

Fig. 1 (Left) — Bevel gears. These shafts intersect at a right angle, although bevel gears may also be used between shafts that intersect at larger or smaller angles. (Courtesy Mobil Oil Corporation.)

This article is an excerpt from Machine Design Fundamentals, John Wiley & Sons, Inc., Publisher.

Transmission of power between non-parallel shafts is inherently more difficult than transmission between parallel shafts, but is justified when it saves space and results in more compact, more balanced designs. Where *axial* space is limited compared to *radial* space, *angular* drives are preferred despite their higher initial cost. For this reason, angular gear motors and worm gear drives are used extensively in preference to parallel shaft drives, particularly where couplings, brakes, and adjustable mountings add to the axial space problem of parallel shaft speed reducers.

In angular drives, the gears not only rotate in different planes, but contact is frequently diagonal across the face of mating teeth (Fig. 1). Such gears are generally more difficult to design, manufacture, and install and thus cost more than equivalent spur and parallel-axis helical gears. They are also more sensitive to mounting and manufacturing errors. In addition, mounting on overhanging shafts makes some types sensitive to shaft deflections. As with spur and helical gearing, optimum design becomes a compromise. Two general classifications cover the right-angle gears: *coplanar* types, which have intersecting axes, and *offset* types, which have nonintersecting or skew axes (their axes do not lie in a common plane).

Bevel Gears

Bevel gears provide the most *efficient* means of transmitting power between intersecting shafts. The related friction wheels are frustrums of cones, and the

Gears For Nonparallel Shafts

by
Dr. Uffe Hindhede
Black Hawk College
Moline, IL

gears developed on these conical surfaces are called bevel gears. If teeth are cut straight across the faces of conical blanks, the gears are called *straight bevel*; when the teeth are twisted along a curved path, the gears are termed *spiral bevel* (Figs. 1 and 2.) The involute tooth form is used.

Customarily, tooth dimensions are determined in a transverse plane (perpendicular to the common element of the pitch cones) at the *large* end of the teeth (Fig. 3a). Intersection of tooth surfaces with this plane gives a tooth profile as shown in Fig. 3b. Fig. 3a also shows that the shaft angle equals the sum of the pitch angles. Thus

$$\Sigma = \Gamma_p + \Gamma_G \quad (1)$$

where

Σ (sigma) = shaft angle; deg
 Γ_p (gamma) = pitch angle of pinion; deg
 Γ_G (gamma) = pitch angle of gear; deg

Fig. 3c indicates that the following relationship exists for $\Sigma = 90$ deg.

$$\tan \Gamma_p = \frac{d}{D} = \frac{N_p}{N_G} \quad (2)$$

$$\tan \Gamma_G = \frac{D}{d} = \frac{N_G}{N_p} \quad (3)$$

where

d = pitch diameter of pinion; mm, in.
 D = pitch diameter of gear; mm, in.

N_p = number of teeth in pinion
 N_G = number of teeth in gear

Nomenclature and symbols commonly used for straight bevel gears are shown

in Fig. 4. The similarity to spur gearing should be noted. With few exceptions, the nomenclature also applies to spiral bevel gears.

Equivalent spur gears is a term commonly used in connection with bevel gears. Two bevel gears roll on each other in the same manner as a pair of spur gears with pitch diameters equal to those of the bevel gears. In Fig. 4 the equivalent spur gear would have a pitch diameter D_G .

AUTHOR:

DR. UFFE HINDHEDE is an Associate Professor in the Engineering Related Technology Department at Black Hawk College, Moline, Illinois. He is a graduate of the Technical University of Denmark and the University of Illinois. Hindhede has authored several technical papers and articles. He is the principal author of *Machine Design Fundamentals* and sole writer of the chapter on Gears for Non-Parallel Shafts.

