asbestos
	Temp up to 600°F	Copper, corrugated or plain
Steam (low pressure)......	Temp up to 220°F	Red rubber, wire inserted
Water.....................	Hot, medium, and high pressures	Black rubber; red rubber, wire inserted
	Hot, low pressures	Brown rubber, cloth inserted
	Hot	Comp. asbestos
Water.....................	Cold	Red rubber, wire inserted
	Cold	Black rubber
	Cold	Soft rubber
	Cold	Asbestos
	Cold	Brown rubber, cloth inserted
Oils (hot)................	Temp up to 750°F	Comp. asbestos
	Temp up to 1000°F	Ingot iron, special ring-type joint
Oils (cold)...............	Temp up to 212°F	Cork-fiber
	Temp up to 300°F	Neoprene comp. asbestos
Air.......................	Temp up to 750°F	Comp. asbestos
	Temp up to 220°F	Red rubber
	Temp up to 1000°F	Spiral-wound comp. asbestos
Gas.......................	Temp up to 1000°F	Asbestos, metallic
	Temp up to 750°F	Comp. asbestos
	Temp up to 600°F	Woven asbestos
	Temp up to 220°F	Red rubber
Acids.....................	(Varies, see section on corrosion)	Sheet lead or alloy steel
	Hot or cold mineral acids	Comp. blue asbestos
		Woven blue asbestos
Ammonia...................	Temp up to 1000°F	Asbestos, metallic
	Temp up to 700°F	Comp. asbestos
	Weak solutions	Red rubber
	Hot	Thin asbestos
	Cold	Sheet lead

Gaskets are made from non-metallic materials, metallic materials, or from combinations of both.

Non-metallic gaskets usually are made from oiled paper, cork, asbestos, rubber, or neoprene and are used on relatively smooth surfaces at low pressures and temperatures.

Metallic gaskets are made from copper, aluminum, or corrugated steel and are used at high pressures and temperatures.

A combination of both metallic and non-metallic materials creates a better seal. The metal in the gasket withstands the pressure of the fluid, and the soft non-metallic material wedges into the groove to provide a pressure-tight seal.

The O-Ring (Figure 6) is a squeeze-type static seal. When the ring is squeezed mechanically, the surfaces deform to fill the groove and to provide a tight seal. Pressure from confined fluid also can develop a seal (Figures 7 and 8).

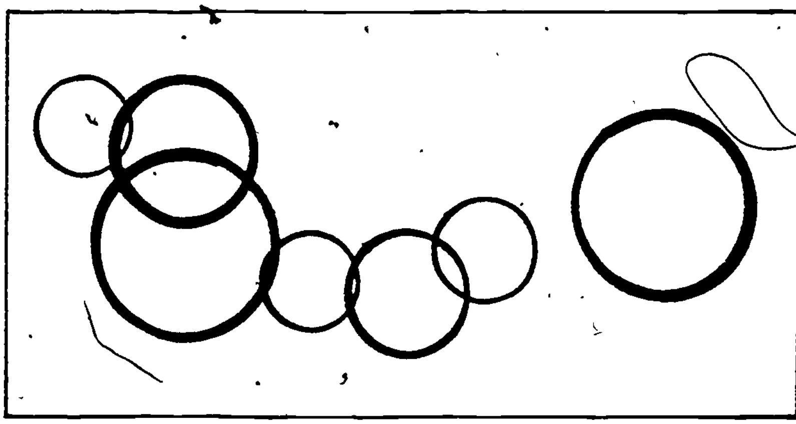

Figure 6. Types of O-rigns.

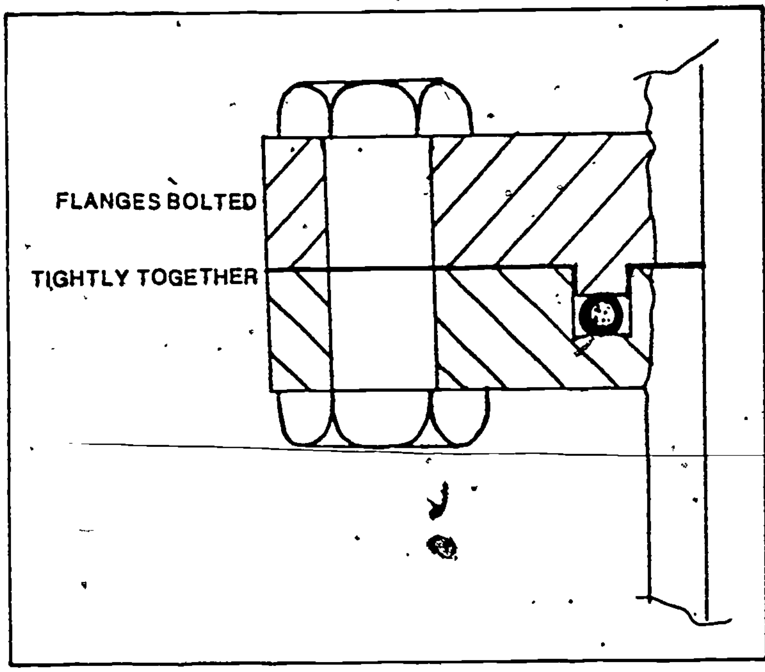

Figure 7. O-Ring in Groove.

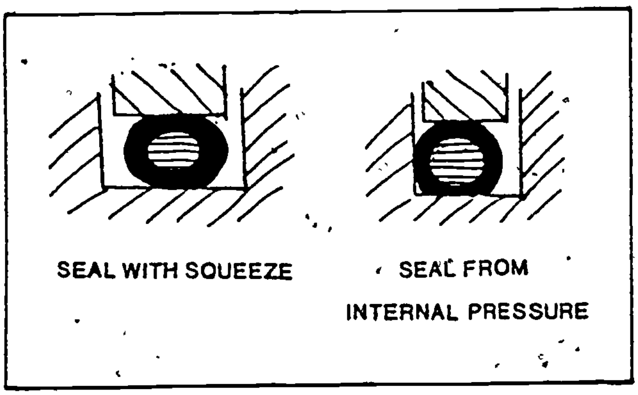

Figure 8. Typical O-Ring Installation.

O-Rings can be molded into a variety of materials. Corrosion-resistant materials such as fluoroelastomers, teflon, Buna-N, and neoprene often are used, although the most common material is rubber. Materials must be suited to the specific application. Table 2 lists some standard commercial materials and the temperatures and applications to which they are suited.

TABLE 2. O-RING MATERIALS AND APPLICATIONS.

POLYMER TYPE	TEMPERATURE RANGE	APPLICATION GUIDE
Buna-N (Nitrile)	-40°F to +275°F -40°C to +135°C	Mineral Oil and Hydraulic Fluids, Water, and Air.
Buna-N (Nitrile)	-40°F to +275°F -40°C to +135°C	Mineral Oil and Hydraulic Fluids, Water, Air, L.P., and Natural Gas. L.P. recognized.
Buna-N (Nitrile)	-22°F to +275°F -30°C to +120°C	Gear Oils S.A.E. 10 to 120, Ester-based Lubricants, Kerosene, and Gasolene.
Buna-N (Nitrile)	-40°F to +275°F -40°C to +135°C	Mineral Oil and Hydraulic Fluids, Water, and Air.
Buna-N (Nitrile)	-40°F to +275°F -40°C to +135°C	Mineral Oil and Hydraulic Fluids, Water, and Air. High Pressures.
S.B.R.	-40°F to 212°F -40°C to 100°C	Castor Based and other Vegetable Oils.
S.B.R.	-40°F to 212°F -40°F to 100°C	Castor Based and other Vegetable Oils.
Noeprene	-22°F to +176°F -30°C to +80°C	Ozone, Oxidation, Weather Resistant.
Polyurethane	-22°F to +194°F -30°C to +90°C	High Abrasion Resistance.

DYNAMIC SEALS

Dynamic seals are employed to prevent the flow of fluid across a sliding or rotating joint. The gland packing seal (Figure 9) is the oldest and simplest type.

Packing, a leak-proof material, is placed around a shaft or rod in a packing chamber and held in place by a gland. As the pressure nut is tightened, the packing is compressed and forced against the sliding or rotating part, thus controlling leakage. Leakage through the packing material is prevented by the material itself and by a lubricant contained in the packing.

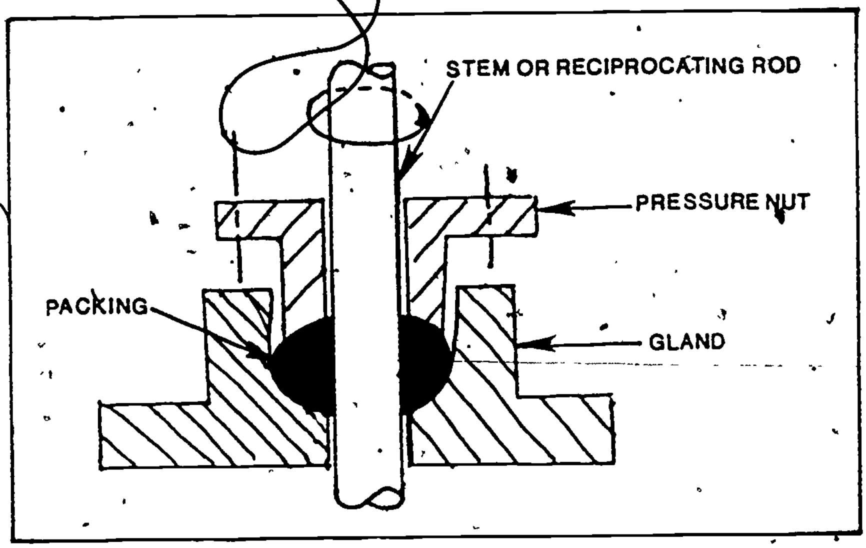

Figure 9. Gland Packing Seal.

Vee packing (Figure 10) is a variation of the gland seal that consists of formed or molded packing rings having a V-shaped cross section. This arrangement reduces the friction between the packing and the moveable element.

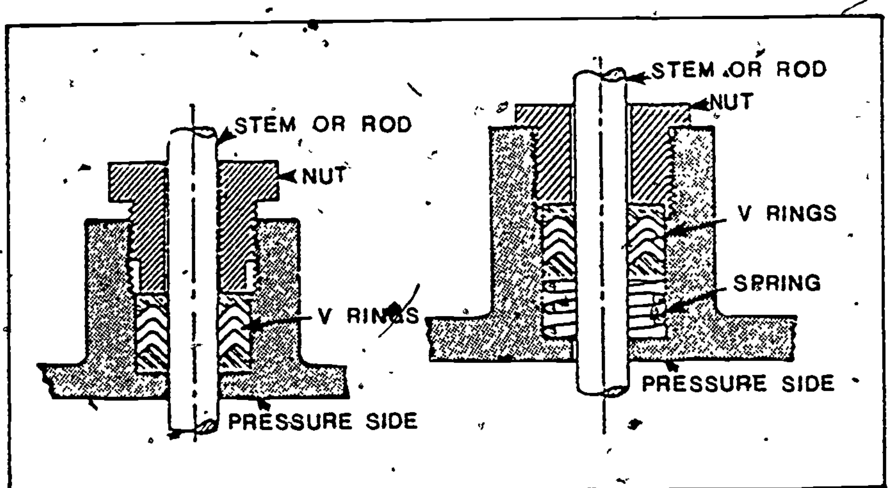

Figure 10. Vee Packing.

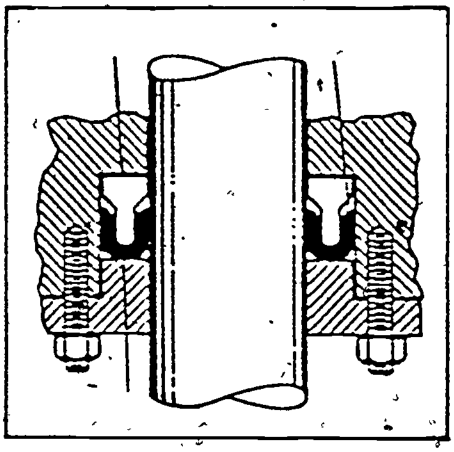

Figure 11. U-shaped Packing.

U-shaped packings also are used in gland sealing applications. Figure 11 illustrates a shaft or piston-rod seal that contains molded U-cups. The U-cup is fitted into a gland and is held in place by a cap or a retaining ring.

The labyrinth packing (Figure 12) is a special design for steam engines. The packing does not actually contact the shaft; rather, steam travels through a series of passages, or "labyrinths," which change the pressure and the flow. Steam then is forced against the small blades mounted on a stationary casing. The steam closes the gap between the blades, thereby reducing leakage.

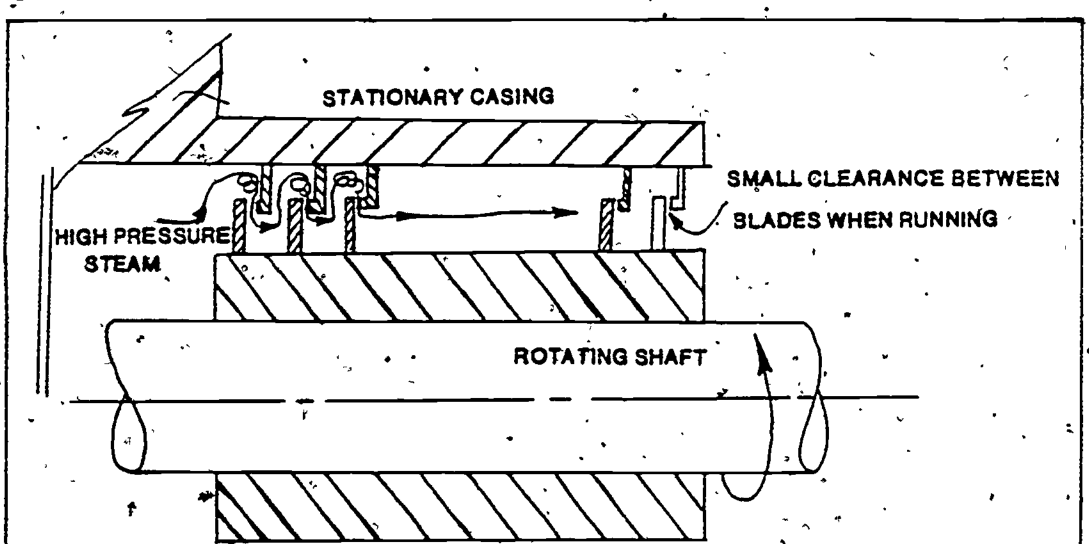

Figure 12. Labyrinth Packing.

MECHANICAL SEALS

Rotating or reciprocating shafts can be sealed by a mechanical seal placed between two flat surfaces (Figure 13). The design of most mechanical seals is much more sophisticated than that depicted in Figure 13, which is intended to illustrate principles, not details, of specific operations. Many types of sealing devices such as packing, O-Rings, and V-Rings, are installed between the two surfaces. The mechanical seal also incorporates a force provided by a spring-loading apparatus designed to hold the surfaces in contact.

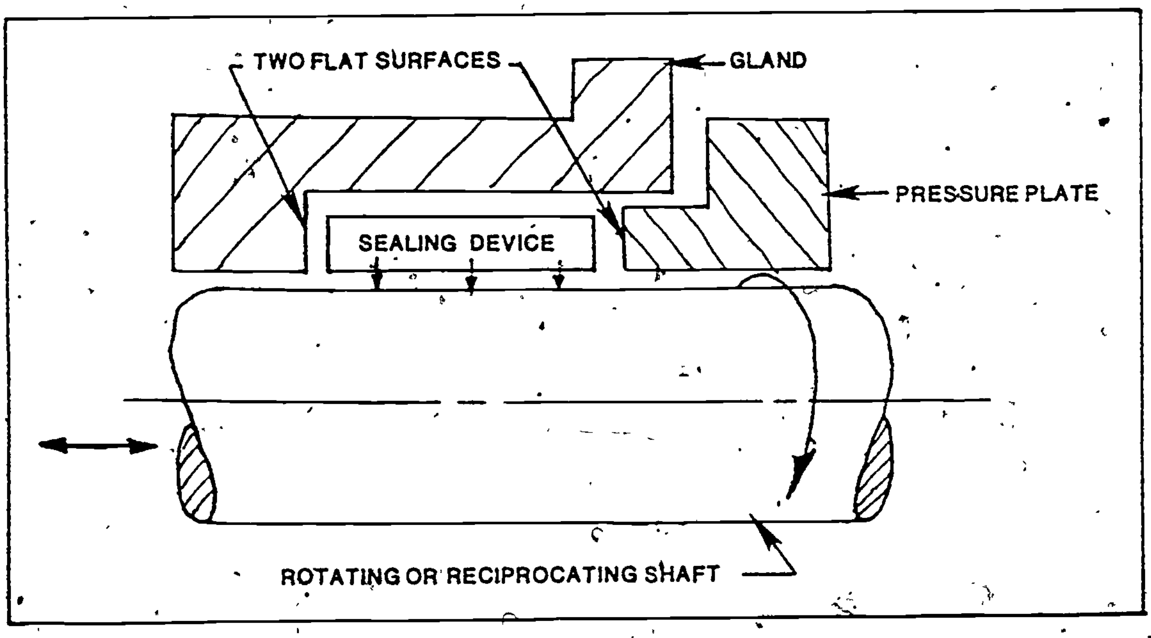

Figure 13. Mechanical Seal.

COUPLINGS

DEFINITIONS

A coupling is a device that connects two shafts end-to-end. The two general categories of couplings are (1) rigid and (2) flexible. Rigid couplings are used when accurate alignment of shafts is required; whereas, flexible couplings are designed to allow for a certain amount of misalignment.

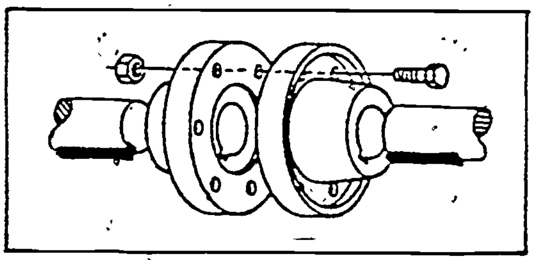

Figure 14. Flange Coupling.

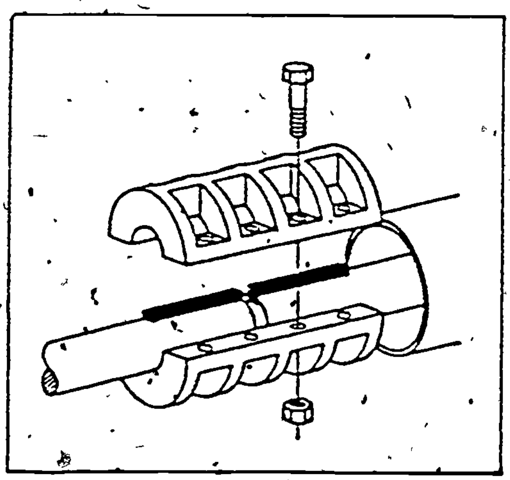

Figure 15: Split-type Muff Coupling.

RIGID COUPLINGS

Flange couplings (Figure 14) consists of two flanges bolted over the shaft and then keyed to the shaft. These couplings usually are designed to withstand severe service.

The clamp coupling (Figure 15) is split into two halves keyed to the shaft and bolted together. This coupling can be installed and removed with ease.

Some rigid couplings are self aligning. The compression coupling (Figure 16) is constructed of two split cones that can be adjusted by bolts. This arrangement allows the coupling to adjust to varying shaft sizes. The use of rigid couplings, however, has several disadvantages:

- Shafts must be aligned accurately.
- No allowance made for axial expansion of the shafts when the system heats up.
- Bolted surfaces must be at right angles to shaft axis, which means that they must be matched after they have been assembled to the shaft. Such a procedure is expensive.

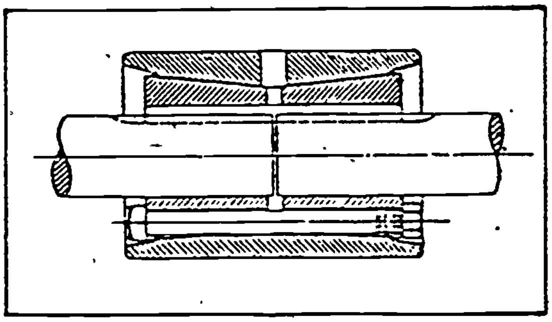

Figure 16. Compression Coupling.

FLEXIBLE COUPLINGS

Flexible couplings allow shafts to be slightly out of line (Figure 17a and b). Close alignment is required, however, when the shafts are turning at high speeds or when they are heavily loaded. Under these conditions, misalignment causes rapid coupling failure.

Couplings should be aligned angularly (Figure 17c) with a caliper. The gap between the coupling halves, or hubs, is checked at four points, and alignment is adjusted until the four measurements are equal. The hubs should be checked for parallel alignment with a straightedge (Figure 17d).

An alternate method of angular and parallel alignment involves the use of a dial indicator attached to one hub and a measuring feeler riding against the other as the hub

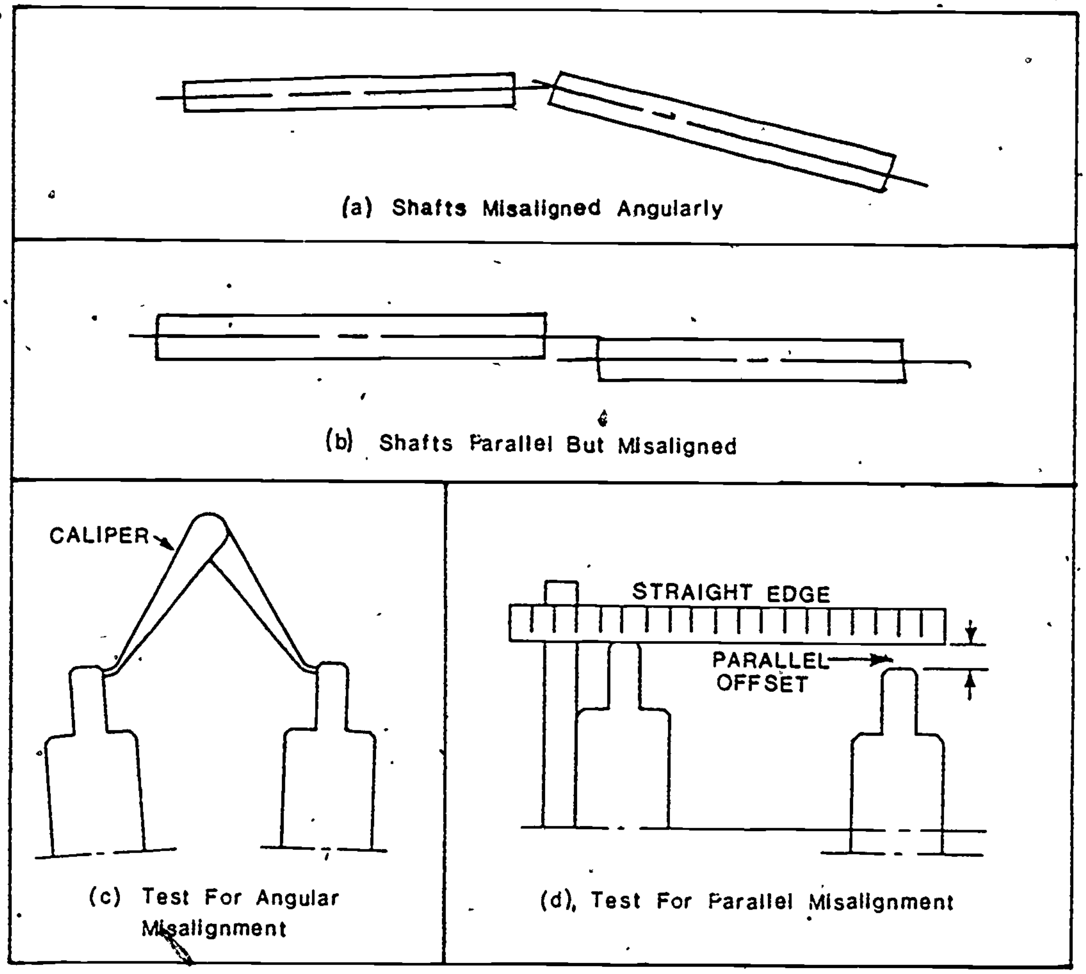

Figure 17. Shaft and Coupling Alignment.

is rotated by hand. The hubs are in parallel alignment when the measurements are equal at all points between them.

The jaw coupling permits longitudinal misalignment and allows for some vibration (Figure 18.) This coupling can be used as a clutch if some arrangement is made to withdraw and to engage one of the halves.

The floating-center coupling (Figure 19) is a variation of the jaw coupling designed to accommodate two shafts that have a slight axial shift. The floating center adjusts for the shift.

The teeth of the toothed coupling permit the shaft some movement in all directions (Figure 20).