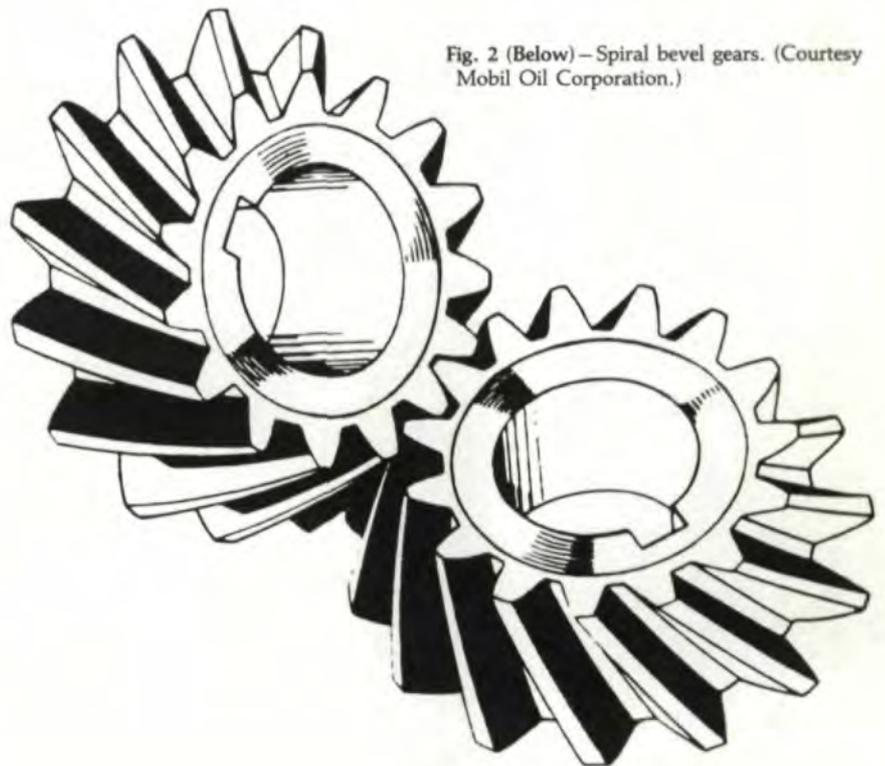


Fig. 2 (Below) — Spiral bevel gears. (Courtesy Mobil Oil Corporation.)

Nomenclature

C	= center distance
d	= pitch diameter of bevel pinion and worm
D	= pitch diameter of bevel gear or worm gear
D_G	= pitch diameter of worm gear
D_w	= pitch diameter of worm
e	= efficiency
L	= lead of worm
m	= module
m_G	= speed ratio
n_G, n_w	= speed of gear and worm, respectively
N_p	= number of teeth in pinion
N_G	= number of teeth in gear
N_w	= number of teeth in worm
p_a	= axial pitch
p_c	= circular pitch
P_d	= diametral pitch
TR	= thermal rating
λ (lambda)	= lead angle
Γ (gamma)	= pitch angle
Σ (sigma)	= shaft angle
ψ (psi)	= helix angle
θ (theta)	= friction angle

The difference between spiral and straight bevel gears is that spiral teeth have a *gradual* pitch line contact and a larger number of teeth in contact. Their teeth, instead of engaging in a full line contact at once, engage with one another gradually. This continuous contact makes it possible to obtain smoother action than is possible with straight bevels.

Arrangement

Bevel gears are widely used where a right-angle change in direction of shafting is required, although the shafts occasionally may intersect at acute or obtuse angles (Fig. 5). When of equal size and mounted on shafts at right angles, they are referred to as *miter* gears (Fig. 5b). A bevel gear with a right (90 deg) pitch angle is a *crown* gear (Fig. 5e). Internal bevel gearing, like internal spur or helical gearing, is sometimes used in planetary or internal gear arrangements (Fig. 5f).

Application

Straight bevel gears, like spur gears,

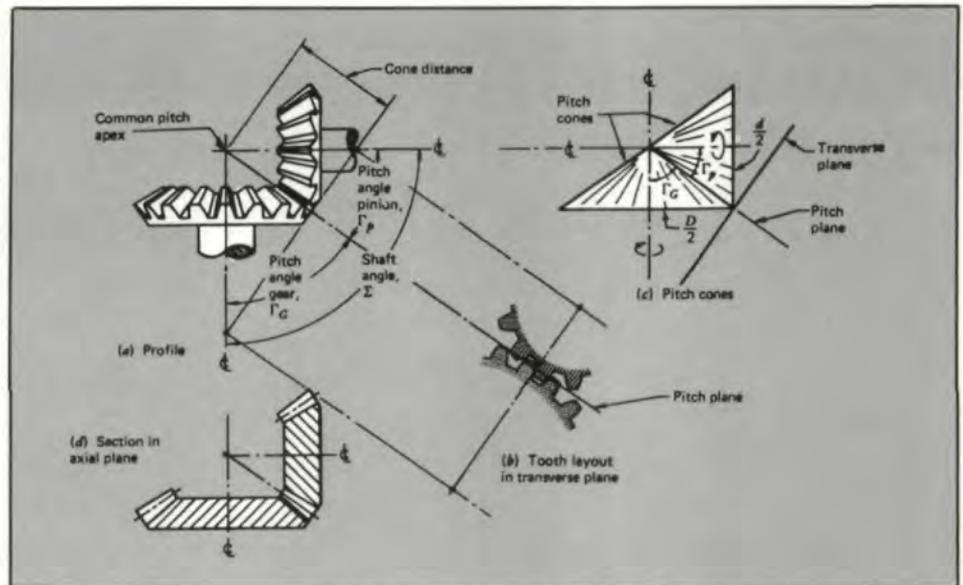


Fig. 3—Basic bevel gear sections. (Courtesy General Motors Corporation.)

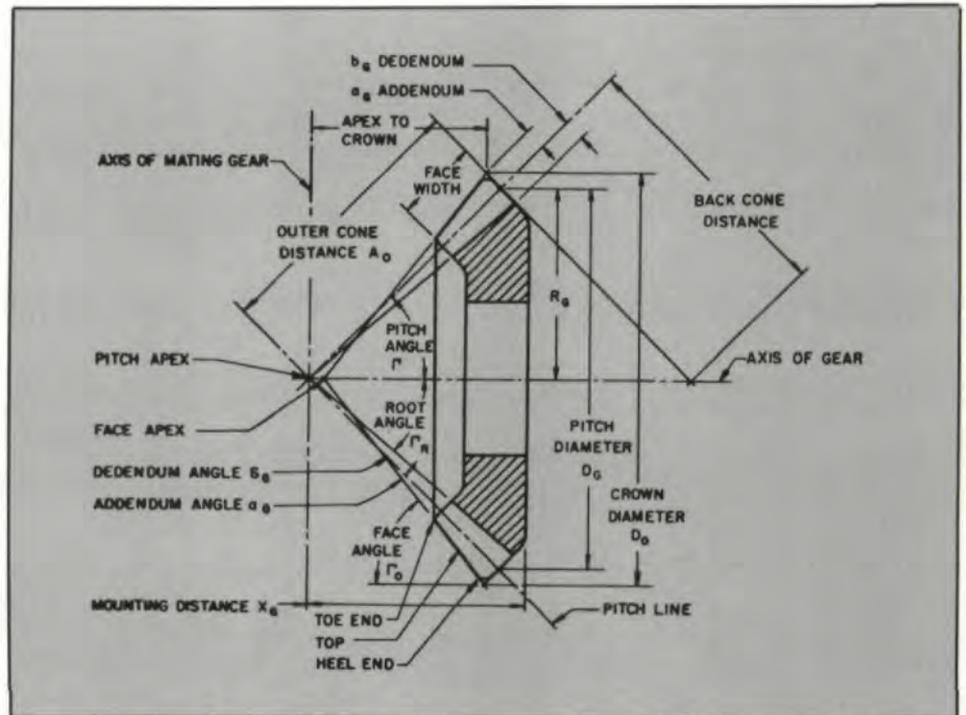


Fig. 4—Nomenclature for bevel gears. (Courtesy General Motors Corporation.)

are well suited for manual and low-speed operations, such as in small hoists, valves, gates, or doors. When greater speed and more power are required, spiral bevel gears are preferable.

Mounting

Bevel gears require larger shaft diameters and heavier bearings because they impose high reaction loads on bearings.

Speed Ratio

As in spur gears, the speed ratio is the

ratio of tooth numbers. For bevel gears, it is also the ratio of corresponding pitch radii or diameters of the pitch cones (Fig. 4).

Design of Bevel Gears

Bevel gears are simple modifications of spur gears. Beam straight and surface durability determine size and surface hardness. The AGMA formulas used are therefore simple modifications of the formulas used for calculating spur gears.