An entire series of flexible couplings uses springs, diaphragms, rubber tubing, and tires to transmit the load and to permit axial movement (Figure 21).

The chain coupling (Figure 22) consists of two sprockets in parallel, coupled with a chain. This design is very rugged, but requires careful lubrication.

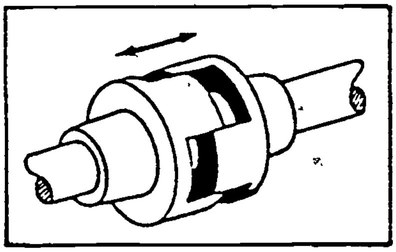

Figure 18. Jaw Coupling.

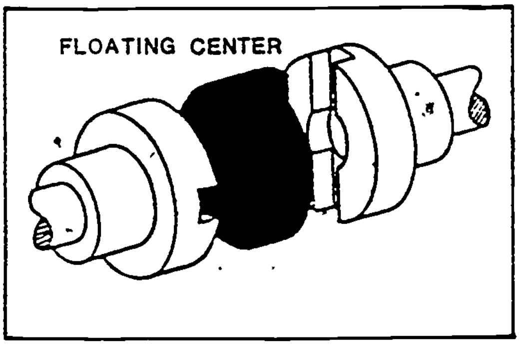

Figure 19. Floating-center Coupling.

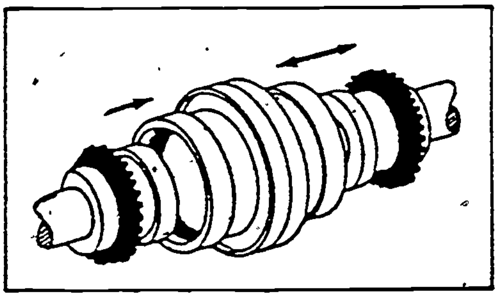

Figure 20. Toothed Coupling.

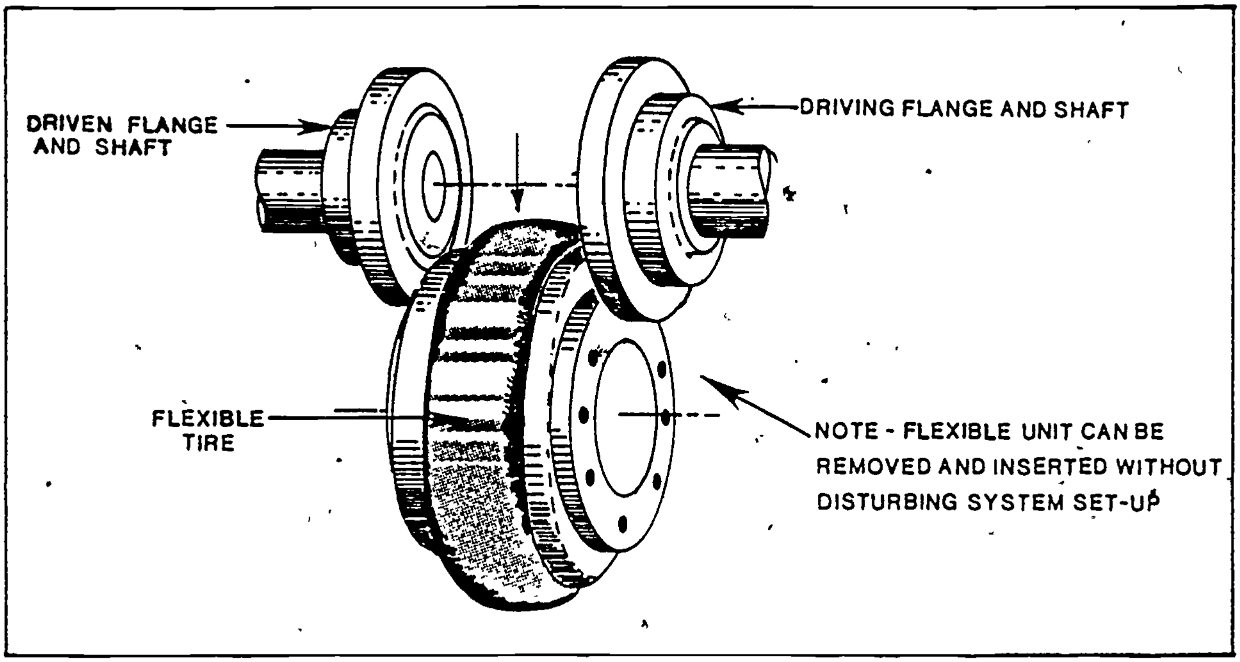

Figure 21. Flexible Tire Coupling.

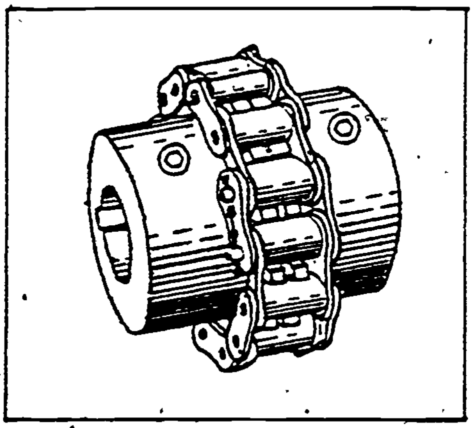

Figure 22. Chain Coupling.

UNIVERSAL JOINTS

The universal joints (Figure 23) allows power to be transmitted through larger angles than are permissible with flexible couplings. Such a joint connects two shafts set at an angle to one another, and the angle can be varied while the shafts are rotating. The most common U-joint is the "Hooke joint," sometimes called the "Cardan joint" illustrated in Figure 23.

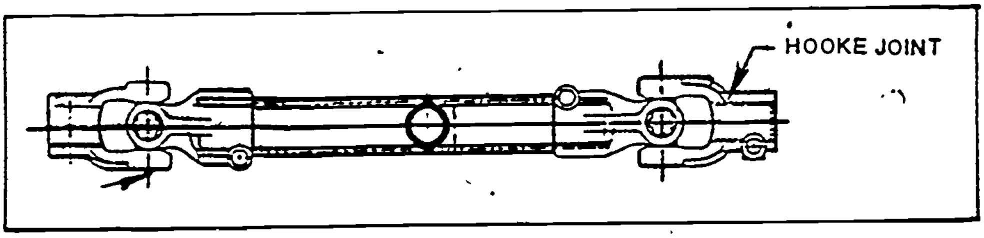

Figure 23. Universal Joint.

When a single Hooke joint is used, the working angle is kept below 15°, since larger angles cause significant variations in the angular velocity of the Driven shaft. This problem can be solved by use of a double Hooke joint (Figure 24). The two Hooke joints are connected by short, intermediate shafts mounted at the same angle (a) to ensure uniform speed.

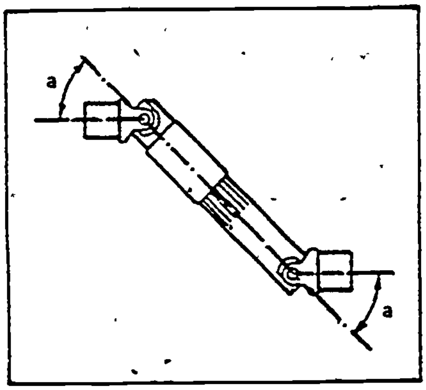

Figure 24. Double Hooke Joint.

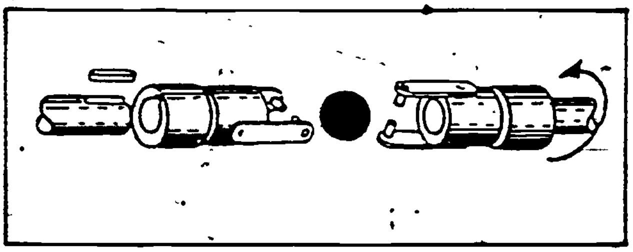

Figure 25. Ball Joint.

The ball joint (Figure 25) is a variation of the Hooke joint; a ball replaces the Hooke-joint yoke.

SELECTION OF COUPLINGS

Selection of economical couplings is similar to the selection procedures for other mechanical components:

- Obtain several manufacturers catalogs.
- Determine the service that the component must provide.
- Obtain service factor from manufacturer's table.
- Multiply service factor and horsepower of motor to obtain equivalent horsepower.
- Use charts in manufacturer's catalogs to determine most economic component.

The service factor should be carefully determined since a miscalculation could raise the initial cost of the system.

CLUTCHES

DEFINITIONS

A clutch is a type of coupling used to connect and to disconnect shafts and driving mechanisms. There are three general categories of clutches:

- Friction clutches.
- Jaw clutches.
- Hydraulic clutches.

FRICTION CLUTCHES

Friction clutches allow the driving force to be transmitted through frictional contact with the two halves. Figure 26 depicts a multiple-disc friction clutch. One set is fastened to one shaft and the other set is fastened to the other shaft. When pressure is applied, the plates are pressed together and transmit power by friction. Because of the multiple contact surfaces, this clutch increases the power-transmitting capacity of the shaft. Automobiles that have standard shifts contain friction clutches.

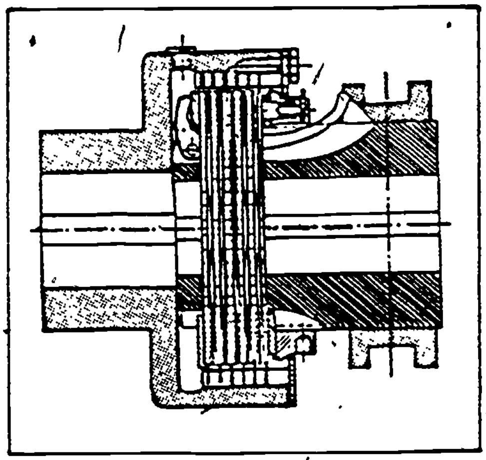

Figure 26. Multiple-disc Clutch.

MAGNETIC CLUTCHES

The magnetic clutch is a form of friction clutch in which the frictional surfaces are brought together by an electromagnet. Other common types of friction clutches are the cone clutch and the shoe clutch.

JAW CLUTCHES

Jaw clutches transmit power through the direct contact of two interlocking surfaces (Figure 27); they must be attached only to slow-moving shafts. The jaws or teeth of the two halves of the clutch interlock, permitting direct, positive power transmission. Figure 27 illustrates two types of jaw clutches — (a) the claw clutch and (b) the geared clutch.

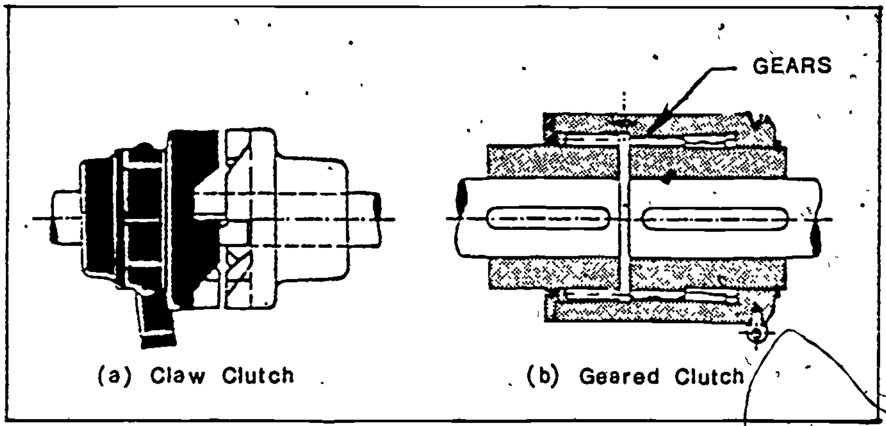

Figure 27. Two Types of Jaw Clutches.

DRY FLUID CLUTCHES

The Dodge FLEXIDYNE® clutch illustrated in Figure 28 is referred to as a "dry fluid drive" because the "fluid" it contains is steel shot. A measured amount of this shot is placed inside the housing, where it is thrown by centrifugal force to the perimeter of the housing and into contact with the blade rotors when the motor is turned on and when its shaft rotates. The housing is attached to the motor shaft, and the rotor assembly is connected to the pulley.

After the starting period, in which there is slippage between housing and rotor, the two lock together to achieve full load speed and efficiency.

Energy is saved and equipment protected by such clutches in the following ways:

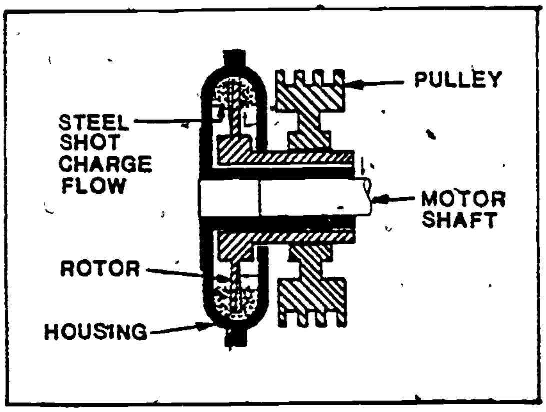

Figure 28. Dry Fluid Clutch.

- Smaller motors can be used because the initial shock load is reduced and because less starting current is required. Power savings can be as much as 35%.
- Smoother starts prevent breakage and reduce maintenance on motors, gears, bearings, and belts or chains.
- Motor overheating during start-up is eliminated.
- If the drive system jams, as sometimes happens, the clutch acts as a torque-limiting device by slipping under excessive load to prevent damage. The amount of shot added to the housing can be changed to adjust the clutch for slippage at a particular torque.

HYDRAULIC CLUTCHES

The operation of the hydraulic clutch (Figure 29) is made possible by hydraulic fluid in contact with impellers and runners enclosed in a housing. The impeller is connected to the Driver shaft; the runner, to the Driven shaft. The

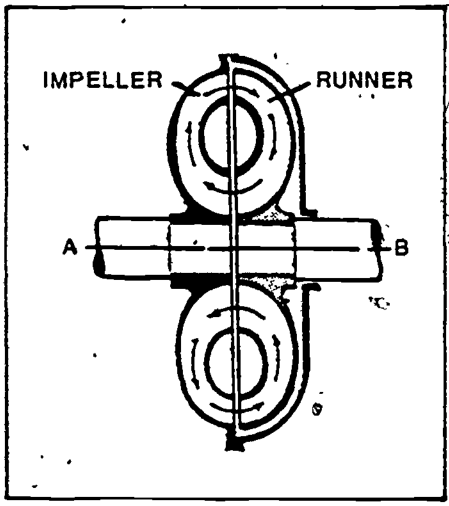

Figure 29. Hydraulic Clutch.

globe-shaped portions of both impeller and runner are filled with hydraulic fluid. Each of these sections also contains blades or vanes. As the impeller rotates, the runner follows: The radial blades of the impeller set the liquid in motion and throw it against similar blades in the runner. This "drag" causes the runner to rotate with the impeller.

The principle of the hydraulic clutch is utilized in several other similar devices such as hydraulic couplings, torque-convertors, and variable-speed drives. The hydraulic fluid tends to minimize shock and vibration.

EXERCISES

1. List the type of gasket material used for the fluids and temperatures given in the table below.

TEMPERATURE	FLUID	GASKET MATERIAL SELECTED
750°F	High-pressure steam	
200°F	Low-pressure steam	
212°F	Hot water	
750°F	1000°F Ammonia	
850°F	Gas	
950°F	Air	
150°F	Oil	

2. List the application for the O-Rings described in the table below.

TYPE	TEMPERATURE RANGE	APPLICATION
Buna-N	-22°F to +275°F -30°C to 120°C	
Polyurethene	-30°C to +194°C	
Silicone	-76°F to +392°F	

LABORATORY MATERIALS

1 - Auto, truck, or tractor drive train assembly with covers, caps, and housings removed. (This system can be the same one used in Module MS-04, "Drive Train Components 1," except that here a clutch is required.)

Any three couplings from among those illustrated in Figures 14 through 25.

LABORATORY PROCEDURES

1. Remove all caps, covers, and housings from drive transmission system.
2. Complete Data Tables 1, 2, and 3 by describing the type of seals, couplings, and clutches used, together with their location and type.
3. Examine the three shaft couplings, and describe type and identify major parts. Complete Data Table 4.

DATA TABLE 1

SEAL #	TYPE OF SEAL	LOCATION	COMMENTS

DATA TABLE 2

COUPLING #	COUPLING TYPE	LOCATION	COMMENTS

DATA TABLE 3

Type of Clutch:
Description of Action:

DATA TABLE 4

COUPLING NO.	COUPLING TYPE	LIST OF MAJOR PARTS
1		
2		
3		

REFERENCES

Carmichael, C.. Kent's Mechanical Engineers' Handbook. New York: John Wiley and Sons, 1975.

D78 Dodge Engineering Catalog. Mishawaka, IN: Dodge Division, Reliance Electric, 1977.

Elonka, Stephen Michael. Standard Plant Operators' Manual. 2nd ed. New York: McGraw-Hill Book Company, 1975.

Miscellaneous Suppliers Handbooks and Data Brochures.

Nelson, Carl A. Millwrights' and Mechanics Guide. 2nd ed. Indianapolis: Theodore Audel & Co., 1972.

Norman, C.; Ault, E.; and Zarobasky, I. Fundamentals of Machine Design. New York: The MacMillan Company, latest edition.

The Way Things Work. Vol. 2. New York: Simon and Schuster, 1971.

1. Describe, with the aid of appropriate sketches, how a gasket seals.

2. List and describe the four types of gasket joints. (Use sketches whenever possible.)

3. Describe at least four types of non-metallic and metallic gasket materials and two types of combination gasket materials.

4. Use Table 1 to select the proper gasket material to be used in a system containing oil that reaches a temperature of 970°F.

5. Describe, with the aid of sketches, how an O-Ring seals; and list four types of O-Ring materials.

6. List at least three types of packing that can be used on a dynamic seal.

7. Describe a mechanical seal, and list two different types.

8. Describe, sketch, and list the design characteristics of three types of rigid couplings and six types of flexible couplings.

9. Describe four types of clutches, and list their design characteristics.

10. Explain how a "dry-fluid" clutch saves energy and protects equipment.

ENERGY TECHNOLOGY

CONSERVATION AND USE

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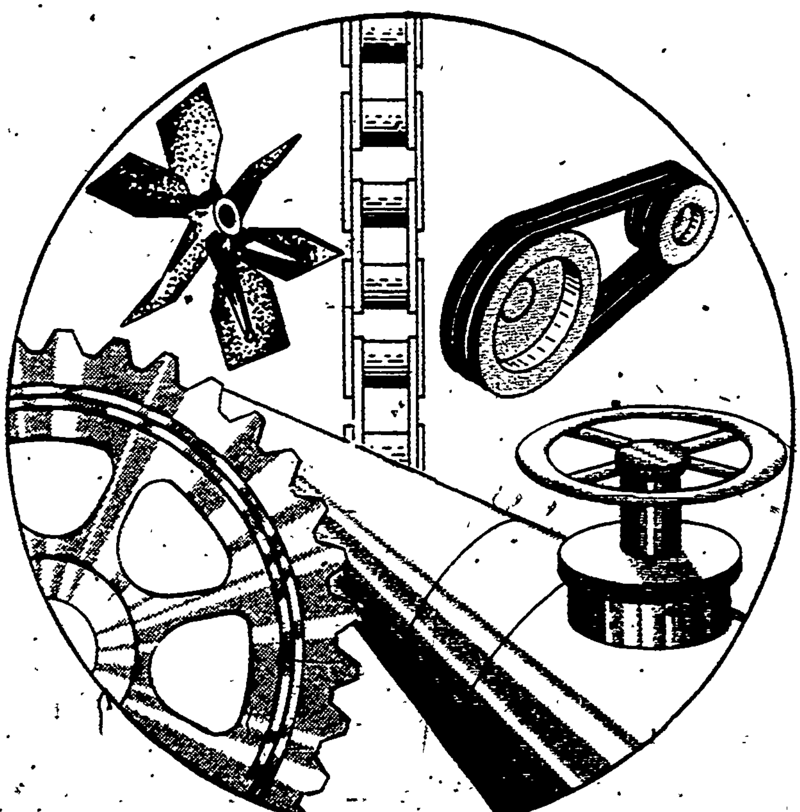
MECHANICAL DEVICES AND SYSTEMS



MODULE MS-06

LINKAGES

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

One of the earliest methods of changing the direction of force was the use of linkages and cams. The design of these devices has become so sophisticated that they have been called the "brains" of automatic machinery.

This module discusses the design, operation, types, and applications of modern linkages and cams. It provides enough information for the student to construct common linkages in the laboratory, to trace their input and output, and to understand their basic operation.

PREREQUISITES

The student should have completed one year of high school algebra.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Given sketches of each of the following types of linkage configurations, properly label and describe the movement of each:
   a. Crank and rocker.
   b. Drag link.
   c. Parallel.
   d. Transport.
   e. Double crank.
   f. Slider crank.

g. Sliding coupler.
h. Oscillating beam.
i. Scotch yoke.
j. Sliding crank and toggle linkage.

2. Describe the design characteristics which distinguish four-bar, slider crank, and toggle linkages.
3. Describe the design characteristics of disc, grooved disc, cylindrical, translational, and geneva cams.
4. List and describe the three major groups of cam followers.

189

LINKAGES

TERMS AND DEFINITIONS

Linkages are mechanical devices, frequently constructed of jointed links or bars used to transmit force from one point to another and to transform rotary motion into straight line motion. Figure 1 is a labeled drawing of a four-bar mechanism, a common type of linkage. The bottom link is

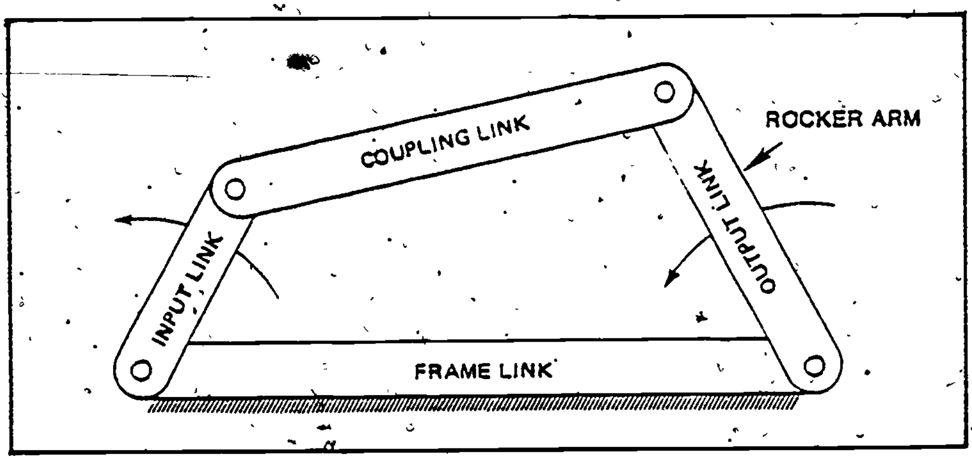


Figure 1. A Four-bar Mechanism.

stationary and constitutes the frame of the mechanism. The shorter link can rotate through 360° and is called the "crank," or "input link." The crank is connected to the lever, or "rocker arm," by the coupling link. When the crank is rotated, the coupling link transforms the rotary motion of the crank to the oscillating, back-and-forth motion of the rocker arm.

TYPES OF LINKAGES

Generally, linkages can be arranged into three major groups:

- Four-bar linkages.
- Sliding joint linkages.
- Toggle linkages.

Four-bar linkages have two fixed points and two moving joints. Common four-bar linkage configurations are the crank and rocker, drag link, parallel, transport, and double rocker linkages.

The crank and rocker (Figure 2) translates the circular motion of the crank into the oscillating motion of the rocker.

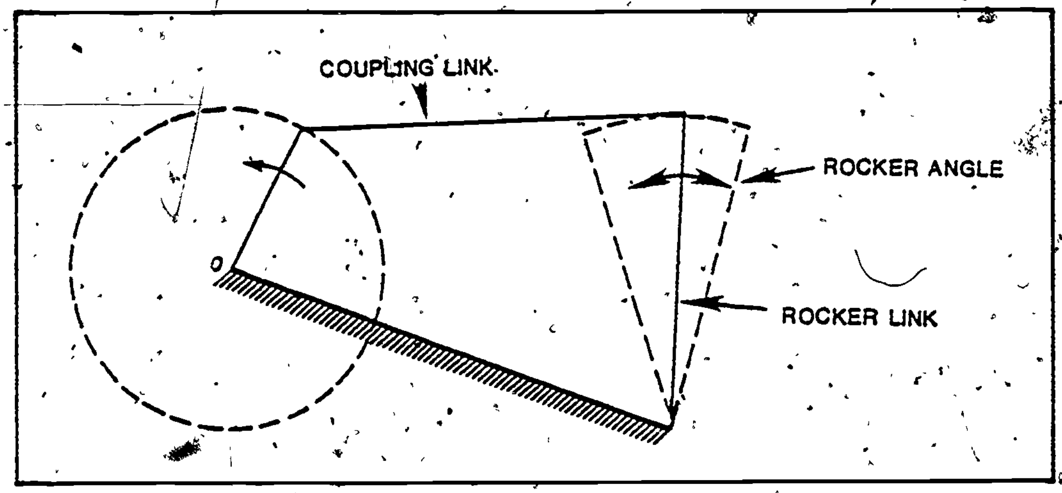


Figure 2. Crank and Rocker.