Example 1

A pair of straight-toothed bevel gears

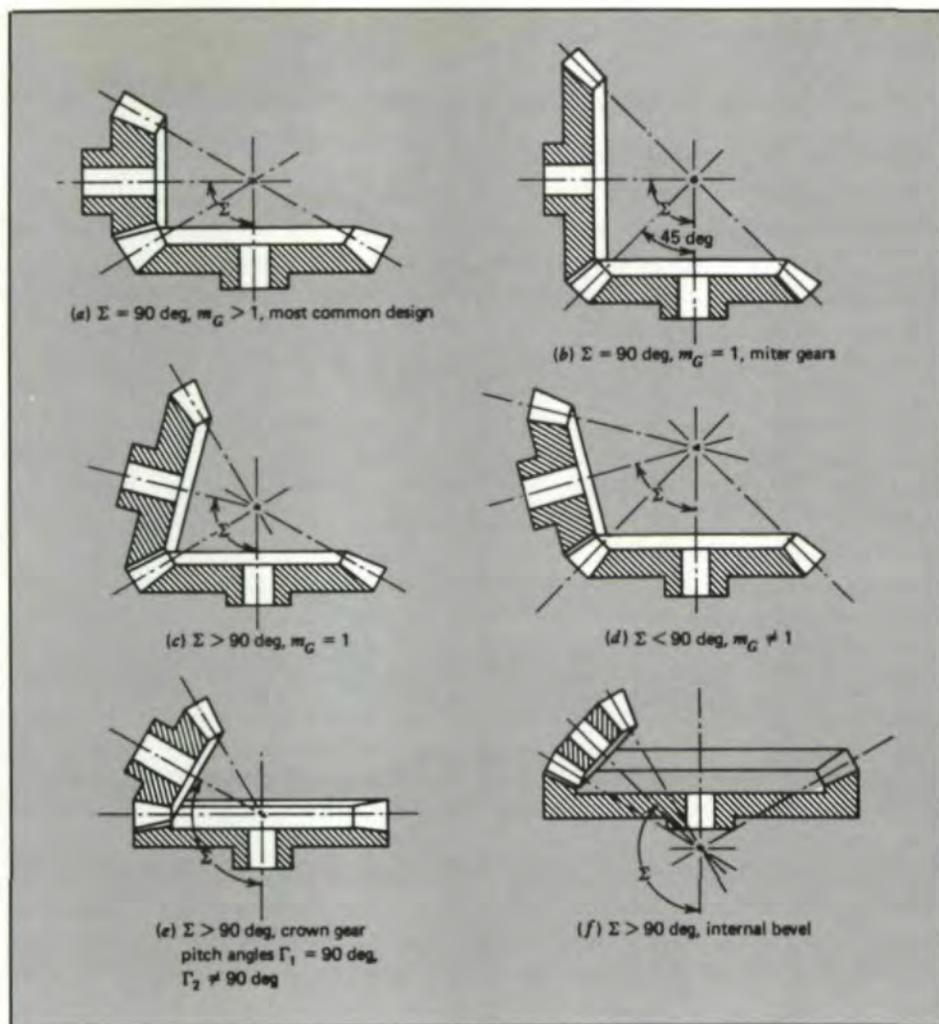
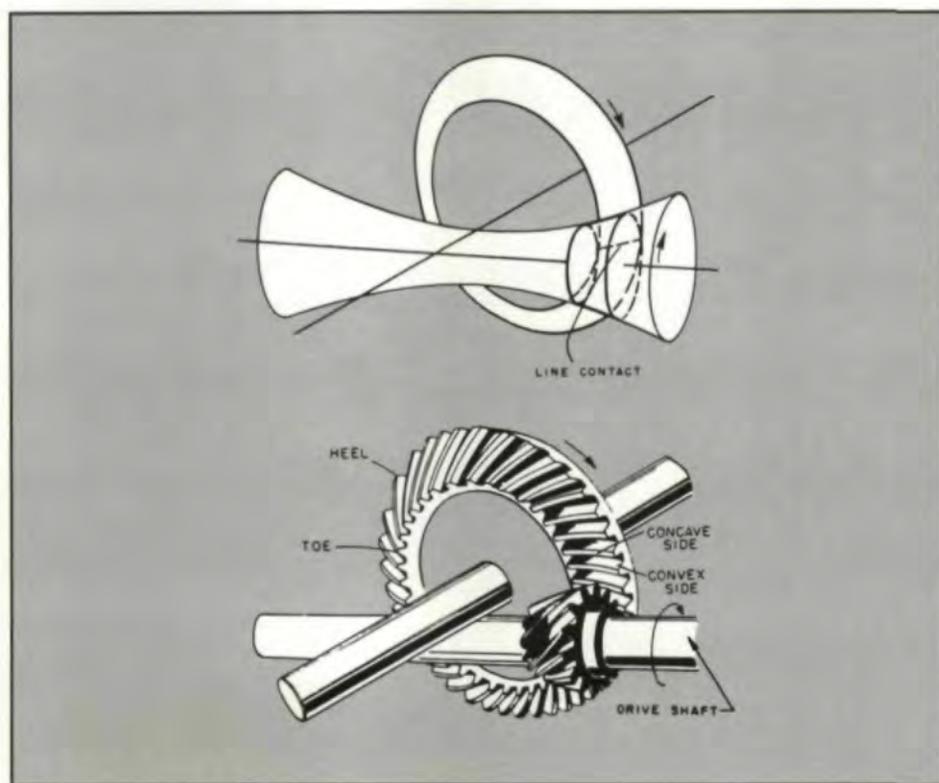


Fig. 5—Bevel-gear arrangements. (Courtesy General Motors Corporation.)



are to be designed for a shaft angle of 90 deg and a reduction ratio of roughly 3:1. If the pinion is to have a minimum of 17 teeth, find pitch angles and the number of teeth in the gear.

Solution

$N = (3)(17) + 1 = 52$ leads to a hunting ratio equal to 3.06:1. Assuming a module m , we obtain for the equivalent spur gears:

$$d = m (17 \text{ mm}) \quad D = m (52 \text{ mm})$$

$$\tan \Gamma_p = \frac{N_p}{N_G} = \frac{17}{52} \rightarrow \Gamma_p = 18.1 \text{ deg}$$

$$\tan \Gamma_G = \frac{N_G}{N_p} = \frac{52}{17} \rightarrow \Gamma_G = 71.9 \text{ deg}$$

Check:

$$\begin{aligned} \Sigma &= \Gamma_p + \Gamma_G = 18.1 \text{ deg} + 71.9 \text{ deg} \\ &= 90 \text{ deg} \end{aligned}$$

Hypoid Gears

Hypoid gears closely resemble spiral bevel gears except that the pinion does not meet the ring gear at its center. It meets it at a lower point (Fig. 6). The pitch surfaces are hyperboloids from which the term "hypoid" was derived. Curved teeth contribute to smooth, noiseless operation even at high speed.