The drag link configuration (Figure 3) allows the rocker bar to make a complete revolution. This linkage was used on the driving wheels of steam locomotives.

The parallel crank linkage (Figure 4) is almost identical to the drag linkage, except that it utilizes an equal length crank and rocker, as well as a coupler bar equal in length to the distance between the fixed joints. Both crank and rocker make complete rotations.

The transport linkage converts rotary motion into regular, intermittent linear motion (Figure 5). This conversion is accomplished when the coupling link is extended beyond the rocker. When the crank is rotated, the rocker arm pulls the pointed end of the coupling link along path P.

The double rocker linkage is the simplest four-bar linkage: No crank is used and the bars simply rock from one position to another (Figure 6).

The sliding-joint configuration has one point that either slides along a line or allows the linkage bar to slide through it.

The sliding crank, a common sliding-joint configuration, employs a crank and a coupler to convert the rotation of the crank to a reciprocating linear movement

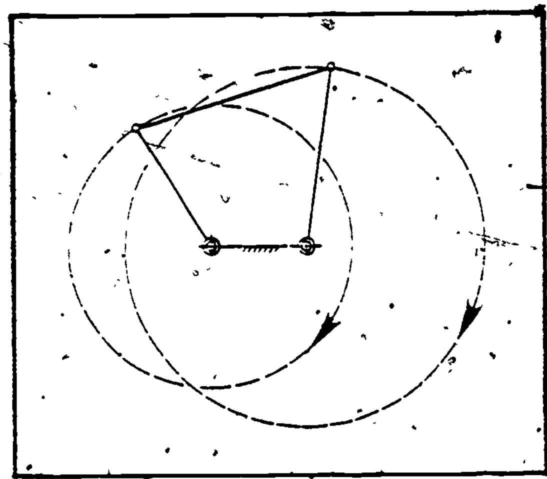


Figure 3. Drag Link.

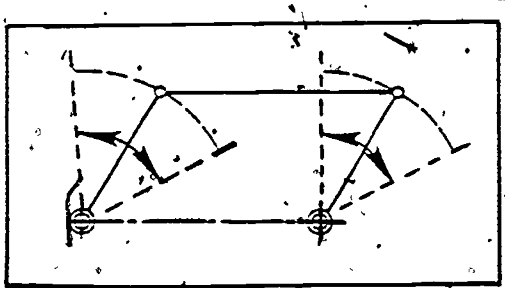


Figure 4. Parallel Crank.

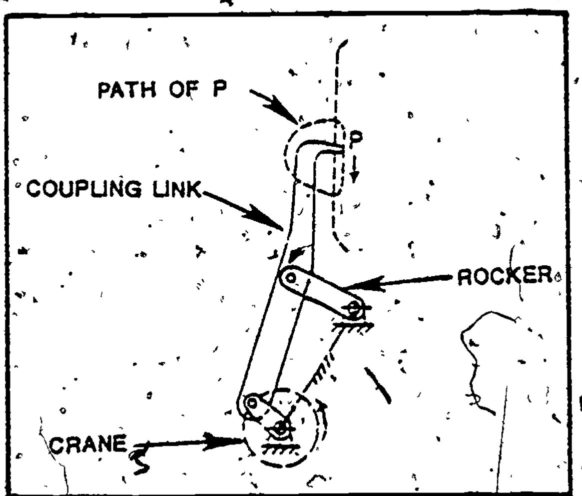


Figure 5. Transport Linkage.

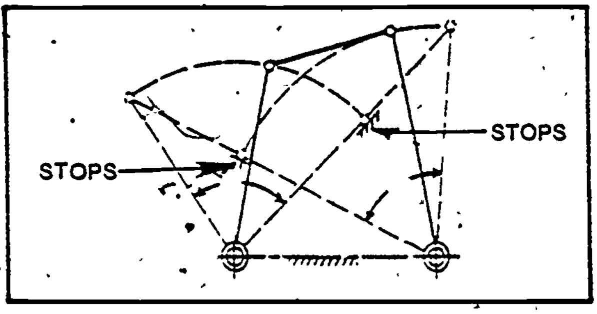


Figure 6. Double Rockers.

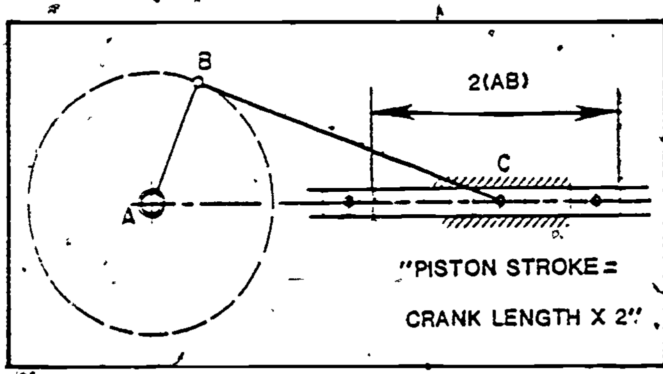


Figure 7. Slider Crank.

(point C in Figure 7), or to convert the linear movement of the connecting coupler to rotational movement. Piston pumps, compressors, contain this configuration. In these systems, "C" is the piston, "BC" the piston rod, and "AB" the crankshaft (Figures 7 and 8).

The sliding coupler allows the coupler itself to slide through a

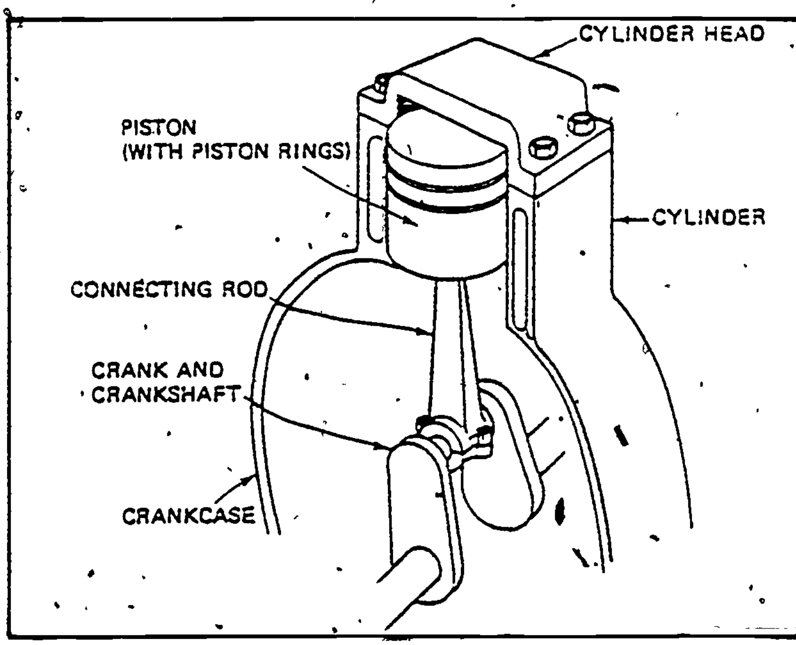


Figure 8. Piston, Piston Rod, and Crankshaft.

fixed pivot point; this action results in an oscillating movement (point C in Figure 9).

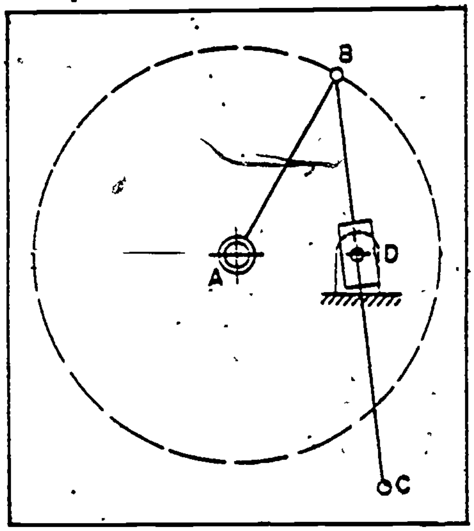


Figure 9. Sliding Coupler.

The oscillating beam linkage is a variation of the sliding coupler. The coupler is mounted on the crank; and as the crank turns, the coupler slides up and down the coupling link, causing the end of the link (point F in Figure 10) to oscillate.

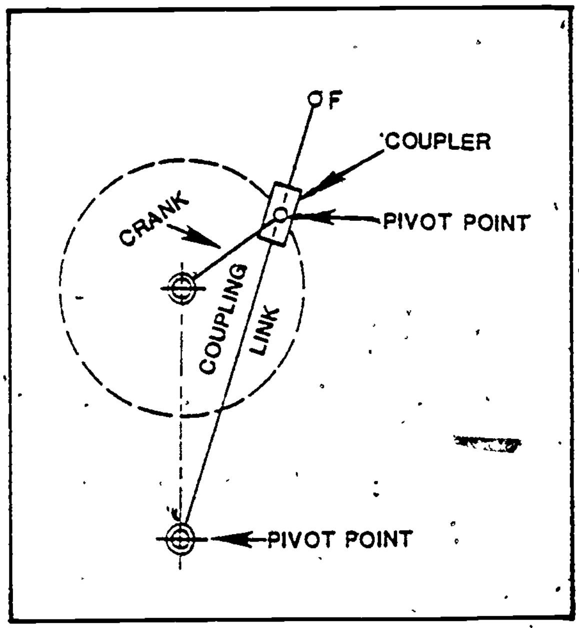


Figure 10. Oscillating Beam.

The scotch yoke can provide a regular linear movement in the guide-cage connector inserted into a yoke. Various movements can be created (Figure 11) if the shape of the yoke is changed as in Figure 11c.

The toggle linkage translates low-energy input into high-energy output. This linkage is composed of members joined together in such a manner that a small force at the joint produces large force at the ends. Figure 12 depicts some typical linkages of this type. When a force is applied at point B, it is transmitted and amplified when it arrives at point C. The arrows in the

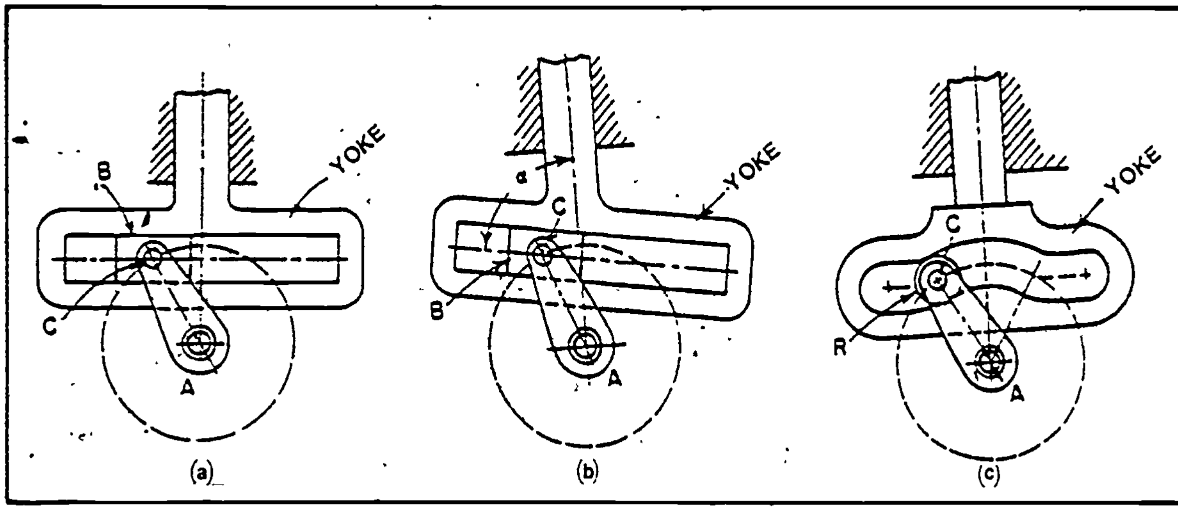


Figure 11. Scotch Yoke and Variations.

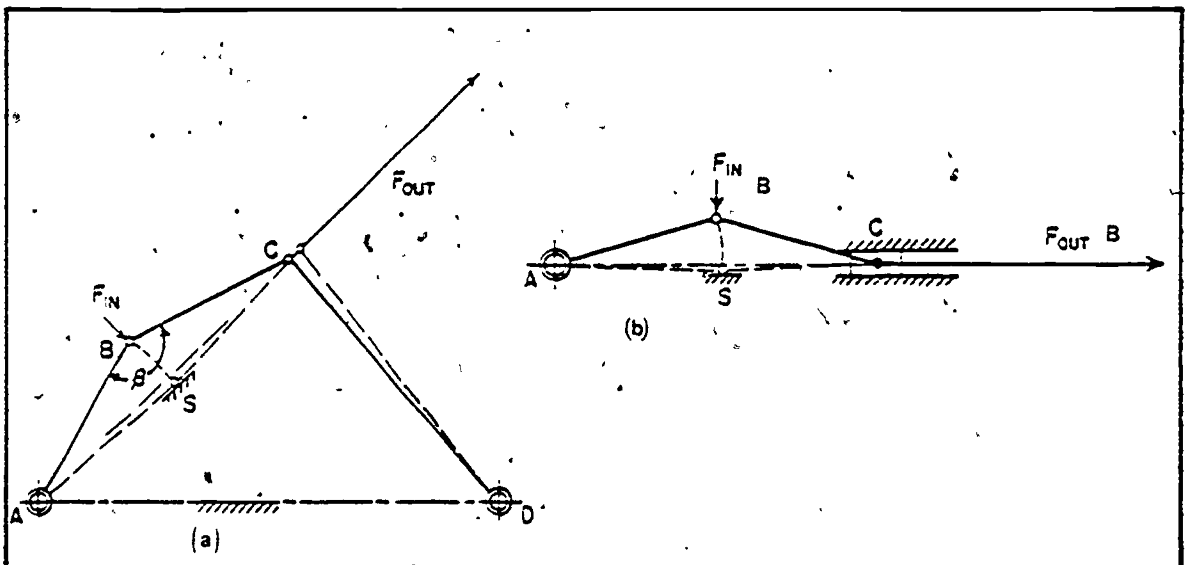


Figure 12. Toggle Linkages.

illustration graphically show the difference in the two forces. The input force is relatively low, and the distance the arm travels when it is pushed is relatively long. As the force travels to point C, it is amplified, and the arm at point C travels only a relatively short distance.

TERMS AND DEFINITIONS

A cam is a component especially designed to guide the motion of a cam follower (Figure 13). Every cam has three parts: (a) the base, (b) the cam, and (c) the follower. The follower is held in contact with the cam by a spring or a guiding groove. The motion of the follower is controlled by the cam.

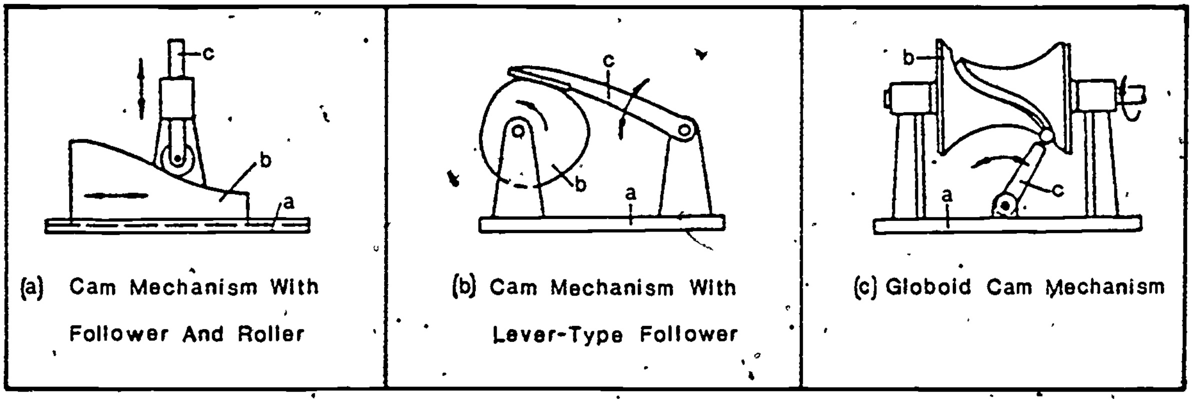


Figure 13. Three Types of Followers.

Cams seldom transmit power in the sense that gears do but often are used to modify a mechanical motion. Cams are the "brains" of many automatic machines, and they are responsible for the motions of many individual machine parts.

TYPES OF CAMS

The disc cam (Figure 14) is the most popular type. This cam translates rotary motion into oscillating motion; the rotation of the cam causes the follower to oscillate.

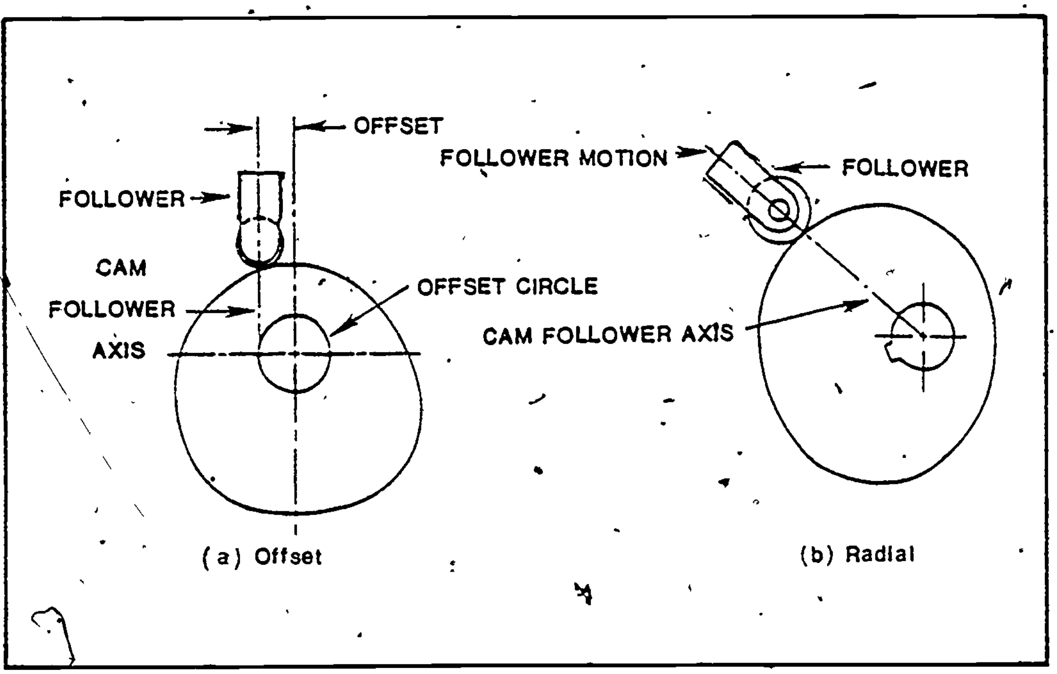


Figure 14. Disc Cams.

The axis of the cam follower for the offset cam (Figure 14a) does not pass through the center axis of the cam, but is "offset." The follower axis of the radial cam does pass through the cam axis (Figure 14b).

The grooved disc cam (Figure 15) is a positive-motion cam because the follower is held by the grooved surface of the cam and tracks positively within the groove.

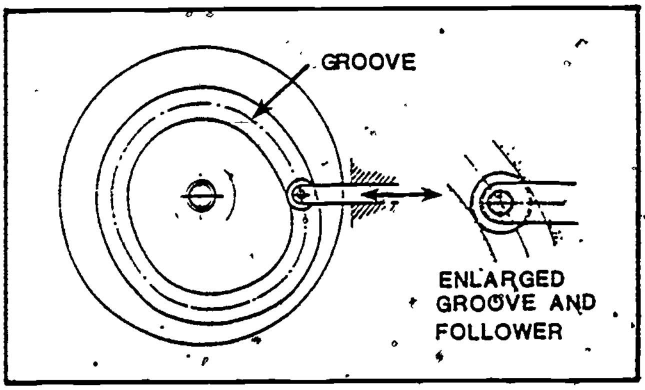


Figure 15. Grooved Disc Cam and Follower.

Two types of cylindrical cams are the cylindrical positive-motion cam (Figure 16) and the open cylindrical cam (Figure 17). The positive-motion cam is equipped with a follower to track within the grooved surface of a cylinder. The open cylindrical cam is equipped with a follower that slides around the circumference of the cylinder (Figure 17).

The translational cam (Figure 18) is mounted on a bar, which, when moved linearally, allows the follower to slide over its contours.

The geneva mechanism is a cam used to generate intermittent rotational motion (Figure 19). As the driving wheel of the mechanism rotates, the pin enters a slot in the wheel, turning the wheel 90° before it exits the wheel. Geneva wheels commonly are manufactured with more than four slots in the wheel. Of course, the more slots in the wheel, the smaller the angle

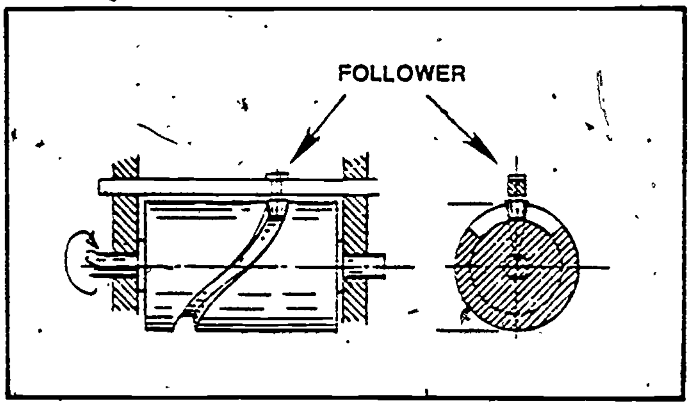


Figure 16. Cylindrical Positive-motion Cam.

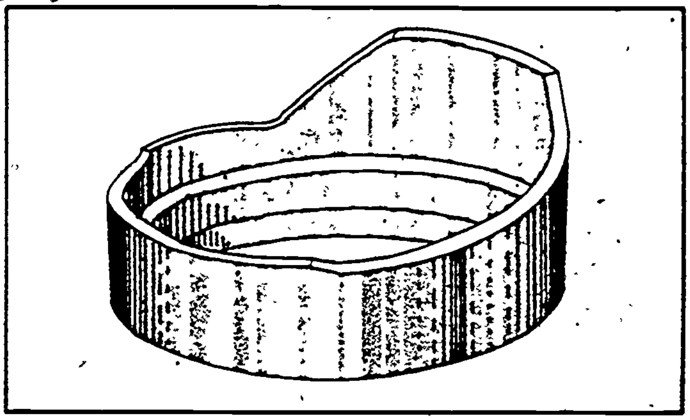


Figure 17. Open Cylindrical Cam.

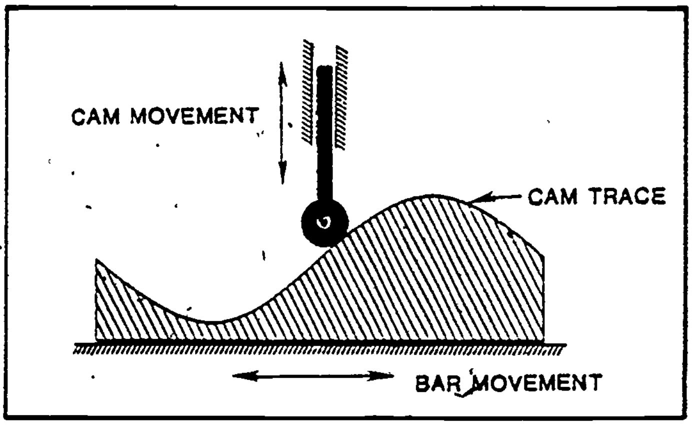


Figure 18. Translational Cam.

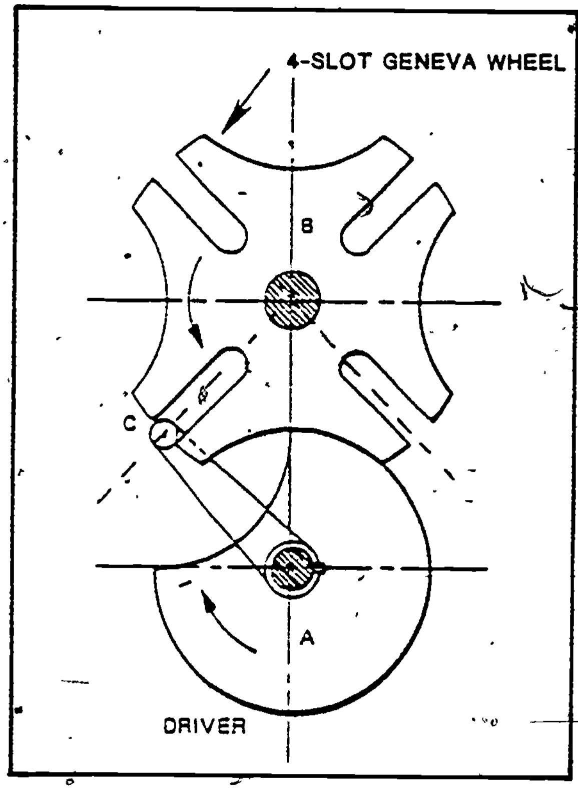


Figure 19. Four-slot Geneva Mechanism.

of rotation. These mechanisms often are used as indexers to move an object into a certain position and to hold it there for a specific period of time.

TYPES OF FOLLOWERS

Cam followers have three basic shapes and are selected according to the service required (Figure 20). The three types are

- Roller followers.
- Kinfe edged followers.
- Flat faced followers.

Roller followers wear very well, even under high loads. Knife-edged followers are capable of much sharper cam tracing than other types and are used for low-load, precision applications. Flat faced followers wear quickly but distribute the load over a wider area than other types.

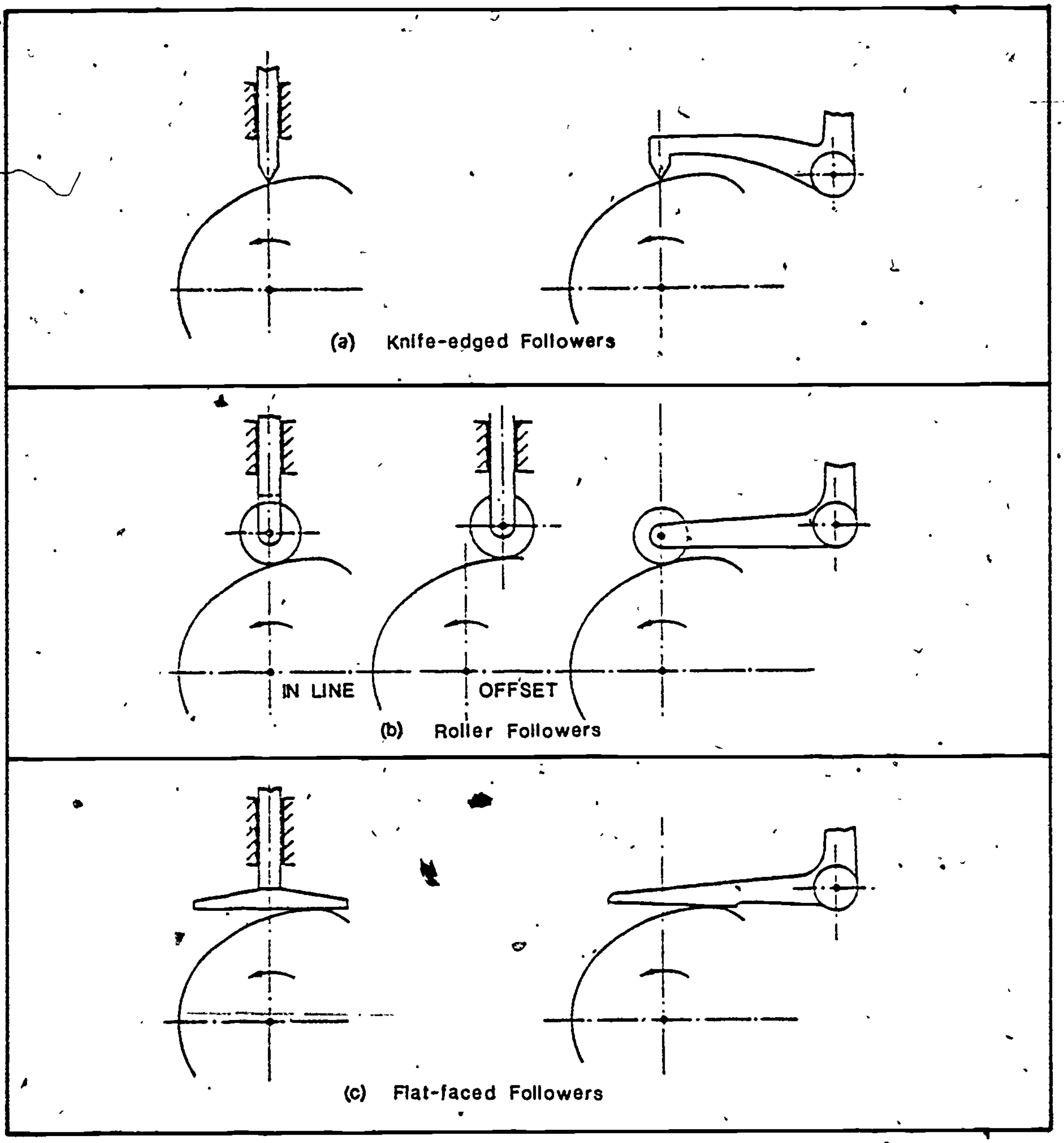
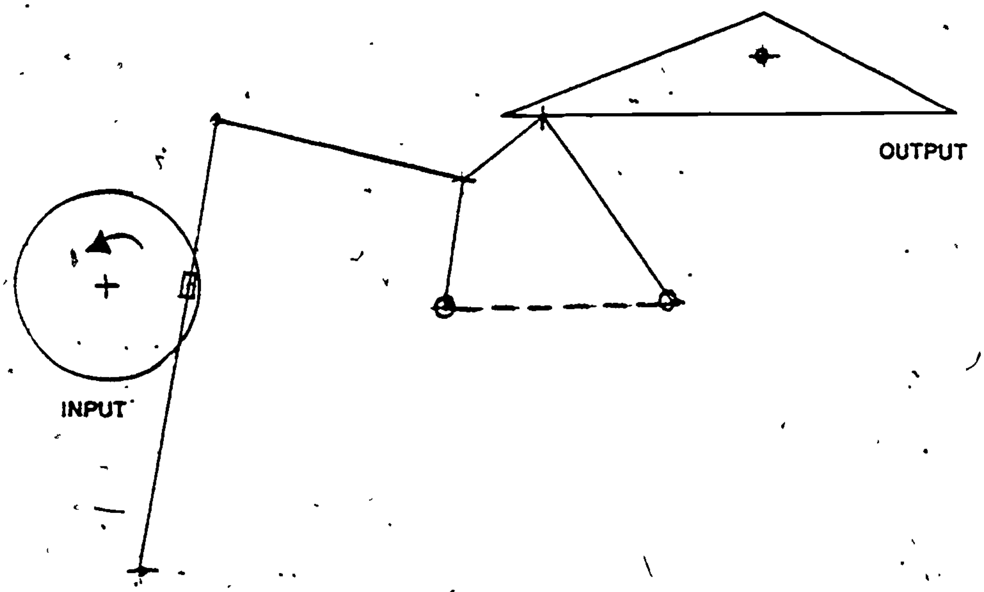


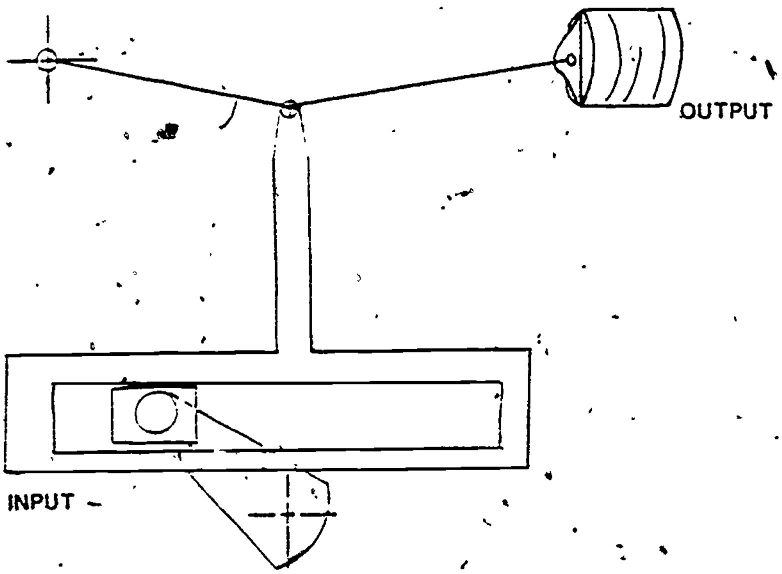
Figure 20. Types of Followers.

Indicate the direction of force output of the following linkage configurations. What linkage configurations are used in each of these problems?

PROBLEM 1



PROBLEM 2



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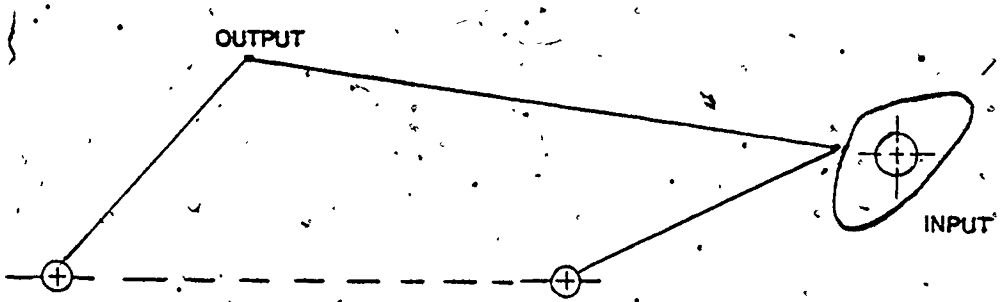

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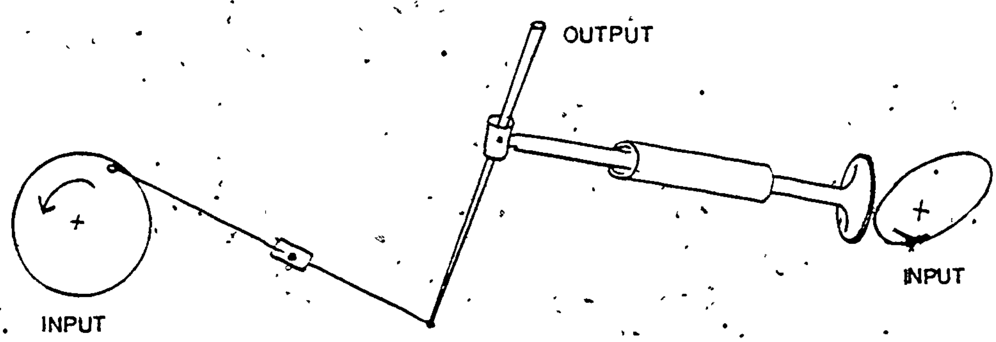


LABORATORY MATERIALS

Access to several of the machines listed in Step 1.
Cardboard.
Pins.
Soda straws.
Automatic pencil leads.
Adhesive tape.
5-large pieces of paper, approximately 24" x 24".

LABORATORY PROCEDURES

1. Examine some of the following machines, and identify the types of linkages and cams used and why these types were chosen for the machines in which they are used. Sketch the mechanism, and describe its movement, using arrows to show the force input and output. Use Data Table to organize data collected.
   a. Bicycles.
   b. Pinball machines.
   c. Record players.
   d. Tape transport mechanisms.
   e. Hand tools and tool boxes.
   f. Animated store displays.
   g. Thermostats.
   h. Typewriters and adding machines.
   i. Air handlers.
   j. Washers and dryers.
   k. Mechanical jacks.
2. Using cardboard, pins, soda straws, automatic pencil leads, adhesive tape, and a thick piece of cardboard

or a piece of wood approximately 1 foot square, fabricate examples of each of the following linkage groups:

a. Crank and rocker.
b. Drag link.
c. Parallel.
d. Transport.
e. Double rockers.

3. Attach a pencil lead to each pivot point, and trace the movement of each mechanism on a large piece of paper.
4. After completing one of each of the examples, combine at least two linkage configurations into one mechanism; and, using the pencil lead, trace the output of the mechanism.

DATA TABLE

DATA TABLE

	DEVICE NAME	MECHANISM NAME	LINKAGE OR CAM CONFIGURATION NAME
1			
2			
3			
4			
5			
6			

REFERENCES

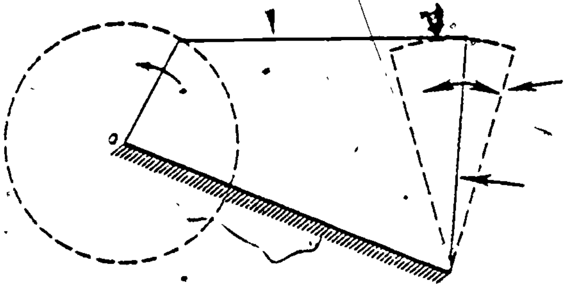
Hirschhorn, J. Dynamics of Machinery. New York: Barnes and Noble, Inc., 1967.

Lnet, D. Analysis and Design of Mechanisms. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1970.

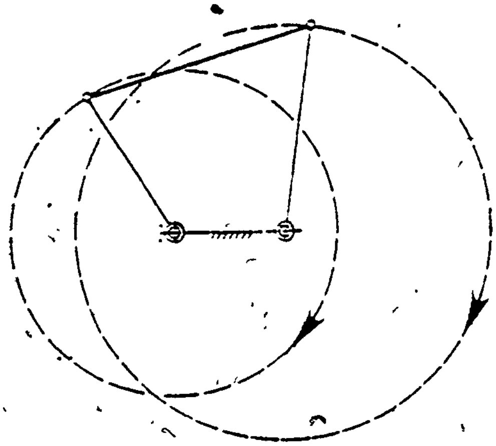
Robertson, L. P.; Tinnell, R. W.; Watts, T. G.; and Yeager, D. A. Mechanisms: Linkages. Electromechanical Technology Series. Albany, NY: Delmar Publishers, 1972.

1. Identify each of the following unlabeled linkage sketches. Use arrows to describe the movement of each type.

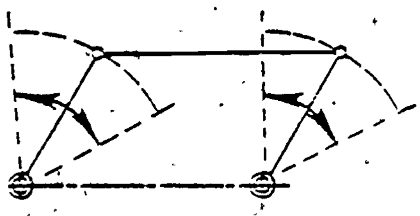
a.



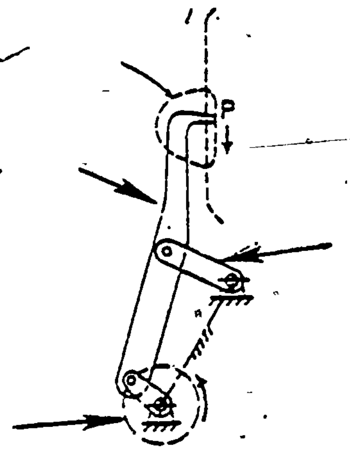
b.



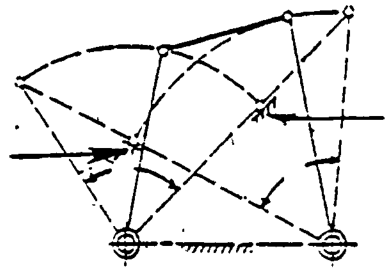
c.



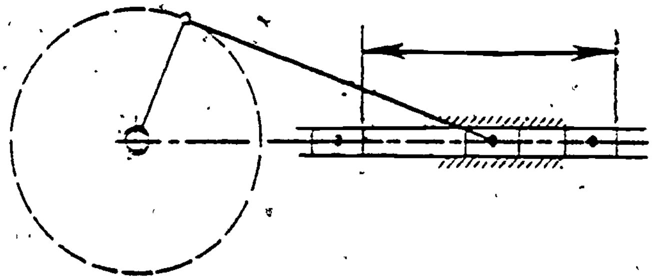
d.



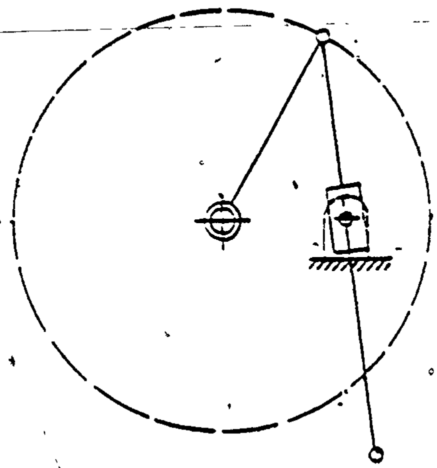
e.



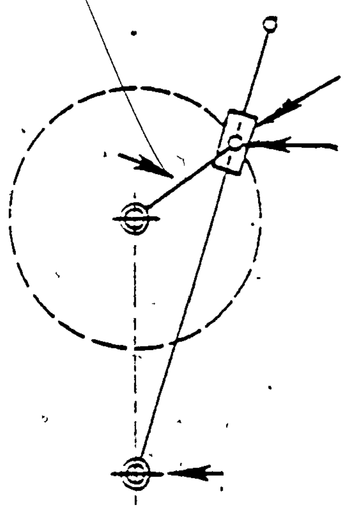
f.



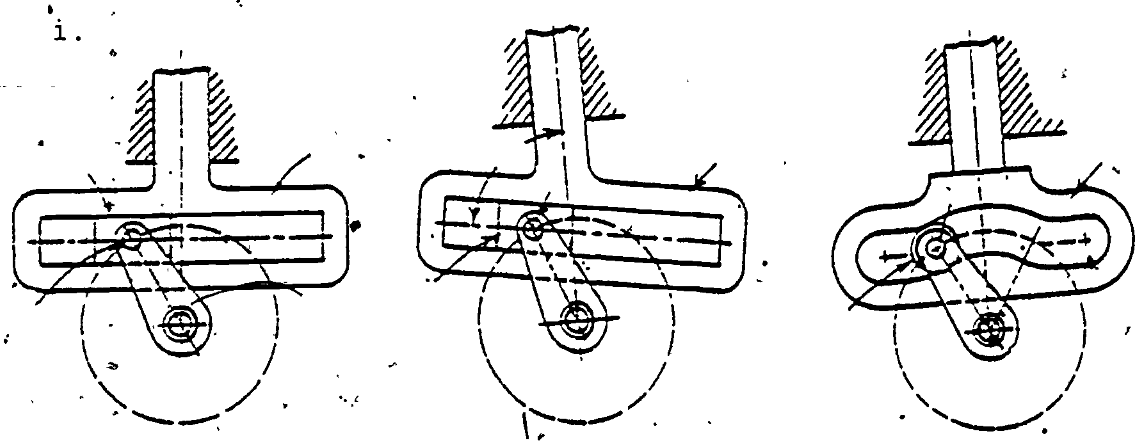
g.



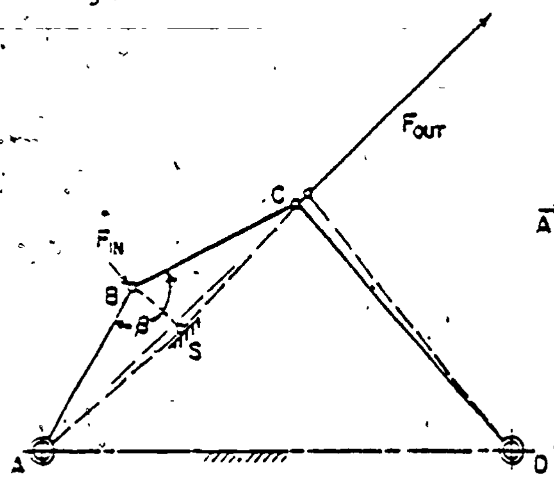
h.

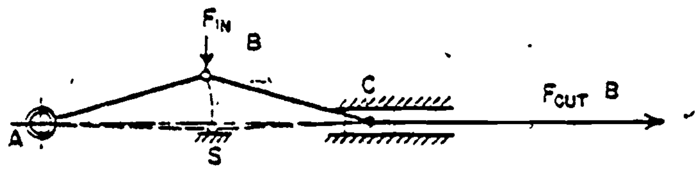


i.



j.





2. Describe the design characteristics that distinguish four-bar, slider crank, and toggle linkages.

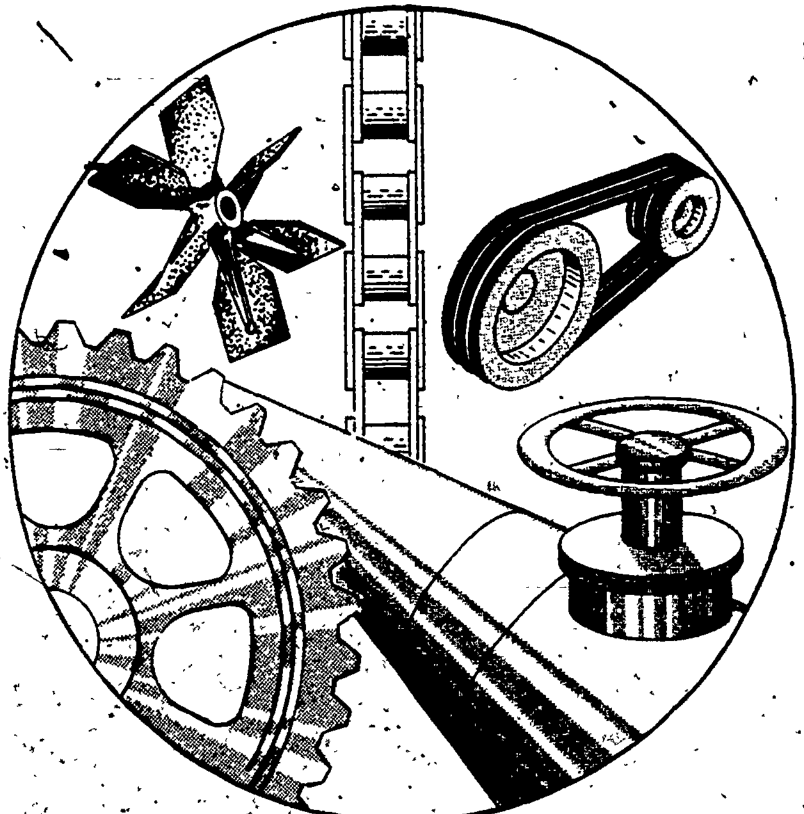
3. Describe the design characteristics of disc, grooved disc, cylindrical, translational, and geneva cams.

4. List and describe the three major groups of cam followers.

ENERGY TECHNOLOGY

CONSERVATION AND USE

MECHANICAL DEVICES AND SYSTEMS



MODULE MS-07

FANS AND BLOWERS

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Fans and blowers are key devices within a surprising number of systems and processes. Such applications include not only the familiar heating, ventilating, and air-conditioning systems, but the less-familiar industrial systems for dust collection, fume removal, and material conveying (the transfer of materials such as powdered coal and metal turnings through ducts). Fans and blowers are used with complex equipment; for example, they cool electronic equipment, aerospace components, and laser heads.

Blowers deliver small volumes of air at relatively high pressure to overcome a pressure head, or resistance. Fans deliver larger volumes of air but at much less pressure than blowers.

Because fans and blowers are utilized in so many varied ways, their proper design, use, and maintenance can result in substantial energy conservation. Some fan systems are designed to conserve energy; for example, the variable-pitch fan and the heat recovery air curtain. These and other energy-efficient systems are discussed in this module.

PREREQUISITES

The student should have completed one year of high school algebra.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Explain the difference between fans and blowers.
2. Describe the two basic types of fans and blowers — axial and centrifugal.
3. Define the following terms:
   a. Damper.
   b. Rotating Blade Anemometer.
   c. Conveying system.
   d. Static pressure.
   e. Velocity pressure.
   f. Total pressure.
4. List and discuss at least two methods of fan control.
5. Explain how each of the following items is beneficial in energy conservation.
   a. Economizer Cycle.
   b. Heat wheel.
   c. Controllable-pitch fan.
   d. Dampers.
   e. Air curtains.
   f. Heat recovery system.
6. Identify the possible causes and corrections for low fan output, bearing failure, and excessive vibration and noise.
7. Apply the six basic fan laws in solving example problems.

The basic differences between fans and blowers are these: (1) fans produce high rates of air delivery at low pressure. (2) Blowers produce high rates at medium air pressure. (Compressors, some of which are similar in design to the centrifugal fan or blower, deliver high pressure.) (3) The primary function of a fan is to move air for the purposes of ventilation, cooling, and heating; whereas, a blower is used to supply forced air for drying, removal of foreign matter, etc.

THE TWO FAN AND BLOWER TYPES

AXIAL-FLOW FANS AND BLOWERS

The axial-flow fan (Figure 1) moves air or gas parallel to the rotating axis. The typical fan of this type produces the swirling helical flow pattern, illustrated in Figure 1.