Hypoid gears grew out of a need for silent automotive differentials that would also allow the drive shaft to be placed well below the centerline of the rear axle, thus contributing to a lower body design. Because the two shafts do not intersect, (1) two rear axles, instead of one, can be successively driven from the same transmission shaft, and (2) bearings can be mounted on both sides of the pinion. Although the altered tooth shape results in more sliding, lower efficiency, and the need for special lubricants, it provides a perfectly smooth drive and solves a major automotive problem—noise.

Helical Gearing

Helical gearing is a term applied to all types of gears whose teeth are of helical form. Helical gears work equally well to connect parallel shafts and nonparallel, nonintersecting shafts. In the latter case, however, a distinction must be made be-

Fig. 6 (Bottom Left)—Hypoid gear and pinion. These gears transmit motion between nonintersecting shafts crossing at a right angle. The pitch surfaces are hyperbolic in form. (Courtesy Mobil Oil Corporation.)



Fig. 7—Crossed helical gears. These gears transmit motion between nonintersecting shafts crossing at an acute angle. The teeth are developed on cylindrical pitch surfaces. Since only point contact exists between the gears, this arrangement is rarely used to transmit loads of any magnitude. (Courtesy of Mobil Oil Corporation.)

tween a gear and a worm, even though both have helical teeth. As seen in Fig. 7, the teeth on this gear make only a *fraction* of a revolution on the base cylinder. That the tooth curvature is helical is not even obvious. What the teeth lack in length, however, they make up for in number, which always exceeds 10.

Crossed Helical Gearing

Fig. 7 shows this form of gearing. For what they can do kinematically, crossed

helical gears are the acme of simplicity. Tooth contact, however, is only a point which greatly limits their power transmission capability.

Worm Gearing

Worm gear drives are used on right-angle applications with nonintersecting shafts. They provide smooth, quiet action and maximum reduction ratios for a given center distance. These favorable characteristics are obtained by using a worm gear combination. As seen in Fig. 8, the gear has teeth inclined at the same angle as the threads in the worm. For speed reduction or torque amplification, the worm is the driver.

In a *worm*, the number of teeth *rarely* exceeds 10 (one to four teeth is common, as shown in Figs. 8 and 9). Each tooth, however, makes at least one revolution on the base cylinder. If only one tooth is used, it winds around the base cylinder several times like a screw thread.

Worm gearing derives its characteristics from the two simple machines of which it is composed: the screw and the lever. From the screw it obtains a *large* mechanical advantage but a somewhat *lower* efficiency because of larger friction forces. The conjugate tooth action is identical to that of a large spur gear and rack (Fig. 8). As the worm revolves, the

thread form advances along its axis and the worm gear rotates a corresponding amount. The presence of a screw instead of a rack ensures a vastly greater output torque on the gear shaft. The net effect is a torque converter of superior capacity but, because of inherent sliding action, one of reduced efficiency.

Worm gear terms are shown in Fig. 9. In this particular case the *lead*, the distance advanced during one revolution, is three times greater than the pitch. Triple-threaded worms are more efficient than single-threaded worms (due to less friction), but their reduction ratio is only one-third that of the single-threaded worm.

Fig. 10 shows the basic difference between single- and double-thread worms. The slope or helix angle of the double-thread worm is *twice* that of the single-thread worm, as is the lead. Thus, for one revolution the double-thread worm will advance or turn its mating gear an angle *twice* that of the single-thread worm.

Tooth breakage from bending action is not prevalent in worm gear sets. With relatively high sliding velocities, the design criteria are usually based on scoring and pitting. *Scoring* is wear resulting from failure of the lubricant film due to localized overheating of the mesh, per-