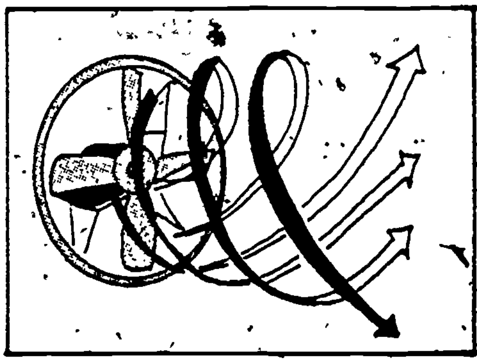


Figure 1. Axial-Flow Fan and its Helical Pattern.

A curved ring, or orifice, that encircles the fan propeller (Figure 2) greatly increases the efficiency of the axial fan. Without the ring, the air tends to recirculate at the propeller tips, causing the fan to be very poor in moving air against resistance.

The tube, or duct, fan consists of a propeller within a duct and a motor either as a direct drive within the duct or a belt-drive system from outside (Figure 3a).

The vane-axial fan (Figure 3b) smooths out the helical flow pattern produced by the propellers. This process increases static pressure and efficiency.

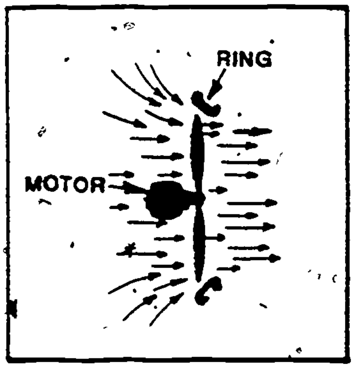


Figure 2. Orifice for Axial Fan.

Most axial units are fans, although a few blowers contain propellers — usually special, high-pressure ones having very wide blades.

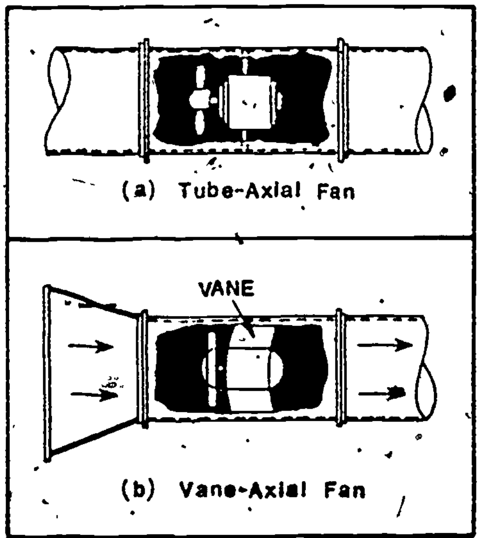


Figure 3. Duct, or Tube, Fans.

CENTRIFUGAL FANS AND BLOWERS

Centrifugal fans operate well when air must be moved against a relatively high resistance. As illustrated in Figure 4, air is drawn in at an opening in the fan housing and into the center of a finned wheel. The wheel spins the air between the blades. The air, tending to move in a straight line, passes out of the housing in the area farthest from the blades.

The bladed wheel (Figure 5) forces air out at 90° to the axis. More pressure can be generated than with an axial fan because not only does the air possess energy in movement, but

but also the energy of the centrifugal force — "force that tends to pull an object away from the center around which it revolves."

The most widely-used blade shapes are shown schematically in Figure 6. The forward-curved blade produces greater air velocity than the backward-curved one, which produces more pressure. The straight blade strikes a medium between these two types. Greater efficiency is characteristic of the air foil type. Fans should be chosen after a careful review of their application. Manufacturers provide characteristic curves for the different blade types.

Centrifugal blowers (Figure 7) are similar in appearance to the fan in Figure 4, except that the bladed wheel is narrower and forces air through a smaller outlet for increased air velocity. Blowers are sealed tightly to prevent leakage.

One of the more useful aspects of blowers is their ability to handle air that contains dust, sawdust, grain, and other particles. The blower often is used as an "exhauster" that picks up these air pollutants on the

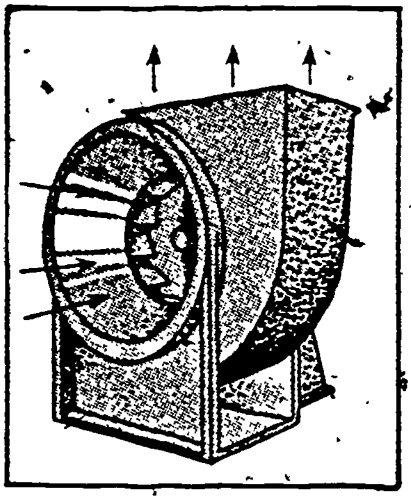


Figure 4. Centrifugal Fan.

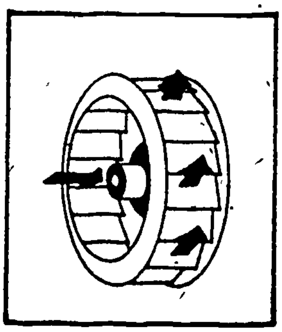


Figure 5. Centrifugal Fan Wheel.

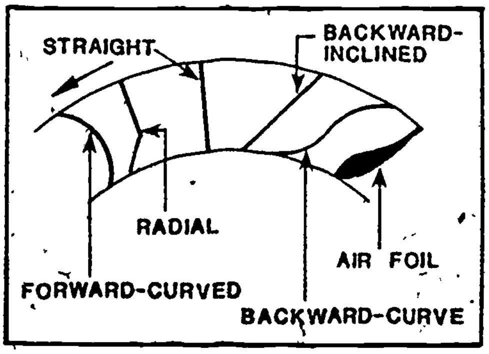


Figure 6. Blade Shapes.

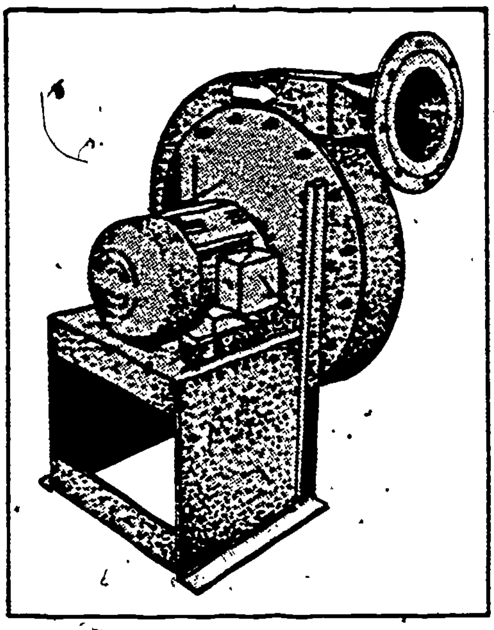


Figure 7. Centrifugal Blower.

vacuum side, and forces them out the blower side into an exit duct (stationary or flexible).

Such pressure blowers as the one illustrated in Figure 7 are employed to furnish air for drying, oil burners, conveying systems, and fabric-structure inflation. A "conveying system" transports, or "conveys," materials from one locality to another. A fan creates a vacuum in a duct into which the material is drawn and carried through a separator, where the air exits and the material is delivered. Materials that frequently are conveyed include powdered coal, metal turnings, sand, portland cement, lime, grain, and cotton.

MATERIALS OF CONSTRUCTION

Standard steel construction is adequate for most fans and blowers. Some applications, however, require special materials in order to withstand corrosion or excessive temperature. Stainless steel withstands high temperatures and many types of corrosion, but is expensive.

Fiberglass or fiberglass-coated metal offers excellent protection against such substances as acid gases and organic minerals.

Various coatings are applied to fan and blower surfaces for protection. These materials include rubber, plastic, and lead.

ACCESSORIES

Vibration shutoff is a valuable feature for larger fans and blowers. A simple device is attached to the fan housing; it senses excessive vibration and automatically shuts off the motor to prevent heavy damage. (Blades have been known to fly through housings.)

The heat "slinger," or "flinger," is a finned disc attached to external fan shafts between the housing and the bearing. Its purpose is to dissipate heat in those systems that operate at high temperature. When high temperatures (above 250°F) are encountered, the bearings must be lubricated with high-temperature grease.

When abrasive materials are being handled, shaft seals should be installed near the bearing to protect the bearing from dust that might be blown out of the shaft opening. The lubricated labyrinth seal is a good choice.

Some manufacturers produce silencers for their blowers. They absorb much of the blower sound.

In some processes, blower air must be filtered of all dust and other particles; special filters are made for this purpose.

THE ECONOMIZER CYCLE

Fans can be used to save energy in the "economizer cycle" of many large air conditioning systems. The economizer cycle refers to the use of outside air, whenever possible, to cool or to heat. The temperature in individual offices of large buildings can be controlled because both hot and cold air are ducted to each office, where a thermostat and dampers control the mixture of hot and cold air to produce the desired temperature for that office. In the summer, the hot air is drawn in from the outside; in the winter, cold air is taken in.

During those seasons when the outside temperature is moderate, both hot air from boilers and cold air from compressors are used. If, however, the outside air is sufficiently different in temperature from the inside air, fresh air can be drawn in from the outside and either the boiler or the compressor turned off. In this case, simple ventilating fans provide a means of great energy savings by efficient use of outside air.

An added variation to this system is the switching off of compressors during cool nights, when the well-insulated and unoccupied building will retain the desired temperature. The systems can be switched off and on manually or by special timing devices.

Large buildings not already equipped for the economizer cycle can be made more energy-efficient if additional equipment is added to gain this important capacity.

Fans used for ventilation can be switched off in a similar manner for additional savings, provided ventilation is not required during the time the fans are not in operation.

THE HEAT WHEEL AND OTHER HEAT EXCHANGERS

Air is exhausted from many large buildings out a large shaft. (Some air has to be ventilated in this manner to allow outside air to be drawn in.) If no exhaust is provided, excessive air pressure builds up in the building.

A considerable amount of heat is lost in most of these venting systems. Heat loss can be reduced if a heat wheel is placed in such a manner that it rotates in both the exhaust air shaft and the outside air shaft (Figure 8). The motor-driven wheel absorbs heat from the exhaust air and transfers it to the outside air as it is drawn in.

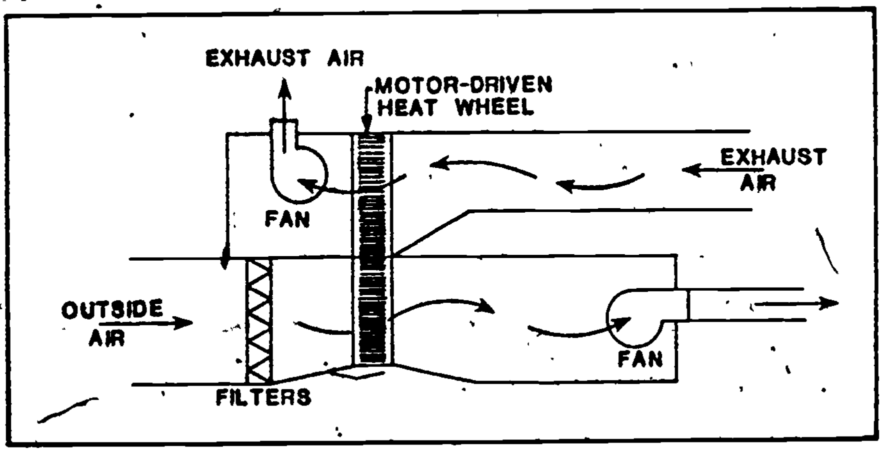


Figure 8. The Motor-driven Heat Wheel.

Other heat wheels are constructed of coils that transfer heat. Fans and blowers are employed in a variety of other heat-exchanger designs to draw heat (or cooling) from one area and to recover it for use somewhere else.

CONTROLLABLE-PITCH FANS AND SPEED CONTROLS

The controllable-pitch propeller fan saves up to 50% in power consumption because its motor does not operate at full load except when required. The fan blades are changed in pitch by a hub attached to them (Figure 9) and connected to a controller that senses heat in the process being controlled and automatically adjusts the fan as required to maintain a predetermined temperature. The controller may operate through pneumatic, hydraulic, mechanical, or electrical systems.

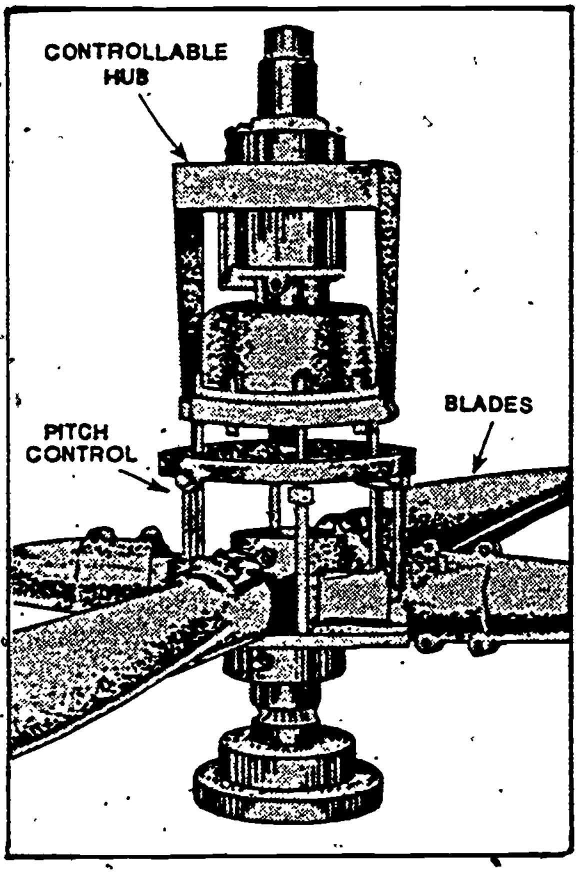


Figure 9. Controllable Pitch Fan.

Applications of the controllable-pitch fan include use in cooling towers of large air conditioning systems, where power savings are attractive. Here, the fan delivers only the amount of air needed to cool the water. This design also is utilized in the processing industries to control temperature to within ±1½°F of a predetermined setting.

Some propeller fans are manually adjusted. Energy can be conserved by adjusting the blade for only the amount of flow required.

Another method of fan-outlet control is speed regulation, accomplished with motor controls, fluid-drive units, magnetic couplings, etc.

Variable inlet vanes provide the centrifugal fan with output control by varying the angle, or degree of spin, of air entering the rotors.

DAMPERS

Dampers (Figure 10) are, perhaps, the least efficient in energy use of the controls. They are used with constant-speed systems by merely closing off part of the flow, either manually or automatically. When they provide much resistance to flow, load is increased upon the fan system, and power consumption is increased.[8]

When dampers are utilized to regulate the amount of make-up air in a system, however, they can be adjusted in such a manner as not to allow too much outside air to flow into the system.

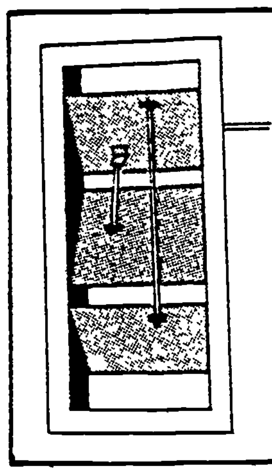


Figure 10. Opposed Blade Dampers.

AIR CURTAINS FOR ENERGY CONSERVATION

The air curtain mounted above an open doorway blows downward and holds warm air in — or cold air in, if desired (Figure 11). Under many conditions, large doors must be left open to traffic; for example, warehouse doors and doors at loading docks. If such doors were left open without the

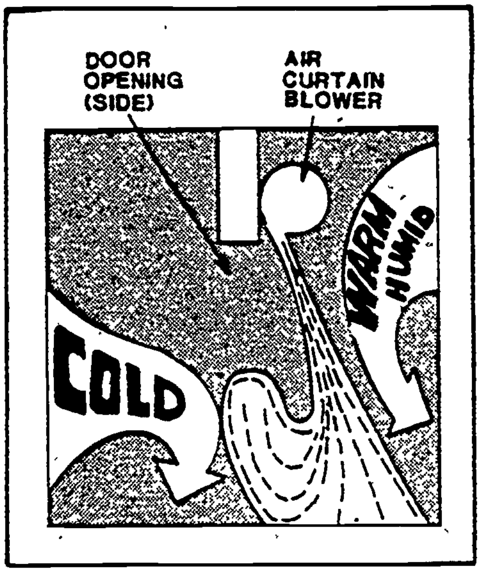


Figure 11. Operation of an Air Curtain in a Doorway.

use of air curtains, much heated or cooled air would be lost, at significant expense. The air curtain aids in keeping out dust and insects.

Air doors similar to that shown schematically in Figure 11 are used in the food industry to seal cold air in cooler/freezers while workers enter and exit constantly. Traffic is speeded up because there are no large doors to open and close.

The Heat Recovery Air Curtain

The heat recovery air curtain is designed to distribute heat evenly in buildings having high ceilings. As depicted in Figure 12a, the normal plant contains colder air near the floor and hotter air — as hot as 90°F — near the roof. Such air stratification requires that to arrive at 68°F at the thermostat located five feet from the floor, the upper, unused air must rise in temperature by about 20°F. Heaters must operate continuously to maintain the 68°F, and the floor is cold.

When a heat recovery air curtain is installed, it circulates the air, drawing it in near the ceiling and forcing it downward through a duct to the floor area (Figure 12b). As a result, the hotter air that normally would be at the ceiling is used at the lower level. Most importantly, fuel consumption is conserved and the heater does not operate as much. The entire building is more comfortable. The heat recovery air curtain can make a substantial contribution to energy conservation.

Some models serve as heat recovery systems during cold weather and as ceiling vents during warm weather.

TESTING AND AIR FLOW MEASUREMENTS

In order that the necessary economic decisions can be made, the energy technician should be able to check fan and blower installations for fan speed, air velocity, and system pressure. Although the technique used may not be as refined as a laboratory test, results can be within ±10% if carefully performed.

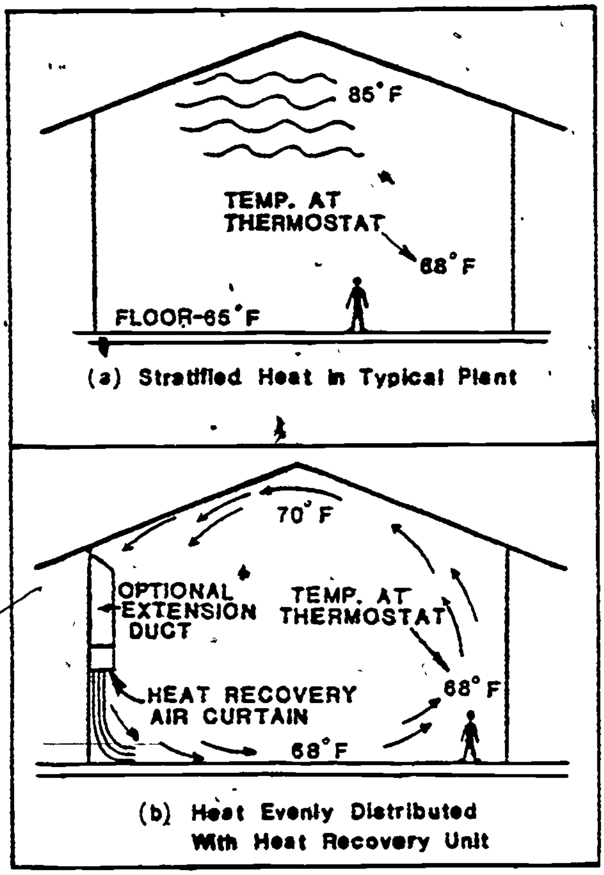


Figure 12. Operation of Heat Recovery Air Curtain.

For pressure systems, a manometer and pitot tube are used to measure air velocity or pressure. Measurements should be taken in a lengthy section of straight ducting, preferably 10–12 duct diameters downstream from the fan. Measurements in the inlet are permissible but not usually as accurate.

Air velocity fluctuates within different sections of both square and round ducts. For this reason, several readings are taken over the cross-sections, from which an average reading then is calculated.

Each reading is taken with a pitot tube at the locations presented in Figure 13.

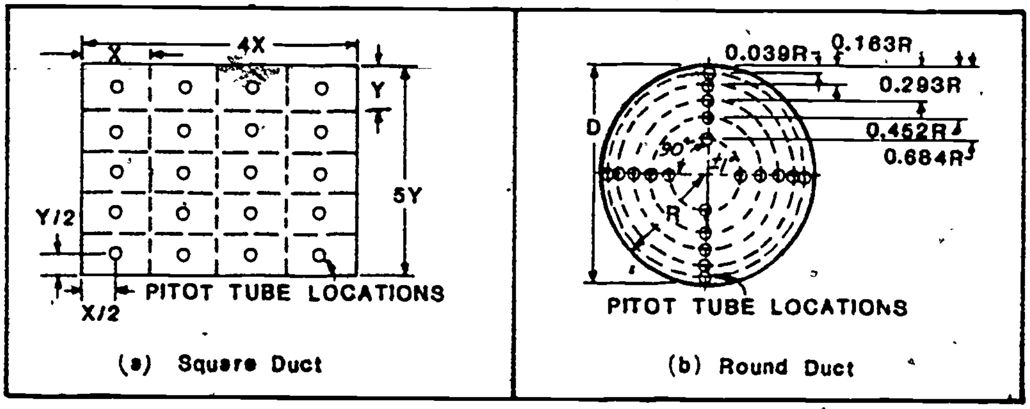


Figure 13. Pitot Tube Locations in Ducts.

The points are in theoretical centers of equal duct areas. Briefly, the procedures can be stated as follows. (These procedures are expanded in the Laboratory section.)

- The pitot head is used to measure the velocity pressure h_v at each of the 20 locations. The square root $\sqrt{h_v}$ is determined, and the 20 readings are averaged and squared. The result is $\sqrt{h_v}$ average².
- The local barometric pressure and temperature of duct air are measured to find the actual air density D in pounds per cubic ft..

$$D = 0.075\left(\frac{530}{460 + \text{Temp. }^\circ F}\right)\left(\frac{\text{Barometric Pres.}}{29.92}\right) \quad \text{Equation 1}$$

- The ratio of standard air density to actual air density is referred to as k and is calculated thusly:

$$k = \frac{0.075}{D} \qquad \text{Equation 2}$$

- Average velocity v of air in the duct is determined.

$$v = \frac{4000}{(\sqrt{h_v})^2 \text{ average}} \qquad \text{Equation 3}$$

- For a round duct, the cross-sectional area A is calculated as follows:

$$A = \frac{\pi d^2}{4} \qquad \text{Equation 4}$$

where:

π = pi, 3.14

d = Duct diameter in feet.

If the duct is rectangular, A = Wh, where W = width, and h = height.

- The duct cross-sectional area A is multiplied by velocity v to obtain the actual cubic feet per minute (CFM) delivered by the fan. This test value can be compared with the rated value by multiplying k x hμ to correct for density.

- Fan horsepower can be calculated from the equations for single-phase supply:

$$\text{FAN HP} = \frac{\text{Watts} \times \text{Motor Efficiency}}{746} \qquad \text{Equation 5}$$

(Motor efficiency, n is obtained from manufacturers tables or motor plate.)

- The HP is corrected for the actual density when it is multiplied by the k factor above.
- The fan's r/min (rpm) is measured with a stroboscope or tachometer. The manufacturers "characteristic curve" for the motor is used to plot HP and pitot readings on the curve for the measured r/min. The results are compared to the calculated ft^3/min. If the calculated ft^3/min value does not match the specified value, the fan is losing efficiency at some point — perhaps a belt is slipping, or there is another problem.

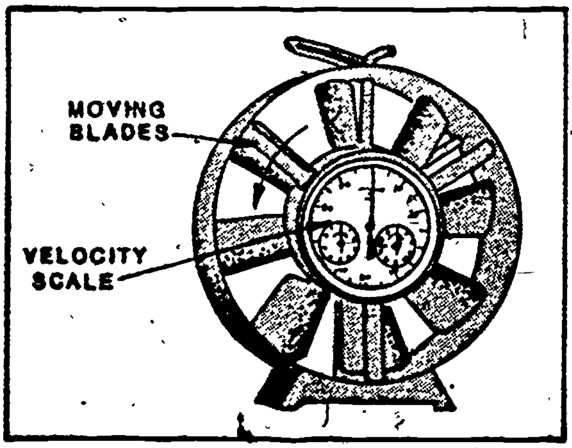


Figure 14. Rotating Blade Anemometer.

ANEMOMETERS

Impact and pitot tubes are suitable only for indirect measurement of air flow; that is, velocities must be calculated from measured pressures. There are, however, several types of instruments available for the direct measurement of velocity. These devices include the rotating cup anemometer, the heat-loss (hot-wire) type, and the rotating blade type.

The rotating blade anemometer (Figure 14) is placed inside the duct, and the fan is placed into operation. Moving air strikes the rotating blades which are attached to a velocity scale that provides a direct velocity reading.

MAINTENANCE

The troubleshooting procedures outlined in Table 1 provide the basic maintenance steps required.

TABLE 1. TROUBLESHOOTING OF FANS AND BLOWERS.

TROUBLE	CAUSE	CORRECTION
Low Output	(a) Dampers closed (b) Loose belts (c) Dirty filters (d) Blower hose plugged (e) Variable pitch or speed control malfunction	(a) Open dampers; clean and adjust damper assembly (b) Tighten belts (c) Clean or replace (d) Clean out house (e) Inspect and repair system as required
Bearing Failure	(a) Bearing not lubricated (b) High-temperature lubricant not used in hot conditions (c) Pillow block on shaft misaligned (d) Belts too tight (e) Dust enters bearing from around shaft	(a) Lubricate properly (b) Use high-temp. lubricant and heat flingers (c) Align (d) Loosen belts (e) Use shaft seal

Table 1. Continued.

TROUBLE	CAUSE	CORRECTION
Excessive Vibration and Noise	(a) Worn bearings (b) Fan rotor out of balance or bend (c) One or more fan or motor mount bad or out of adjustment	(a) Replace (b) Balance or straighten (c) Replace mount and/or adjust all mounts to bear equal load

FAN SELECTION

There are usually dozens of different fans that will perform a given task, although only a few — perhaps one — will do it economically.

GENERAL INFORMATION AND TERMS

The calculation of fan performance for different conditions is important and should be studied thoroughly.

Calculation of Fan Delivery at a Given r/min (rpm)

For a given speed change, fan size, resistance of system, and air density, fan delivery is calculated from Equation 6.

$$\frac{\text{Capacity at } ① = Q_1}{\text{Capacity at } ② = Q_2} = \frac{r/min_1}{r/min_2} \qquad \text{Equation 6}$$

This equation is used to solve a problem in Example A.

EXAMPLE A: FAN DELIVERY AT A GIVEN SPEED.	
Given:	A fan delivers 6000 ft^3/min of air at 650 r/min.
Find:	How much it will deliver if the speed is increased to 950 r/min.
Solution:	Use Equation 6:

$$\frac{Q_1}{Q_2} = \frac{r/min_1}{r/min_2}$$

$$\frac{6000}{Q_2} = \frac{650}{950}$$

$$Q_2 = (6000)\left(\frac{950}{650}\right)$$

$$= (6000)(1.46)$$

$$Q_2 = 8769\ ft^3/min.$$

Pressure Increases

Pressure increases as the square of the speed, as indicated by Equation 7 and Example B.

$$\frac{\text{Pressure at (1)}}{\text{Pressure at (2)}} = \left(\frac{r/min_1}{r/min_2}\right)^2 \qquad \text{Equation 7}$$

EXAMPLE B: PRESSURE INCREASES.	
Given:	The fan of Example A, for which the pressure at (1) is assumed to be 4" of water.
Find:	The new pressure at (2).
Solution:	Use Equation 7:

$$\frac{p_1}{p_2} = \left(\frac{r/min_1}{r/min_2}\right)^2$$

$$r/min_1 = 650$$

$$r/min_2 = 950$$

$$\left(\frac{r/min_1}{r/min_2}\right)^2 = \left(\frac{650}{950}\right)^2$$

$$= 0.468$$

$$p_1 = 4" \quad \therefore \quad \frac{4}{p_2} = 0.468$$

$$p_2 = \frac{4}{0.468}$$

$$p_2 = 8.54" \text{ water.}$$

Horsepower Required for a Particular System

The required horsepower increase to accommodate an increase in motor speed is calculated from Equation 8.

$$\frac{HP_1}{HP_2} = \left(\frac{r/min_1}{r/min_2}\right)^3 \qquad \text{Equation 8}$$

This equation is employed in Example C.

EXAMPLE C: REQUIRED HORSEPOWER INCREASE.	
Given:	The speed change in Example B.
Find:	The increase in horsepower if the original motor size was 10.0 HP.
Solution:	Use of Equation 8 results in —

$$\frac{HP_1}{HP_2} = \left(\frac{r/min_1}{r/min_2}\right)^3$$

$$\left(\frac{r/min_1}{r/min_2}\right)^3 = (0.684)^3 = 0.318$$

$$HP_1 = 10, \therefore HP_2 = \frac{10}{0.318} = 31.3 \text{ HP}.$$

Summary of Examples A, B, and C

When the fan's r/min is increased from 650 to 950, the capacity is increased 6,000 CFM to 8,769; and pressure is increased from 4" to 8.54" of water. Motor horsepower is increased from 10.0 to 31.3 HP.

Fan Laws

The efficiencies of fans remain constant for symmetrical design; however, when one or more conditions change, the other conditions vary according to the fan laws presented in Examples D through G.

EXAMPLE D: FAN LAWS 1, 2, AND 3.

Given: A fan delivers 14,000 ft^3 of air per minute at 450 r/min against a static pressure of 1.5" water. The motor input is 5.0 HP.

Find: The (1) speed, (2) static pressure, and (3) power if the volume is increased to 17,500 CFM.

Solution:

(1) The first three fan laws are as follows:

a. Air capacity (delivery) varies with the fan speed.

b. Pressure (static, velocity, and total) varies as the square of the fan speed.

c. Power absorbed by the fan varies as the cube of the fan speed.

$$\text{New Fan Speed} = \left(\frac{17500}{1400}\right)(450)$$
$$= 562.5 \text{ r/min.}$$

(2) New Static Pressure (p_s):

$$p_s = \left(\frac{562.5}{450}\right)^2(1.5)$$
$$= (1.25)^2(1.5)$$
$$= (1.56)(1.5)$$
$$p_s = 2.34\text{" water.}$$

(3) New power input (P_{in}):

$$P_{in} = \left(\frac{562.5}{450}\right)^3(5.0)$$
$$= (1.25)^3(5.0)$$
$$= (1.95)(5.0)$$
$$P_{in} = 9.76 \text{ HP.}$$

233

EXAMPLE E: FAN LAW 4.

Given: A fan delivers 14,000 CFM of air at 70°F at standard atmospheric pressure (p = 0.075 HgS/ft^3) and at a static pressure of 1.5" H_2O when operating at 450 r/min and needing 5.0 HP.

Find: (1) Static pressure and (2) power if the air temperature is increased to 200°F and if the fan speed remains the same.

Solution: The fourth fan law states that at a constant speed and capacity the pressure and power vary directly as the density.

air density at 70°F = 0.075 HgS/ft^3.
air density at 200°F = 0.0602 HgS/ft^3.

(1) New static pressure:

$$p_s = \left(\frac{0.0602}{0.075}\right)(1.5)$$

$$= (0.8)(1.5)$$

$$p_s = 1.2\text{" water.}$$

(2) New power:

$$P_{in} = \left(\frac{0.0602}{0.075}\right)(5.0)$$

$$P_{in} = 4.0 \text{ HP}$$

EXAMPLE F: FAN LAW 5.

Given: The speed of the fan in Example D is increased to produce a static pressure of 1.5" of H_2O at 200°F.

Find: (1) Speed, (2) capacity, and (3) power.

Example F. Continued.

Solution: At a constant pressure, the speed, capacity, and power vary inversely as the square root of the density (fan law No. 5).

(1) New Speed:

$$\text{Speed} = (450)\left(\sqrt{\frac{0.075}{0.0602}}\right)$$

$$= (450)\sqrt{1.25}$$

Speed = 503.1 r/min.

(2) New capacity;

$$\text{Capacity} = (14000)\ \frac{0.075}{0.0602}$$

$$= (14000)(1.12)$$

Capacity = 15680 CFM at 200°F.

(3) New Power:

$$P = (5)\left(\sqrt{\frac{0.075}{0.0602}}\right)$$

$$= (5)(1.12)$$

P = 5.6 HP.

EXAMPLE G: FAN LAWS 6 AND 7.

Given: The speed of the fan in Example F is increased until it will deliver the same weight of air at 200°F as at 70°F.

Find: (1) Speed, (2) capacity, (3) static pressure, and (4) power.

Solution: The 6th rule states, "For a constant weight of air, the speed, capacity, and pressure vary inversely as the density." Rule 7 states, "For a

Example G. Continued.

constant weight of air, the HP varies inversely as the square of the density."

(1) New speed:

$$\text{Speed} = (450)\left(\frac{0.075}{0.0602}\right)$$

$$= (450)(1.25)$$

$$\text{Speed} = 562.5 \text{ r/min.}$$

(2) New static pressure:

$$p_s = (1.5)\left(\frac{0.075}{0.0602}\right)$$

$$= (1.5)(1.25)$$

$$p_s = 1.88'' \; H_2O.$$

(3) New power:

$$P = (0.5)\left(\frac{0.075}{0.0602}\right)^2$$

$$= (0.5)(1.25)^2$$

$$= (0.5)(1.56)$$

$$P = 7.81 \text{ HP}.$$

Fan Wheel Diameter

If a fan system that works against a constant pressure, air density, and rating is replaced by a geometrically similar fan that has a blade (or wheel) diameter, then — capacity Q and HP vary as the diameter squared. This relationship is given by Equation 9.

$$\frac{Q_1}{Q_2} \text{ or } \frac{HP_1}{HP_2} = \left(\frac{d_1}{d_2}\right)^2 \qquad \text{Equation 9}$$

Fan Speed and Wheel Diameter

Speed of a fan varies as blade or wheel diameter (Equation 10).

$$\frac{r/min_1}{r/min_2} = \frac{d_2}{d_1} \qquad \text{Equation 10}$$

Pressure and Pressure Difference

The terms "pressure" and "pressure difference" have the same meanings as "head" and usually are measured in inches of water. "Static pressure" is the force per unit area exerted on the inside of the duct system.

"Total pressure" refers to the combined effects of static pressure and velocity pressure. "Velocity pressure" is the head over and above the static pressure; it is caused by the movement of air inside the system.

Figure 15 is a simplified diagram that illustrates the use of a manometer to measure static head, velocity head, and total head when it is inserted into a fan duct, or "discharge," system.

Manometer A in Figure 15 measures static pressure against the duct walls. Total pressure — both the static pressure and the velocity pressure caused by air movement — are measured by manometer B. Manometer C also measures static and velocity pressure but automatically subtracts the static from the

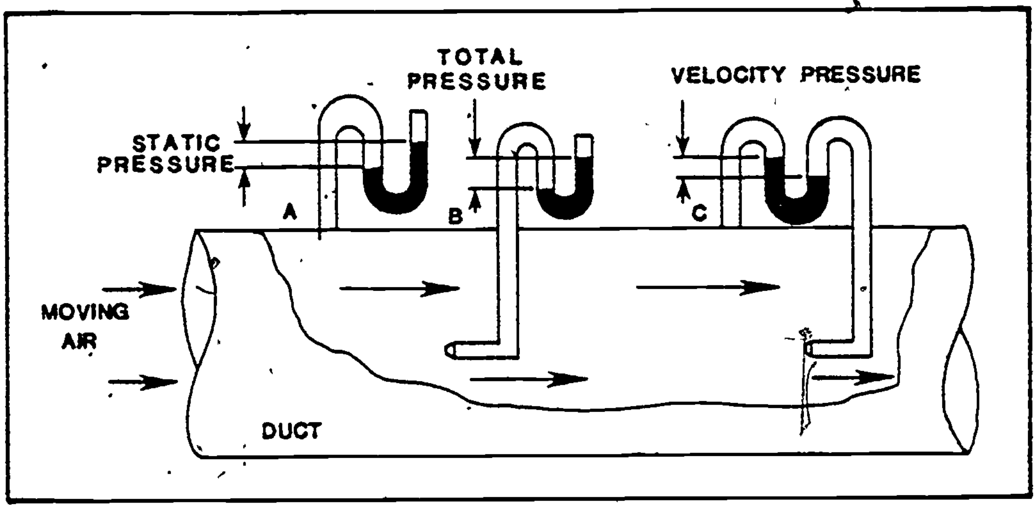


Figure 15. Manometer Measurements within a Duct.

velocity to give true velocity pressure. Sometimes, Manometer C is referred to as a "pitot tube."

Air Horsepower

"Power" usually is described as "horsepower." For fans, the designation "air horsepower" is used and can be calculated from Equation 11.

$$AHP = \frac{Q_{V\Delta p}}{6356} \qquad \text{Equation 11}$$

where:

AHP = Air Horsepower.

Q_V = Volumetric flow rate of air through fan in CFM.

Δp = Differential pressure head across fan in inches of water.

Because both static and total pressure heads are considered in fan systems, air horsepower can be called "static air horsepower" (AHP_s) or "total air horsepower" (AHP_t). The latter is equal to the pound in output. Example H clarifies static and total AHP.

EXAMPLE H: STATIC AND TOTAL AIR HORSEPOWER.	
Given:	A fan system carries 6,500 CFM of air; the static pressure across the fan is 4½" of water; and the total pressure is 8" of water.
Find:	(1) Static air horsepower and (2) total air horsepower.
Solution:	(1) $AHP_s = \frac{Q_V \Delta p}{6356} = \frac{(6500)(4.5)}{6356}$; $AHP_s = 4.6$ HP
	(2) $AHP_t = \frac{Q_V \Delta p}{6356} = \frac{(6500)(8.0)}{6356}$; $AHP_t = 8.18$ HP
The power output of the fan is 8.18 HP.	

239

Air Density

Air density changes the total and static pressures. It is affected by both pressure and temperature; and, in turn, the horsepower requirements. Pressure head and horsepower vary inversely as the fluid temperature and directly as the fluid pressure (or fluid density). For these reasons, pressure and temperature changes must be taken into account when a fan system is selected.

These variables are clarified by use of a fan performance curve (Figure 16).

Air density is discussed further in the Laboratory Procedures.

Total head is calculated from Equation 12.

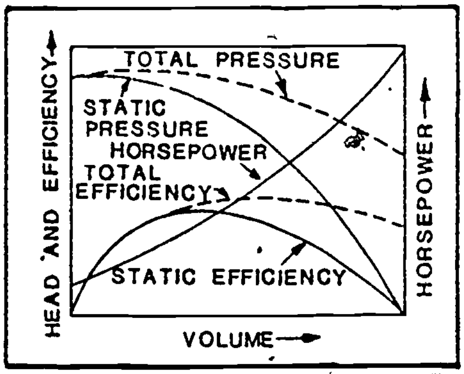


Figure 16. Fan Performance Curve.

$$p_t = \frac{p_s}{p_v} \qquad \text{Equation 12}$$

where:

- p_t = Total head pressure.
- p_s = Static head pressure.
- p_v = Velocity head pressure.

Efficiency

Efficiency is calculated by use of Equations 13 and 14.

$$\eta_s = \frac{AHP_s}{P_{in}} \qquad \text{Equation 13}$$

where:

η_s = Static efficiency.

AHP_s = Static air horsepower.

P_{in} = Power input.

$$\eta_m = \frac{AHP_t}{P_{in}} \qquad \text{Equation 14}$$

where:

η_m = Mechanical efficiency.

AHP_t = Total air horsepower.

241

EXERCISES

1. A fan delivers 1,200 cubic feet per minute of CO_2 gas at 350 r/min. How much gas will be delivered if the fan speed is increased to 600 r/min?
2. A fan 8" in diameter delivers 1,200 CFM of air, using 15.0 HP at 1750 r/min. How much air will be delivered if the fan horsepower is reduced to 12.0 HP at 1750 r/min?
3. A simple straight-duct system handles 600 CFM of air. The static pressure is measured at 4.5" of water, and the total pressure at 6.7". What is the velocity pressure in the duct?

LABORATORY MATERIALS

1 axial duct fan (motor driven) in circular duct, as illustrated in Figure 17. The duct should be 10–12' in length with holes drilled or cut as described in the Laboratory Procedures, Step 2.
1 wattmeter, in-line type for 110 V.
2 water manometers, 3/16" bore and colored water for each.
1 impact tube as in Figure 19.
1 static pressure tube.
1 thermometer, 0–212°F.
2 wooden scales, calibrated in 1/32".
Assorted rubber tubing for manometers. (See Figure 17.)
1 roll of duct tape.

FAN CHARACTERISTICS

1. Set up experiment as illustrated in Figure 17.

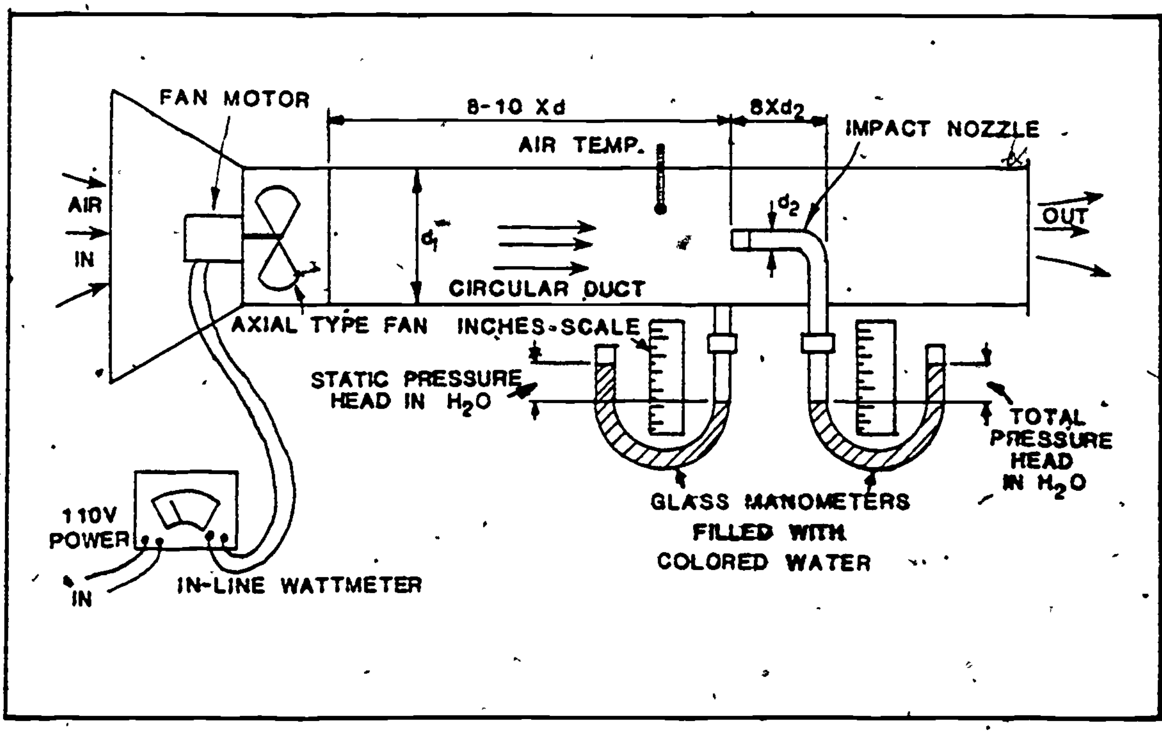
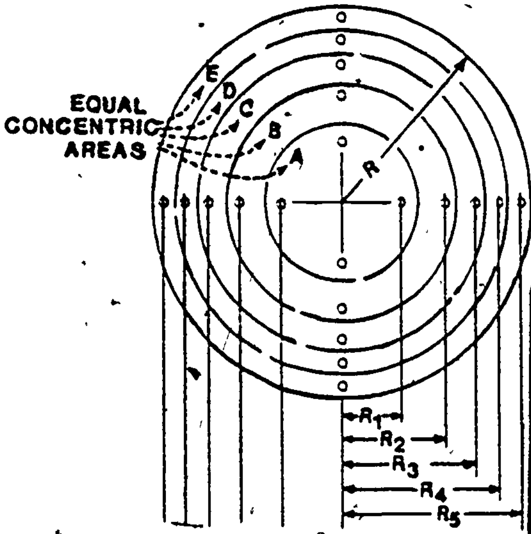


Figure 17. Laboratory Setup.

2. Determine the location of five equal concentric areas within duct. Figure 18 gives these dimensions – each of which is a specific distance from the duct center and is a percentage of the radius. These distances, of course, vary with duct diameter.



No. Equal Areas	Distance of pitot station from center of pipe, % of pipe radius, R.				
	R_1	R_2	R_3	R_4	R_5
3	40.8	70.7	91.3	—	—
4	35.4	61.2	79.1	93.5	—
5	31.6	54.8	70.7	83.7	94.9

Figure 18. Points of Impact Measurement.

3. Transfer the distances A, B, C, D, and E determined in Step 2 to impact nozzle as illustrated in Figure 19. If necessary, position a piece of masking tape on the nozzle and write the distance numbers on it.
4. Drill or cut holes in duct at nine points located as

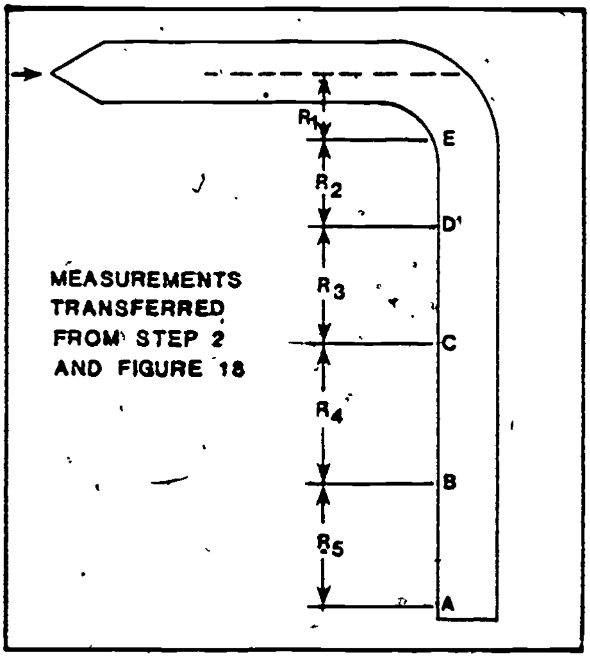


Figure 19. Points of Impact Measurement on Impact Head.

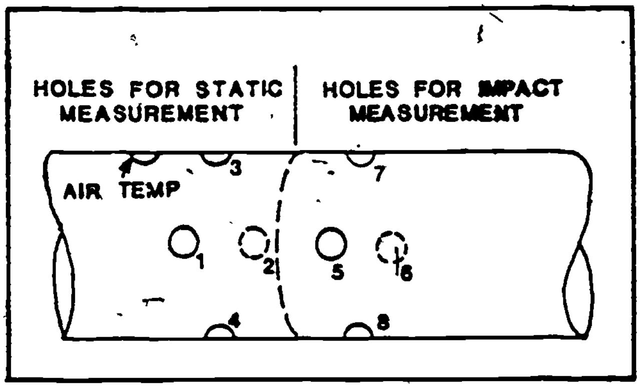


Figure 20. Duct Holes for Static and Impact Measurements.

in Figure 20. Cut them only large enough for measuring heads. During the measuring process, all holes not being used for a given measurement must be covered with duct tape. Otherwise, the measurements will be inaccurate because of the escaping air.

5. Refer to Figure 20 again for the locations and numbers of measuring the holes.
6. Place impact head in hole 5 of duct, lining up letter A on head with duct. With fan motor running, measure total pressure head and record in Data Table.
7. Place static head barely in hole 1. Measure and record static head pressure.
8. With fan still running, measure and record temperature of air.
9. With wattmeter connected in line to motor, measure and record watts consumed.
10. Measure and record barometric pressure.
11. Repeat Step 6 for positions B, C, D, and E on impact head.
12. Repeat Steps 6–11 for impact holes 6, 7, and 8. Take static reading at hole 2 for impact hole 6; hole 3, for 7; and hole 4, for 8. (Static pressure must be measured on same side of duct as impact pressure.) Record measurements.
13. Calculate actual air density D from the following equation:

$$D = 0.75\left(\frac{530}{460 + \text{Temp. } ^\circ F}\right)\left(\frac{\text{Barometric Reading}}{29.92}\right)$$

Substitute Average Temp. and barometric reading into equation:

$$D = 0.75\left(\frac{530}{460 + \underline{\quad\quad} ^\circ F}\right)\left(\frac{\underline{\quad}}{29.92}\right)$$

$$= 0.75 \times \underline{\quad\quad} \times \underline{\quad\quad}$$

$$D = \underline{\quad\quad\quad} ft^3.$$

14. Calculate k from this equation:

$$k = \frac{0.075}{D}$$

$$= \frac{0.075}{(\underline{\quad\quad})}$$ (from Density equation)

$$k = \underline{\quad\quad\quad}.$$

15. Calculate average velocity v as follows:

$$v = \frac{4000}{(\sqrt{h_V})^2_{ave}}$$

$$= \frac{4000}{(\quad\quad)^2}$$ (from Data Table)

$$v = \underline{\quad\quad\quad}$$ ft per min.