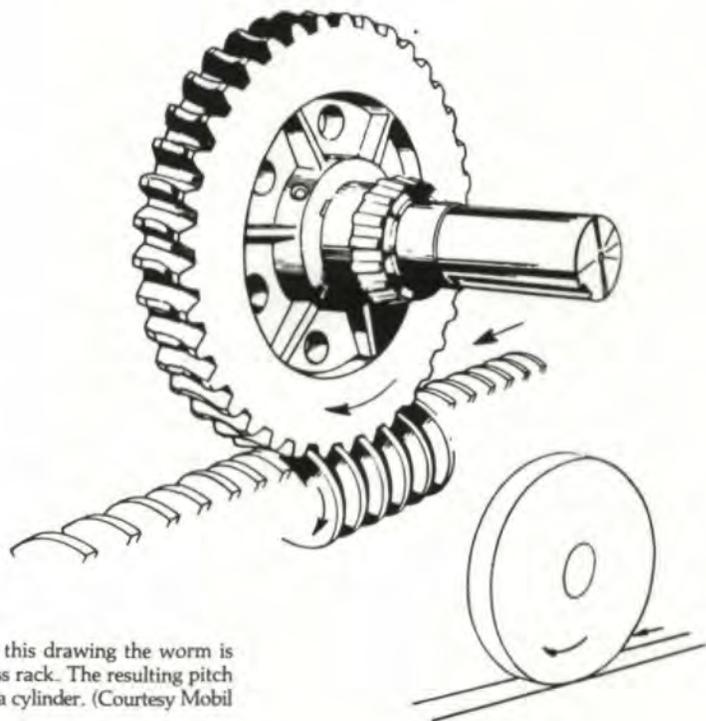


Fig. 8—Worm gear. In this drawing the worm is represented as an endless rack. The resulting pitch surfaces are a plane and a cylinder. (Courtesy Mobil Oil Corporation.)

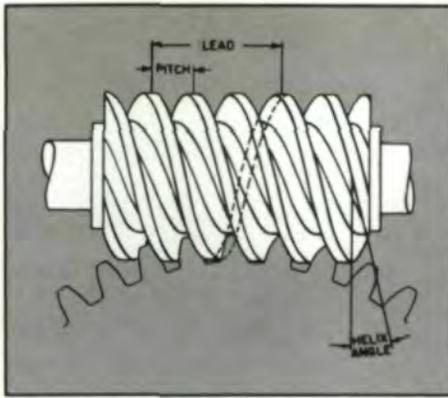


Fig. 9—Worm gear terms. (Courtesy Mobil Oil Corporation.)

mitting metal-to-metal contact. Because more teeth are in contact simultaneously, worm gearing provides smoother operation than involute gearing. The contact area is also larger. Thus load capacity is high despite sliding action and line contact. Entering side wedges are produced on modern worm gears to generate a load-supporting oil film.

The advantages of worm gearing compared to spur and helical gearing are:

1. A more compact design for the same reduction ratio or power capacity.
2. Much greater speed reduction and torque amplification in a single step.
3. Smooth and silent operation that can withstand higher shock loads and higher momentary loads.

The disadvantages compared with ordinary gearing are:

1. Lower and varying efficiency.
2. Greater axial forces requiring costlier bearings.
3. Overheating that limits duration and capacity for power transmission.

Worm Gear Terminology and Kinematics

Fig. 11 shows worm gear terminology and development of a worm thread. For reasons of clarity, a triple-threaded worm was used. A worm can be single, double, triple, quadruple, or multi-threaded, plus left or righthanded. Threads in excess of 10 are rarely advantageous.

Axial pitch (p_a) of a worm (Fig. 11) is the distance measured axially from a point on one thread to the corresponding

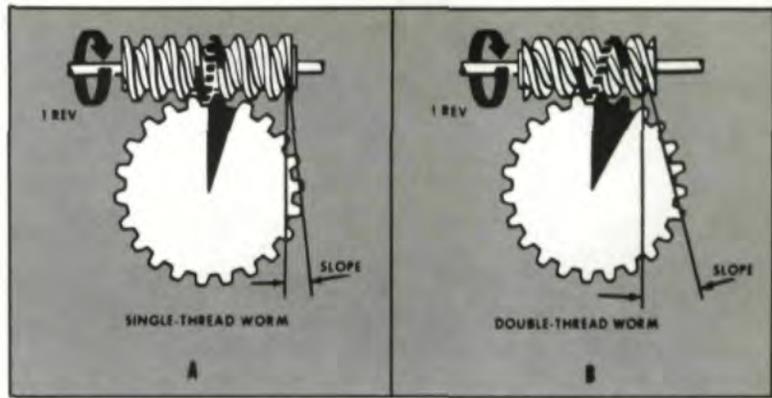


Fig. 10—The difference between a single- and a double-thread worm. (Courtesy Bureau of Naval Personnel.)

A CUT ABOVE THE REST DAVIS KEYSEATER



For saving time and money, nothing outperforms the Davis Keyseater:

- It cuts keyways and slots faster than hand broaching.
- Fast set up time to match today's more frequent changes and smaller production runs.
- Economical and easy to operate.
- Ideal for all types of keywaying: maintenance, jobbing, production in a cell.
- Versatile enough to accommodate simple fixtures for external slotting.

Priced from \$5,775, there's no comparison.