16. Calculate area of duct.

$$A = \left(\frac{\pi}{4}\right)d_1^2$$ (d_1 = duct dia. in feet)

$$= (.7854)(\underline{\quad\quad})$$

$$A = \underline{\quad\quad\quad} ft^2.$$

17. Calculate volume flow rate.

$$Q_V = vA$$

$$= (\underline{\quad\quad})(\underline{\quad\quad})$$

$$Q_V = \underline{\quad\quad\quad} CFM.$$

18. Calculate fan horsepower from the following equation, assuming motor efficiency at 85%.

$$HP = \frac{\text{Watts x Motor Eff.}}{746}$$

$$= \frac{(\quad)(\quad)}{746}$$

HP = ________.

DATA TABLE

Static Head p_s		Total Head (Impact) p_t	Marks on Head					Velocity Head p_v $(p_t - p_s)$		Watts	Temperature (°F)	Barometric Pressure
Hole No.	Reading	Hole No.	A	B	C	D	E	p_v	$\sqrt{p_v}$	For Point A Only	For Point A Only	For Point A Only
1		5										
2		6										
3		7										
4		8										

Total of $\sqrt{p_v}$'s: ________ ________. Total (T) = ________.

Total Squared: ________ Average = $\frac{T}{5}$ = ____°F. Average = $\frac{B}{5}$ = ____.

REFERENCES

Aberback, Robert J., ed. "Fans: A Special Report." Power, March 1968, pp. 2-24.

Alden, J. L. and Icane, J. M. Design of Industrial Exhaust Systems. 4th ed. New York: Industrial Press, Inc., 1970.

AMCA Fan Application Manual. Arlington Heights, IL: Air Moving and Conditioning Association.

Elonka, Stephen Michael. Standard Plant Operators' Manual. 2nd ed. New York: McGraw-Hill Book Company, 1975.

Hartzell Propeller Fan Company. Various Catalogs. Piqua, OH: Hartzell Propeller Fan Company, 1978.

Industrial Air Fans and Air Moving Equipment. Amelia, OH: Industrial Air, Inc., 1978.

Miniveil Air Curtain Systems. New Castle, PA: Berner International Corporation, 1978.

Osborne, William C. Fans. Oxford, England: Pergamon Press, 1966.

Thumann, Albert. Plant Engineers & Managers Guide to Energy Conservation. New York: Van Nostrand Reinhold Company, 1977.

TEST

1. A fan moves _____ volumes of air at _____ pressure.
   A blower moves _____ volumes of air at _____ pressure.
2. Name and describe the two basic types of fans and blowers.

3. Define the following terms:
   a. Damper.
   b. Rotating Blade Anemometer.
   c. Conveying system (air).
   d. Static pressure.
   e. Velocity pressure.
   f. Total pressure.

4. List and discuss two methods of fan control.

5. Explain how each of the following terms is beneficial in energy conservation.

   a. Economizer cycle.

   b. Heat wheel.

   c. Controllable-pitch fan.

   d. Dampers.

   e. Air curtains.

   f. Heat recovery system.

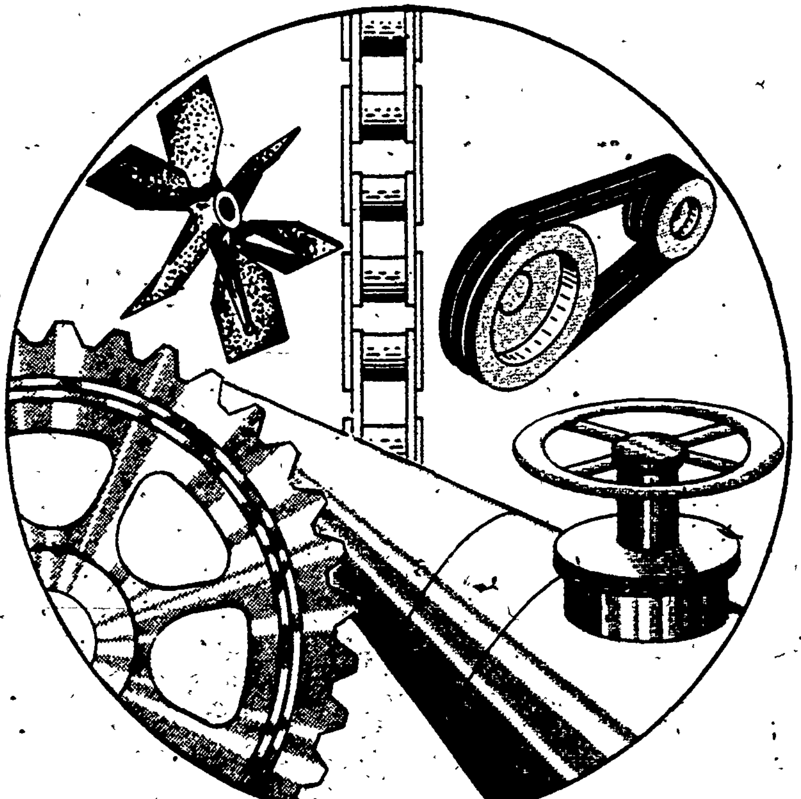
6. List and briefly describe three possible causes and the corrections for each of these fan or blower problems: low output, bearing failure, and excessive vibration and noise.

7. A fan delivers 13,100 CFM of air at a 500 r/min motor speed against a static pressure of 1.5" of water. The motor input is 5.0 HP. If the volume is increased to 17,000 CFM, what is the speed? And, what is the static pressure and the power?

ENERGY TECHNOLOGY

CONSERVATION AND USE

MECHANICAL DEVICES AND SYSTEMS



MODULE MS-08

VALVES

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

INTRODUCTION

Valves are devices that regulate the flow of fluids and gases; they have evolved from the simple plug valve used to stopper a cask of ale to the many complex industrial valves used today. Valves are an integral part of modern industry; come in many shapes and sizes; and perform many functions, from simple throttling to emergency relief of dangerous pressure.

This module discusses the variety of valves that the technician may encounter, their uses, applications, design, characteristics, advantages, and disadvantages. Procedures are outlined for the selection of valves for particular applications. This module provides general maintenance guidelines for valves, although specific maintenance procedures for a given valve are specified only in the manufacturers literature.

PREREQUISITES

The student should have completed one year of high school algebra.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Given an unlabeled sketch of a typical valve, identify the following components:
   a. Movable closure element.
   b. Movement of flow control element.

c. Flow seals.

d. Stem seals.

2. List the six general valve functions.

3. Given a sketch of any or all of following types of valves, identify each valve correctly; cite at least one specific application, advantage, or disadvantage of each; and describe design characteristics that distinguish each:

   a. Ball.
   b. Taper plug.
   c. Gate.
   d. Butterfly.
   e. Swing.
   f. Poppet.
   g. Pinch.
   h. Globe.
   i. Needle.

4. Given a table of "Materials for Valves" and the proper name of the fluid that will pass through the valve, determine the best material for the valve.

5. List at least four examples of the kind of information commonly marked on valves.

6. Describe design characteristics that distinguish any or all of the following types of actuators:

   a. Mechanical.
   b. Automatic mechanical.
   c. Hydraulic.
   d. Electric.
   e. Pneumatic.

7. Cite four general procedures to be followed when inspecting a valve.

8. Give at least one specific application, advantage, or disadvantage for each of the following types of packing:
   a. Braided and twisted.
   b. Fabric and rubber.
   c. Metallic.
   d. Plastic.
   e. Die molded.
9. Describe the general procedures used to replace worn packing.

COMPONENTS AND OPERATING PRINCIPLES

Valves are devices used to regulate the flow of fluids in piping systems or in machinery. They are constructed from a wide variety of materials and can be classified according to construction or function. Most valves are manufactured and marketed as off-the-shelf hardware items and meet standards set forth by various national organizations. Figure 1 depicts a "typical" valve.

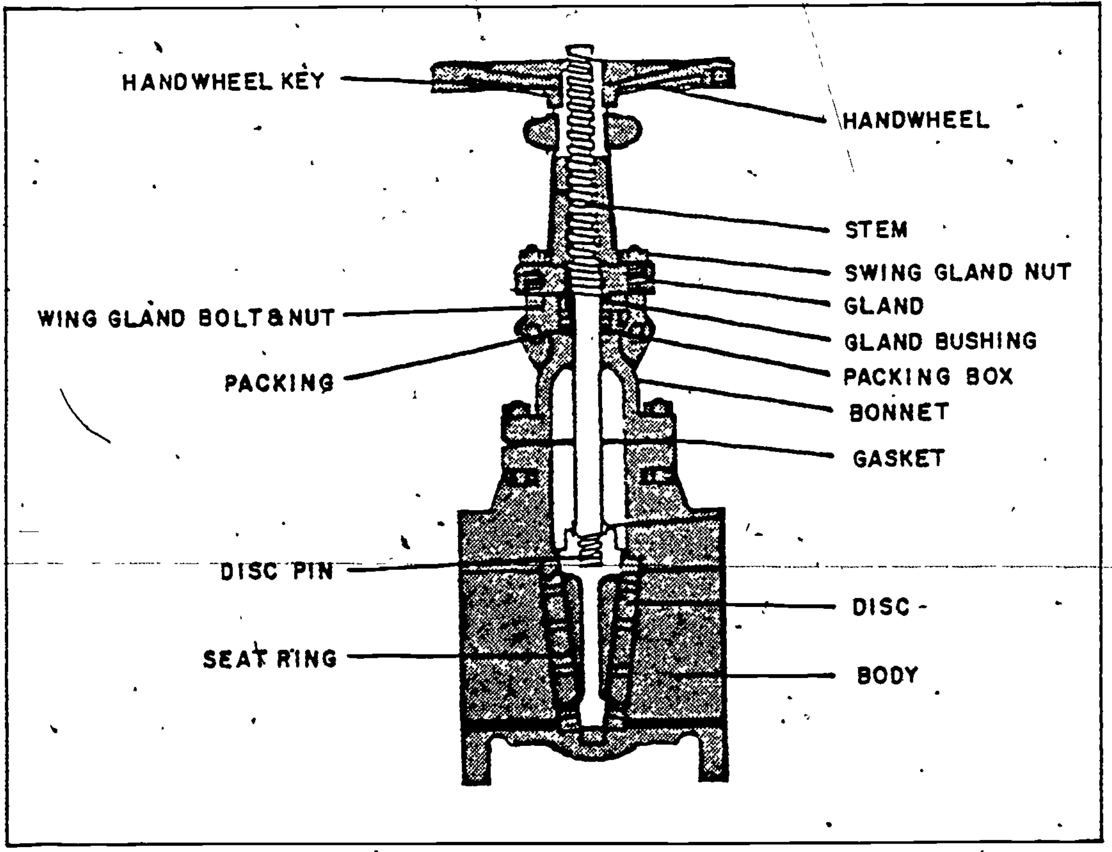


Figure 1. Gate Valve.

The valve illustrated in Figure 1 is in the closed position. As the hand wheel is turned counterclockwise, the yoke bushing causes the stem to rise. The stem pulls the disc up out of the stream flow. As the hand wheel is turned, the swing gland forces leakproof packing around the stem in such a manner that the liquid or gas from the stem cannot leak around it.

These are the chief elements of a valve:

- A body, or housing, able to withstand the internal pressure of a fluid, directs the fluid in a suitable path and supports the other valve components.
- A movable closure element (disc, ball, or plug) that can reduce or stop the flow through the valve.
- A device to position the movable element, called the "movement of flow control element."
- A seal around the stem to allow the stem to move without leaking fluid out of the housing.

The movable closure elements are also known as "flow control elements." In general, there are four basic valve designs employed to control flow:

- A disc or a plug is moved against an orifice (hole).
- A flat, cylindrical, or spherical surface is slid across an orifice.
- A rotating disc is placed in the path of fluid flow.
- The flow is allowed to move through flexible tubing pinched to produce the proper flow.

All valves use one or more of these methods.

Rotating stems, clamps, springs, and even air pressure can be used to position the movable element. Wheels, levers, floats, ratchets, and automatic devices actuate (put into motion) the movement of flow-control devices.

Valves must be sealed to prevent leakage of the fluid and to prevent outside air from leaking into the unit:

- Flow seals must prevent the fluid from leaking through the closure element when the valve is closed. These seals may be metal to metal, or a metal that contacts a resilient material.
- Stem seals usually consist of a stuffing box that contains a packing material such as asbestos-graphite, or TFE. (TFE is a resin that exhibits a very high resistance to most chemicals or solvents.)
- Outside seals are provided by a covering called the "bonnet." The bonnet must be removed before access can be gained to the flow control element.

USES OF VALVES

There are six basic reasons for using a valve:

- To start and stop flow.
- To regulate flow.
- To prevent backflow.
- To regulate pressure.
- To relieve pressure.
- To perform special functions such as controlling the direction of flow and sampling flow.

The distinction between pressure regulation and pressure relief is important. Pressure-regulation valves reduce and maintain pressure in the flow stream. These valves operate in specified ranges and automatically reduce and maintain pressure below that of the source. Pressure relief and safety valves are designed to reduce overpressure by "popping" at a predetermined pressure, releasing excess pressure and keeping the system within safe limits.

VALVE TYPES

The ball valve (Figure 2) consists of a metal ball having a hole in it and attached to a handle in such a manner that it can be rotated either to block or to allow flow through the hole. These valves are used with a wide range of fluids and are effective at high temperatures and pressures. They regulate flow as well as turn it on and shut it off. They are lightweight, can be opened quickly, allow solid particles in the fluid to pass, and offer very little resistance to flow. Unfortunately, because they open quickly, they may allow the fluid to surge at undesirable pressures; the ball itself can be deformed by the pressures caused by the sudden stoppage of flow.

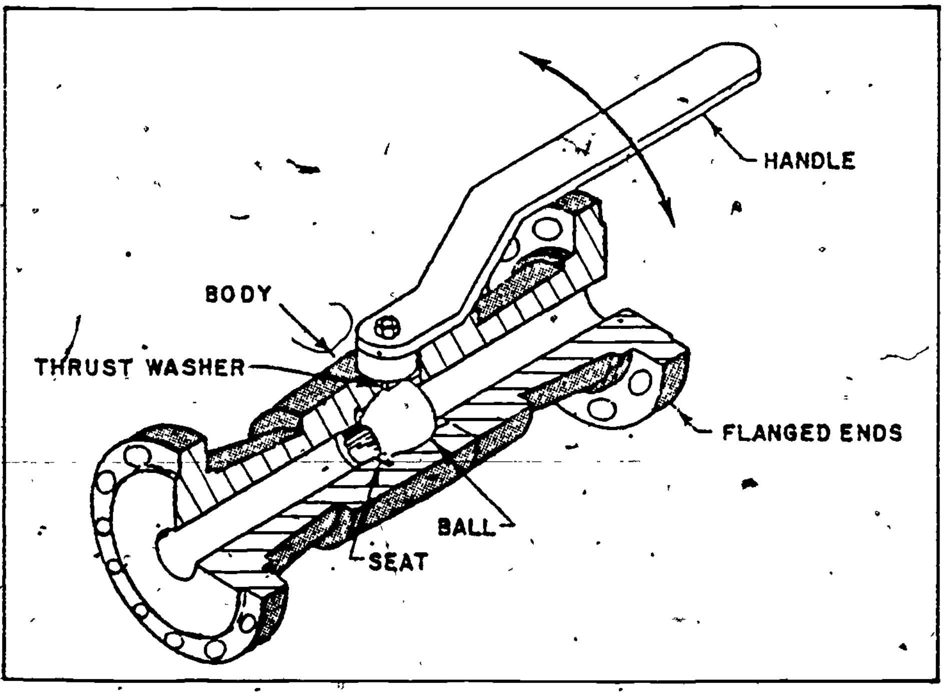


Figure 2. Flanged Ball Valve.

The taper plug valve (Figure 3) is similar to the ball valve, except that the movable closure element consists of a plug instead of a ball. This valve is useful in high-temperature, low-pressure applications. It provides a tight, leakproof seal and requires very little space. Most plug valves require lubrication, since the plug tends to stick and bind unless it is well lubricated. The lubricant itself may cause problems if it passes into the flow stream and contaminates it.

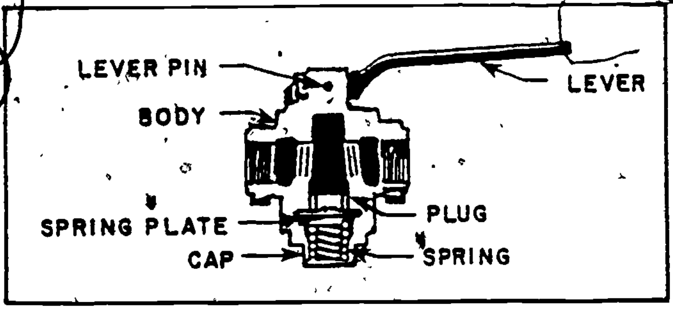


Figure 3. Taper Plug Valve.

Gate valves (Figure 1) operate by the raising or lowering of a wedge or a disc into the stream of flow and are always in a fully open or closed position. There are many design variations, one of which is the Knife Gate Valve. Gate valves are available in a wide assortment of sizes and weights and are particularly useful in high-temperature and high-pressure applications. They provide a tight seal, but they open and close rather slowly and require more effort from the operator.

The butterfly valve (Figure 4) resembles the knife gate valve, except that the stopping plate remains in the flow and can rotate to block it. The plate is mounted on a shaft in a housing and closes against a ring seal to shut off flow. These valves normally are used in large-diameter lines in which pressure is low and leakage is relatively unimportant. Special seals are required to prevent leakage, and these seals often are damaged by the flow pressure. Since the

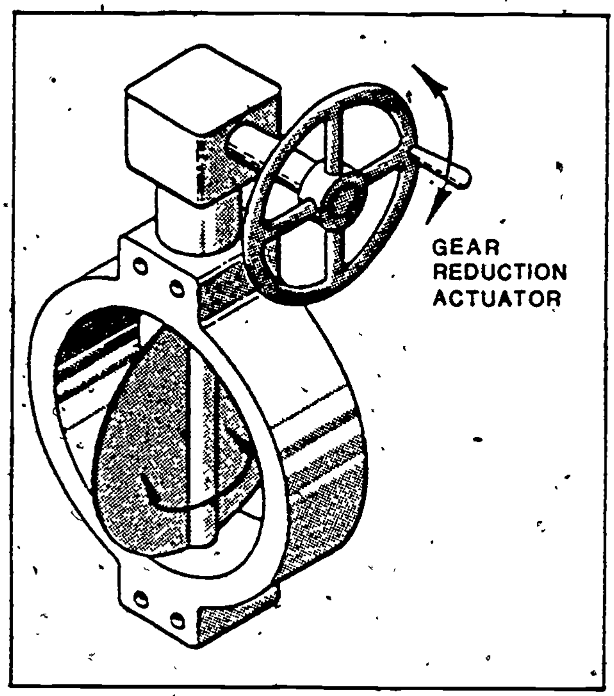


Figure 4. Butterfly Valve.

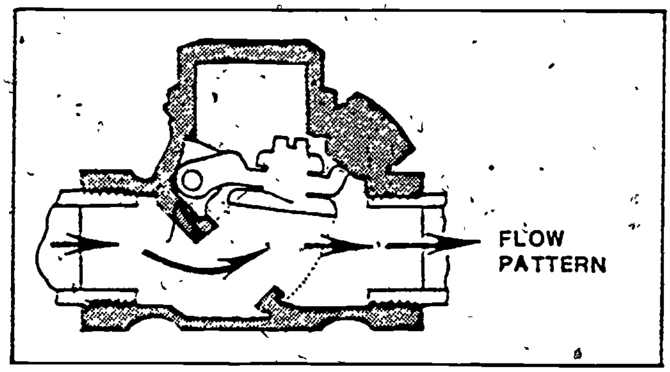


Figure 5. Swing Check Valve.

stopping plate is actually in the flow, a large force is required to close these valves.

Swing valves, often called "swing check valves" (Figure 5), are used almost exclusively to prevent the reverse flow of fluid in a system. A plug or a disc is mounted on an arm and hinged to fall over the opening in the valve when flow through the valve reverses. The higher the reverse pressure on the valve, the tighter it seals. Although these valves are plagued by the same problems as the butterfly valves (leakage and valve-seat wear), they also share many of the butterfly valve's advantages.

Poppet valves are used mainly in pressure control, check, and safety. A spring or similar device holds a plug against the valve seat and the flow. When pressure on the input side is too high and the pressure on the output side too low, the pressure exerted by the spring against the flow is overcome, and the valve pops open. These valves can provide a large flow and excellent leakage control. They are, however, subject to pressure unbalances, which can cause the valve plug to jump erratically.

The pinch valve (Figure 6) consists of a rubber sleeve, known as a "body," which, when pinched in the middle, restricts flow through it. Pinch valves can be operated by clamps or by high-pressure air pumped into a case around the body. They are useful in systems that handle fluids containing suspended solids such as woodmill pulp, raw sewage, or sludge. They can be closed tightly, but the forces requires to close them are rather high. They generally are limited to low-pressure and low-temperature applications. The flexible material from which the body is made fatigues rather rapidly and must be replaced.

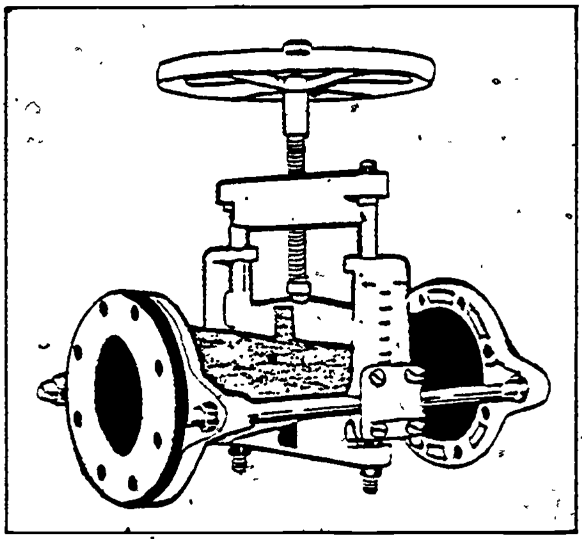


Figure 6. Pinch Valve.

The globe valve (Figure 7) superficially resembles the gate valve, which is designed merely to shut off flow. The globe valve, however, is designed to control flow. The sliding disc of the gate valve is moved perpendicular to the actual flow; the disc or plug of the globe valve is perpendicular to a ring shaped seat, which may be at any of several angles to the flow.

The angle valve and Y-globe valve are variations that differ in the angle and placement of the seat. In all three types the flow passes from the inlet port through the seat to the outlet port.

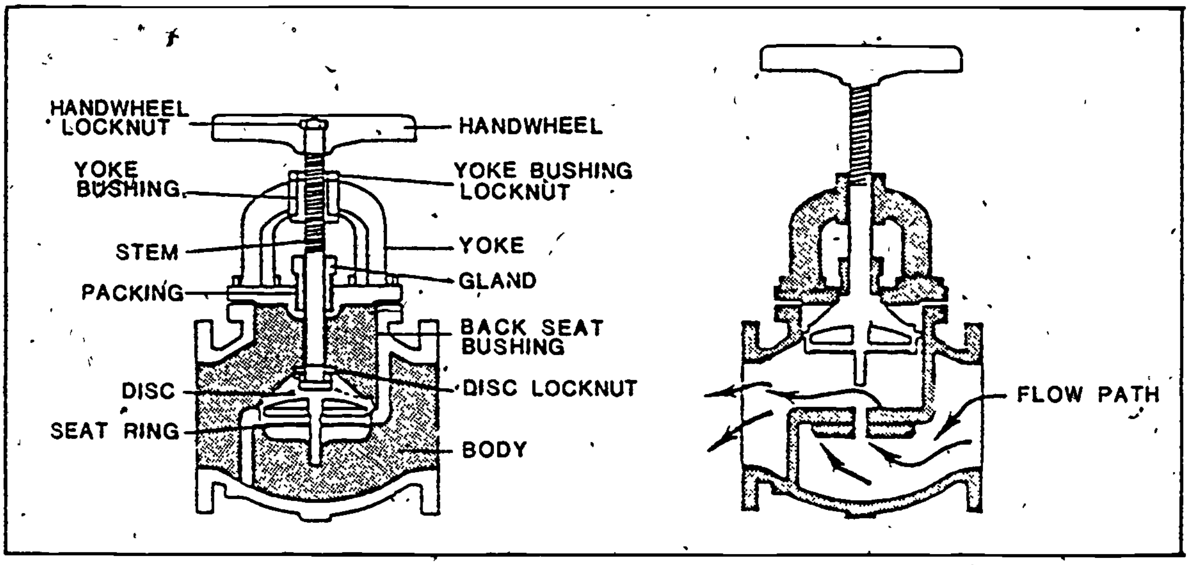


Figure 7. Globe Valve.

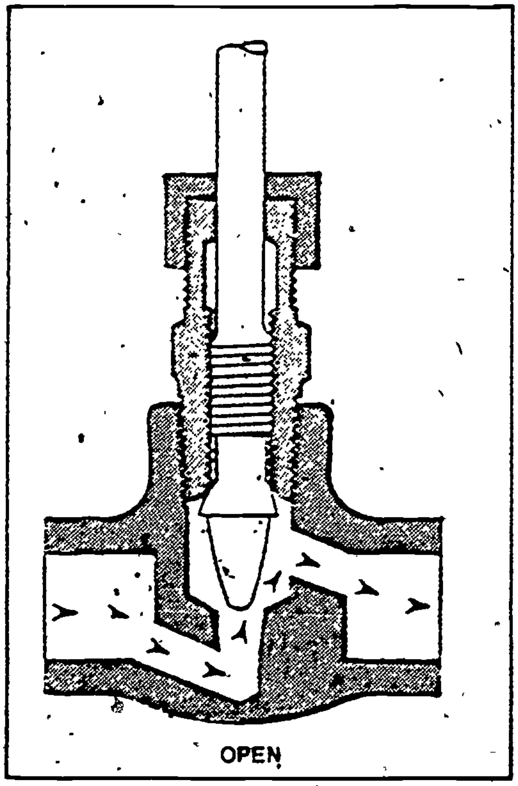


Figure 8. Needle Valve.

The globe valve can be opened and closed quickly but, in large sizes, requires large amounts of force to activate. Their seating surfaces are less subject to wear, and they are more leak resistant than gate valves.

Needle valves (Figure 8) operate according to the same principle as globe valves, but use cones or needles as closing devices (Figure 8). Needle valves typically are used in very low-volume applications, but can withstand high temperatures and pressures.

MATERIALS FOR VALVES

Valves are manufactured from a variety of materials. Table 1 lists some typical valve materials and the applications to which they are best suited. The materials from which a valve is constructed are directly related to the corrosiveness, abrasiveness, or other special properties of the fluid that must pass through it, and to the operating pressure and temperature of the system. Table 1, for example, indicates that valves through which hydrochloric acid must flow can be made of any of a number of materials, including aluminum and bronze. When a valve is selected for a specific application, similar tables must be consulted.

TABLE 1. MATERIALS FOR VALVES.

	Aluminum	Bronze	Cast Iron	Carbon Steel	Ductile Iron	Monel	Neoprene	Stainless Steel
Alcohol	✓	✓	✓	✓	✓	✓		✓
Ammonia	✓	✓	✓	✓	✓	✓		✓
Brine		✓		X	✓	✓		X
Chlorine	X	X			X	X		X
Gasoline	✓	✓	✓	✓	✓	✓	✓	✓
50-100% Hydrochloric Acid	X	X	X	X	X	✓		X
Nitric Acid 40%	✓	✓	✓	✓	✓	✓	X	✓

X Not recommended.

✓ Recommended.

VALVE CODES AND MARKINGS

A number of regulating organizations are responsible for setting standards for valves and valve components. Some of these standards are industry wide; others – such as the specifications set down by the Nuclear Regulatory Commission – are applicable to a particular industry. Table 2 lists some of the more common regulatory agencies and groups.

TABLE 2. REGULATORY AGENCIES.

American Bureau of Shipping (ABS)
American National Standards Institute (ANSI)
American Nuclear Society (ANS)
American Petroleum Institute (API)
American Society of Mechanical Engineers (ASME)
American Society of Testing and Materials (ASTM)
American Water Works Association (AWWA)
Manufacturers Standardization Society of the Valve and Fitting Industry (MSS)
National Electrical Manufacturers Association (NEMA)
Nuclear Regulatory Commission (NRC)
United States Coast Guard (USCG)

When valves are manufactured, they are marked with a variety of symbols that specify the type of fluids the valve is designed to carry, the recommended pressure rating, the type of service for which it is intended, and the specifications it meets. Figure 9 depicts a typical valve and its markings.

The marking "125S" indicates that the valve service rating is 125 lbs. of steam. This means that for temperatures lower than the temperature of steam, the safe working pressure is greater. The letters WOG indicate that the valve is suitable for transporting water, oil, or gas. The best guide to the interpretation of markings on a valve are manufacturers' handbooks.

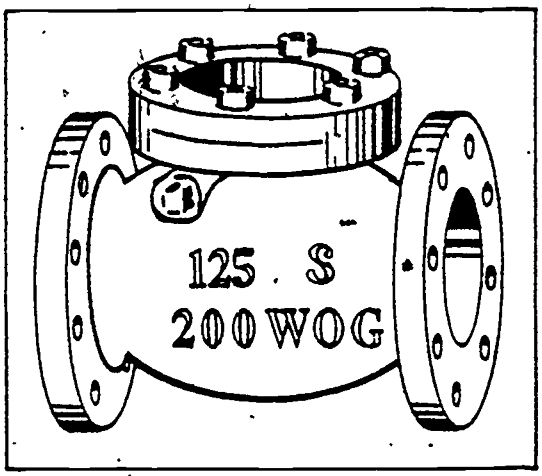


Figure 9. Typical Valve Markings.

VALVE ACTUATORS

Valves open and close only if mechanically actuated — something or someone must raise, lower, or turn the movable closure element. Many valves rely upon automatic controls; many others are activated manually.

Mechanical actuators include wheels, chain wheels, gear drives, levers, floats, ratchets, and many other devices. Mechanical actuators often are used as backups for automatic systems.

There are several categories of automatic actuators: hydraulic, pneumatic, electric, and mechanical.

Automatic mechanical actuators consist of the same kind of mechanical configurations as manual actuators, but are operated automatically. The float valve is an example (Figure 10); it automatically controls the level of fluid in tanks.

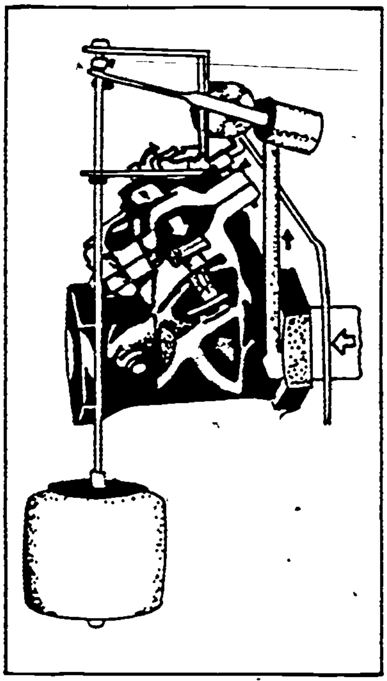


Figure 10. Float Valve.

Electrical valve actuators may be either motor operated (Figure 11) or solenoid operated (Figure 12). Motor drives invariably are a combination of an electric motor and speed reducing gearbox; they usually are backed up by a manual actuator. The solenoid is an electromagnet that raises and lowers the valve stem as it alternately is magnetized and demagnetized. In Figure 12a, the solenoid is energized, causing the core to move upward, to compress a spring, and to open the valve. In Figure 12b, the process is reversed when the electrical power is switched off.

In either hydraulic or pneumatic actuators, a spring-loaded diaphragm is attached to the valve stem (Figure 13). When there is no pressure of hydraulic fluid or air on the diaphragm, the spring lifts the valve stem and opens the valve. When pressure is exerted, the spring lowers the stem and closes the valve.

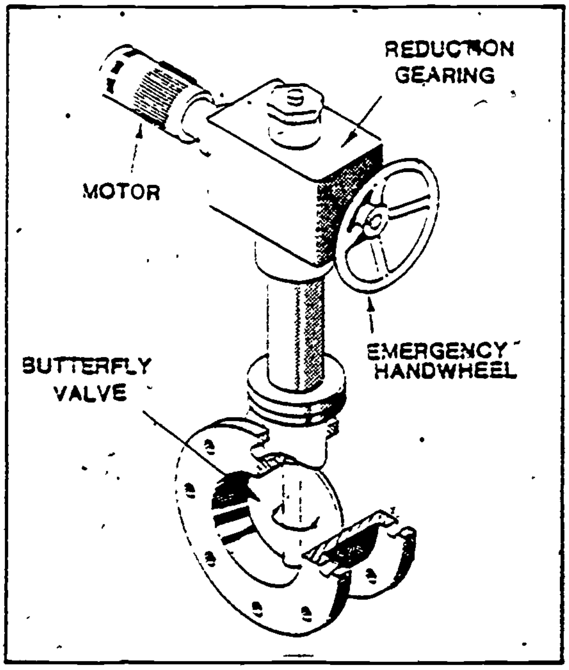


Figure 11. Motor-driven Valve Actuator.

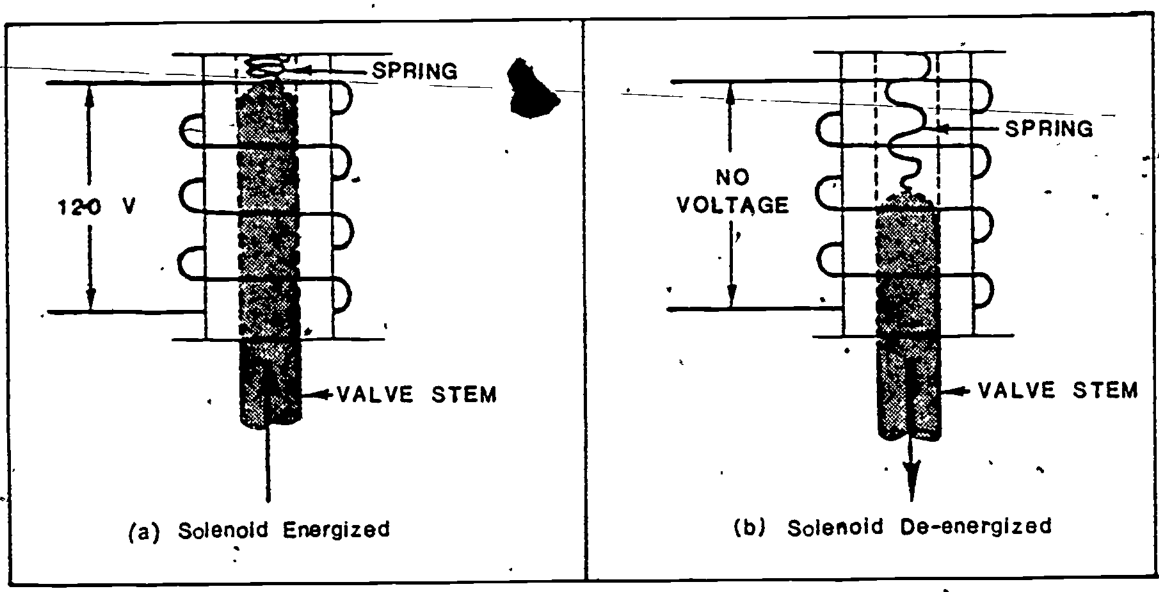


Figure 12. Electrical Valve Actuators.

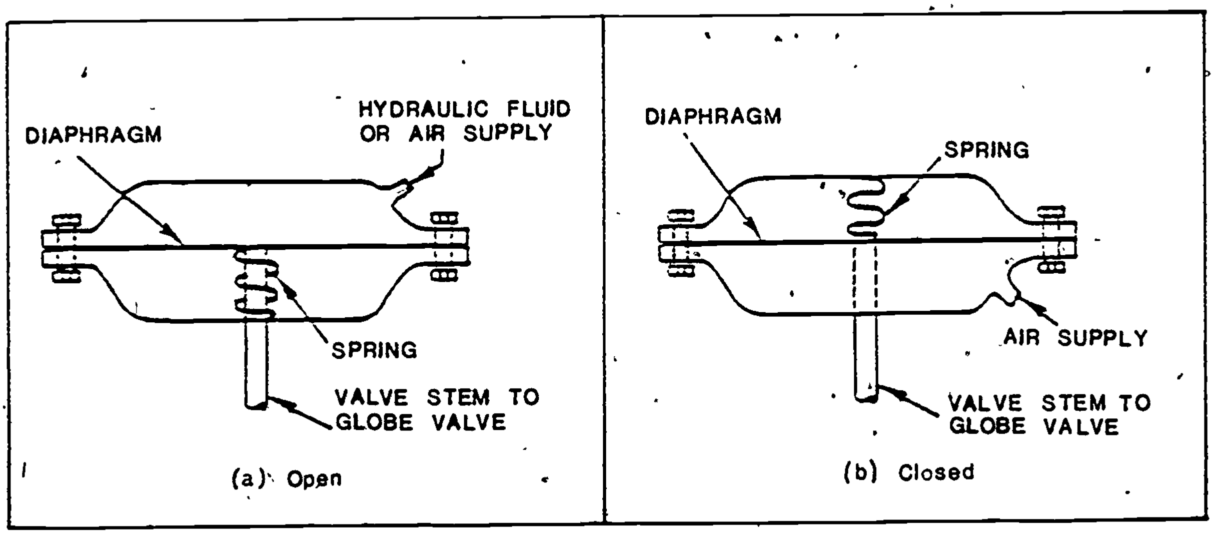


Figure 13. Diaphragm Actuators.

WHEN AUTOMATIC CONTROLLERS ARE USED

Such diaphragm valves often are connected to, and operated by, remote automatic controllers. They regulate pressure, back pressure, or temperature. These automated valves are a vital part of many chemical and manufacturing operations.

Whether or not automatic controllers are used depends upon a number of variables; however, they frequently are installed under the following conditions:

- The desired pressure- or temperature-control point is beyond the range of self-operated or piloted control valves.
- Closer control is required than can be achieved with a self-operated or piloted control valve.
- The process being controlled requires wide proportional band, automatic reset, and/or derivative action.
- The control instrument is mounted on a remotely-located board.
- Cascade control is required (one controller used to reset another).
- The pressure drop is too small for self-operated or piloted control valves.
- Extra power is needed to assure positive valve opening after prolonged shut-off.
- Extreme pressure reductions are necessary in a single stage.
- The controlled process is a variable other than pressure, temperature, or liquid level.

VALVE MAINTENANCE

Valves should be checked periodically for leaks and for proper lubrication. The manufacturer's handbook is the best guide for maintenance, although the following procedures generally should be followed:

- Lubricate valve stem.
- Inspect bonnet for leaks.
- Inspect packing area for leaks.
- Lubricate packing gland; replace packing if necessary.

DANGER!! BE SURE THAT THERE IS NO PRESSURE ON THE VALVE BEFORE LOOSENING ANY FITTINGS OR JOINTS.

The following steps are recommended:

- Close inlet shut-off valve.
- Allow pressure to bleed off toward downstream piping. Do not cause a reverse flow by bleeding pressure from upstream side of valve.
- When downstream pressure gage indicates no pressure in the line, close the outlet shut-off valve.
- Close the control-line shut-off valve.

Packing-gland lubricants usually are graphite- or molybdenum-base types such as FEL-PRO or NEO-LUBE. These lubricants ease operation of the stem as it slides through the packing without comprising leak tightness.

Inadequate valve packing is one of the greatest causes of maintenance problems. Packing keeps fluid from leaking out of the valve through the actuator stem hole (Figure 14).

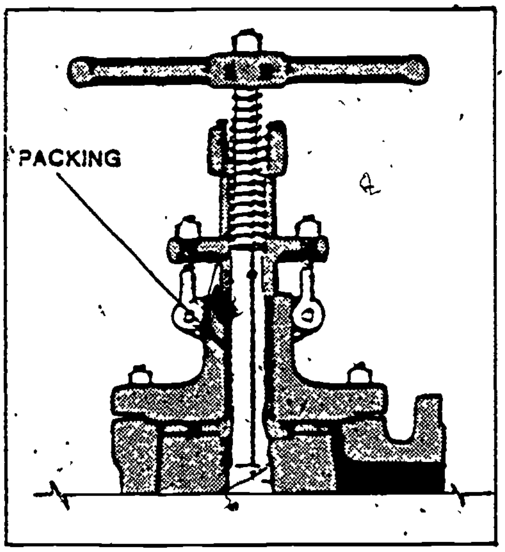


Figure 14. Valve Packing.

Several types of packing material are used:

- Braided and twisted packings.
- Fabric and rubber packings.
- Metallic packings.
- Plastic packings.
- Die molded packings.

Briaded and twisted packings frequently are constructed of asbestos yarn impregnated with various materials such as graphite, beeswax, and mineral fat.

Regular braid packing is flexible and easily conforms to stuffing boxes. It is especially suited for high speeds and high pressures.

Braid-over-braid packing can be braided round or square at the time of manufacture. It holds its lubrication well, and its density enables it to withstand high pressures. This type of packing will stop leaks even when the stem is misaligned with the barrel.

Twisted packing is practical for emergency use. Because its strands are easily undone, they can be twisted to the desired size by using only the number of strands needed.

Diagonally-braided packing combines the toughness and density of braid-over-braid with the flexibility of regular packing. It is suited especially for application around small valve stems.

Cotton duck and asbestos packing are formed with rubber into rings, spirals, or coils to produce fabric and rubber packings. They can be treated with glycerol and graphite lubricants and are a good general-utility packing.

Metallic packings are made from metallic foil wrapped over a nonmetallic core (usually asbestos). They are used in high-temperature and high-pressure applications.

Plastic packings usually are made of asbestos combined with binding plastics and lubricants. TFE packings are a type of plastic packing produced from the TFE resin. These packings are soft and readily formable and are suited especially to the sealing of gasses and highly-mobile liquids. TFE packing is used for highly-corrosive materials.

Die-molded packings are a general category that includes all packing materials in a molded form. This mold ensures a tight fit around the stem and generally is more leak resistant than jam type packing.

Each type of packing is suited to specific applications; therefore, valve construction and operating conditions will affect the ultimate packing choice.

Replacement of worn packing is the most common maintenance procedure associated with valves. Some general procedures are outlined below:

- Make sure that there is no pressure on the valve.
- Follow manufacturer's instructions to remove old packing.
- Ensure that packings are clean. Dirt and abrasive materials should not come in contact with packing.
- Clean stuffing box thoroughly.
- Replace with all new packing. Follow manufacturer's instructions.
- Reassemble unit.
- Adjust per manufacturer's instructions.

EXERCISES

1. Use Table 1. What valve materials should be used with the following fluids?
   a. Lactic acid.
   b. Kerosene.
   c. Lead acetate.
2. What types of valves are suited best to the following applications?
   a. Pressure control.
   b. A large volume of a low-temperature fluid under low pressure.
   c. Preventing the reverse flow of a fluid.
   d. A high-temperature fluid under high pressure. The valve must be quick opening.
   e. Very low volume of fluid under fairly high pressure.

LABORATORY MATERIALS

1 each – ball, butterfly, gate, knife gate, globe, needle, pinch, poppet, swing, and taper plug valves and appropriate manufacturers literature. (The instructor should label each valve with a different number, from one to ten, as required by Step 1 and Data Table 1.)

Valve grease – FEL-PRO, NEOLUBE, or similar product.

Valve packing materials – spiral and die-molded ring.

Paper and pencil.

Toilet flush mechanism.

Assortment of hand tools, including packing pullers.

LABORATORY PROCEDURES

1. Observe the various valves on display. Using Data Table 1, note the valve type, body markings, and the meaning of those markings. The valves are marked with a code number that corresponds to a blank in the Data Table.
2. Using Data Table 2, record at least one of each of the advantages and disadvantages of the listed valve designs.
3. Using Data Table 1, record in Data Table 3 the recommended construction materials.
4. Disassemble, sketch, and identify parts; and reassemble the flush toilet valve actuator system. Describe how this valve works.
5. Disassemble, sketch, and identify parts; and reassemble a common industrial valve. Relubricate and repack valve during reassembly. Identify all areas of wear.

DATA TABLE 1.

Valve #	Valve Type	Body Markings	Explanation (Working Fluid & Pressure)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

DATA TABLE 2.

Valve Type	Advantages	Disadvantages
Ball		
Butterfly		
Gate		
Knife Gate		
Globe		
Needle		
Pinch		
Poppet		
Swing		
Taper plug		

DATA TABLE 3.

Working Fluid	Max. Temp.	Recommended Construction Materials
1. Alcohol		
2. Ammonia (liquid)		
3. Brine		
4. Chlorine		
5. Gasoline		
6. Hydro-chloric acid		
7. Nitric acid (concen-trated)		

REFERENCES

Berger, J. R. Control-Valve Compendium. Pittsburgh: Instrument Society of America, 1973.

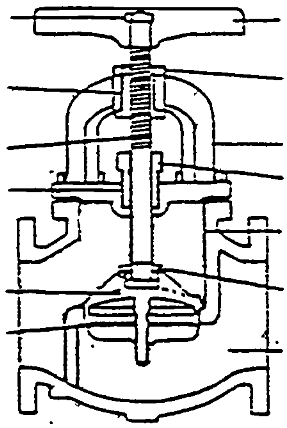
Hutchison, W. J. ISA Handbook of Control Valves. Pittsburgh: Instrument Society of America, 1973.

Jordan Valve. Latest valve catalogs. Cincinnati, OH: Jordan Valve (Division of Richards Industries, Inc.), 1978.

Lyons, J. L. and Ashland, C. L. Lyon's Encyclopedia of Valves. New York: Van Nostrand Reinhold Co., 1975.

Schweitzer, P. A. Handbook of Valves. New York: Industrial Press, Inc., 1972.

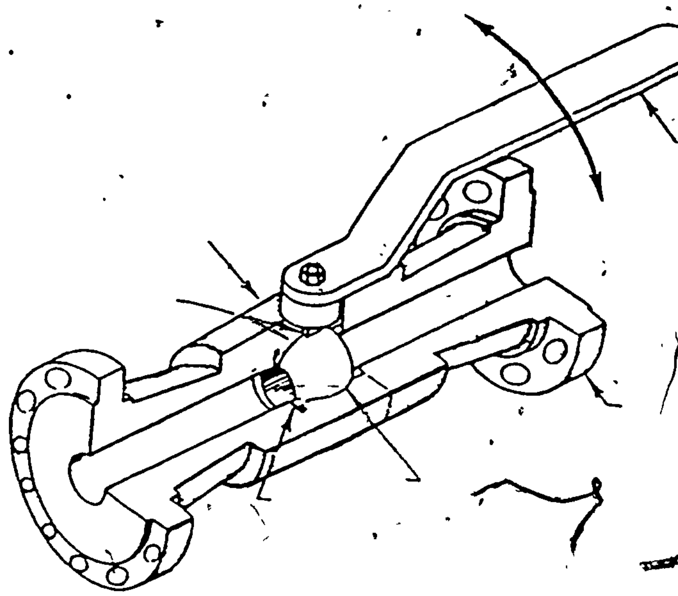
1. On the unlabeled sketch below, identify the valve components:
   a. Movable closure element.
   b. Movement of flow control element.
   c. Flow seals.
   d. Stem seals.



2. List the six general valve functions.
   a.
   b.
   c.
   d.
   e.
   f.

3. Identify each of the valves sketched below, cite at least one specific application, advantage, or disadvantage of each; and describe the design characteristics that distinguish them:

a.

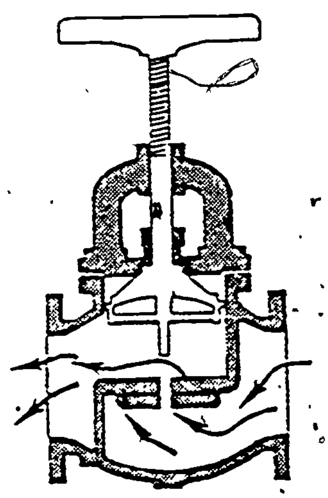


Advantage:

Disadvantage:

Design characteristic:

b.

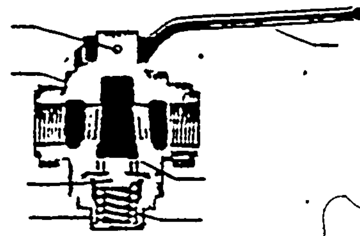


Advantage:

Disadvantage:

Design characteristic:

c.
Advantage:



Disadvantage:

Design characteristic:

4. What materials should be used for the following valves and working fluids? Use Table 1.
   a. Alcohol:

   b. Brine:

   c. Salt water:

5. List four examples of the type of information commonly marked on valves.
   a.

   b.

   c.

   d.

6. Describe the design characteristics which distinguish:

a. Mechanical actuators:

b. Automatic mechanical actuators:

c. Pneumatic actuators:

7. What four general procedures should be followed when inspecting a valve?

a.

b.

c.

d.

8. List one specific application, advantage, and disadvantage of the following types of packing:

a. Braided and twisted:

b. Fabric:

c. Metallic:

d. Plastic:

e. Die-molded:

9. What procedures should be followed to replace worn packing?

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