HANSFORD
DAVIS KEYSEATER

Hansford Manufacturing Corp.
3111 Winton Road South
Rochester, New York 14623
(716) 427-0660



CIRCLE A-23 ON READER REPLY CARD

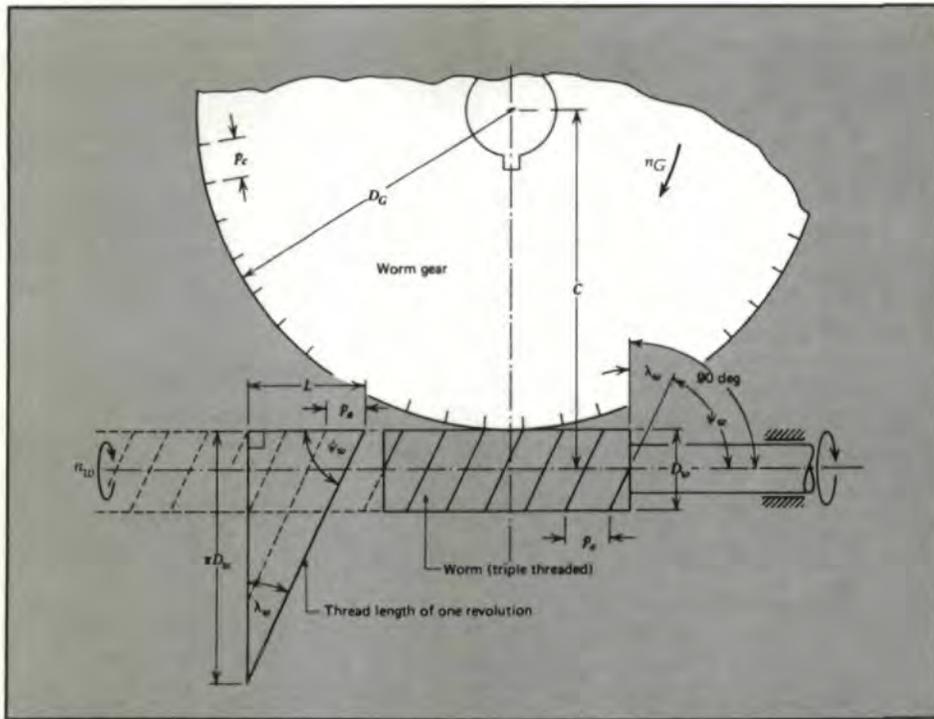


Fig. 11—Worm gear terminology and development of a worm thread. (For clarity, a multithreaded worm was used.)

point on the next thread. For proper mesh, p_a must equal the circular pitch p_c of the gear.

Lead (L) is the distance L that a thread advances in one turn of the worm. Thus

$$L = N_w p_a \quad (4)$$

where N is the number of threads on the worm; e.g., $N_w = 2$ for a double-threaded worm.

Lead angle (λ_w) is the angle between a tangent to the thread at the pitch diameter and a plane normal to the worm axis.

Velocity ratio (m_G) is the ratio of pitch circumference of gear to lead of worm, which equals tooth ratio. It is also the ratio of worm speed to gear speed. Thus

$$m_G = \frac{p_a N_G}{L} = \frac{N_G}{N_w} = \frac{n_w}{n_G} = \frac{D_G}{D_w \tan \lambda_w} \quad (5)$$

For worm and gear to mesh properly, the lead angle of the worm must equal the helix angle of the gear ($\lambda_w = \psi_G$), and axial pitch of the worm must equal circular pitch of the gear ($p_a = p_c$). Since the circumference of the pitch circle of the gear can be expressed as πD_G or $p_c N_G$, this leads to

$$p_c = \frac{\pi D_G}{N_G} = p_a \quad (6)$$

Substitution into Eq. 5 gives

$$n_G = \frac{L}{\pi D_w} n_w \text{ rpm} \quad (7)$$

as another expression of the speed relationship.

Development of one turn of the worm leads to a triangle, as shown in Fig. 11. This triangle shows that

$$\tan \lambda_w = \frac{L}{\pi D_w} \quad (8)$$

Center distance is $0.5 (D_w + D_G)$, which can also be expressed as

$$C = \frac{L}{2\pi} (m_G + \cot \lambda_w) \quad (9)$$

Thermal Ratings

When worm gear teeth slide across the surfaces of mating worm threads, far more heat is generated than when the same load is carried by any other type of gearing. These thermal conditions raise the operating temperature of the oil, thereby reducing its load-carrying capacity. To keep oil temperatures below critical levels, manufacturers publish thermal ratings for each unit that indicate the maximum power input that produces a safe rise in oil temperature. Because

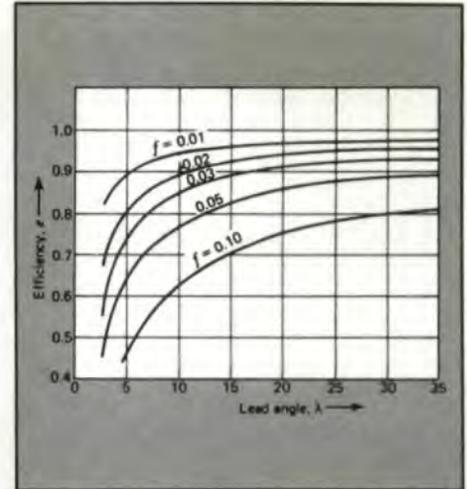


Fig. 12—Efficiency as a function of lead angle and coefficient of friction.

common gear lubricants deteriorate rapidly at temperatures above 90°C (195°F), operating levels are usually kept at or below 75°C (170°F). Clearly, design of worm gearing must include temperature effects, as well as strength and wear, as a limiting factor. Of the three, overheating is the controlling parameter. For example, a worm gear may have a thermal rating of 5 kW and a mechanical rating of 7 kW for the higher speed ranges. This means that the gearing is capable of transmitting more than 5 kW as far as strength and wear are concerned—but not without overheating. Recently, however, the use of computers has improved worm geometry, thereby narrowing the gap between thermal and mechanical capacity.

Efficiency of Worm Gearing

While spur and helical gearing exhibit very high and virtually constant efficiencies (0.98 to 0.99), those of worm gearing may range from a low of 0.50 to a high of around 0.98. Generally, efficiency varies inversely with speed ratio provided the coefficient of friction does not change. The various parameters determining efficiency do not have a linear relationship (Fig. 12). Instead, efficiency e increases with decreasing coefficients of friction. Efficiency is greatly influenced by the lead angle for small values, but less and less as λ increases. A maximum is reached for $\lambda = 45$ deg.

For a well-designed, well-lubricated unit, the following is a fair approxima-

Fig. 13 (Right) — Typical worm gear reduction unit. (Courtesy Bodine Electric Company.)

tion to efficiency.

$$e = \frac{\tan \lambda}{\tan(\lambda + \theta)} \quad (10)$$

where

$$\theta = \arctan f = \text{friction angle}$$

Back-driving is the term used when the gear drives the worm. In this reverse action speed is increased at the expense of force. Back-driving can thus be used to advantage in speedup drives for centrifuges and turbochargers. The corresponding expression for efficiency is

$$e = \frac{\tan(\lambda - \theta)}{\tan \lambda} \quad (11)$$

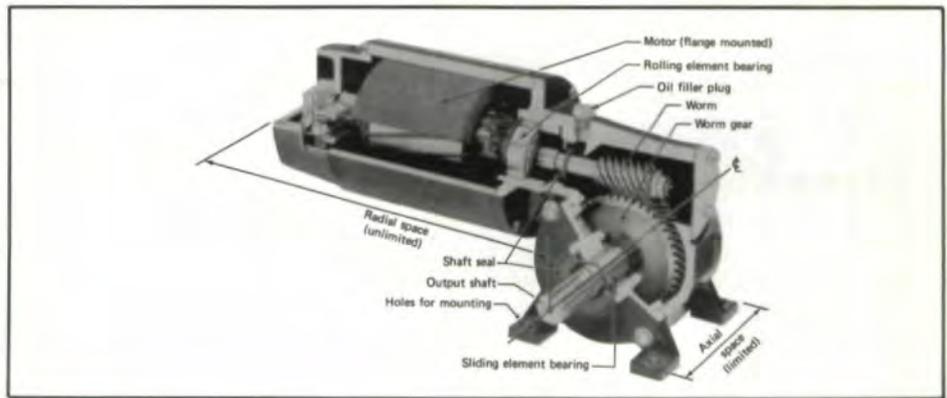
Theoretically, back-driving is possible only for $\lambda > \theta$, that is, when the lead angle is greater than the friction angle. In reality, this reverse action occurs for higher values of θ . Vibration, present in most mechanical equipment, effectively lowers friction, thereby reducing "self-locking" to "a mechanical fringe benefit." Only a brake can effectively prevent back-driving.

Optimum Design

Even though worm gear drives are among the oldest mechanisms, they are one of the least understood. Because of their inherent complexities, precise analytical methods have not evolved, so design relies heavily on trial-and-error testing. Worm gears have, however, reached a high degree of perfection. Thus, by analyzing the expression for efficiency, we may single out major design parameters and compare them with the industrial end product.

Low coefficients of friction are obtained by (1) using dissimilar metals for worm and gear, (2) providing smooth tooth surfaces, and (3) ensuring adequate lubrication. For instance, hardened and ground steel worms are used with gears of phosphor bronze or cast iron. Special lubricants are available for worm gearing.

Large lead angles are also desirable, but are obtained at the expense of lower



CNC GEAR HOBBER

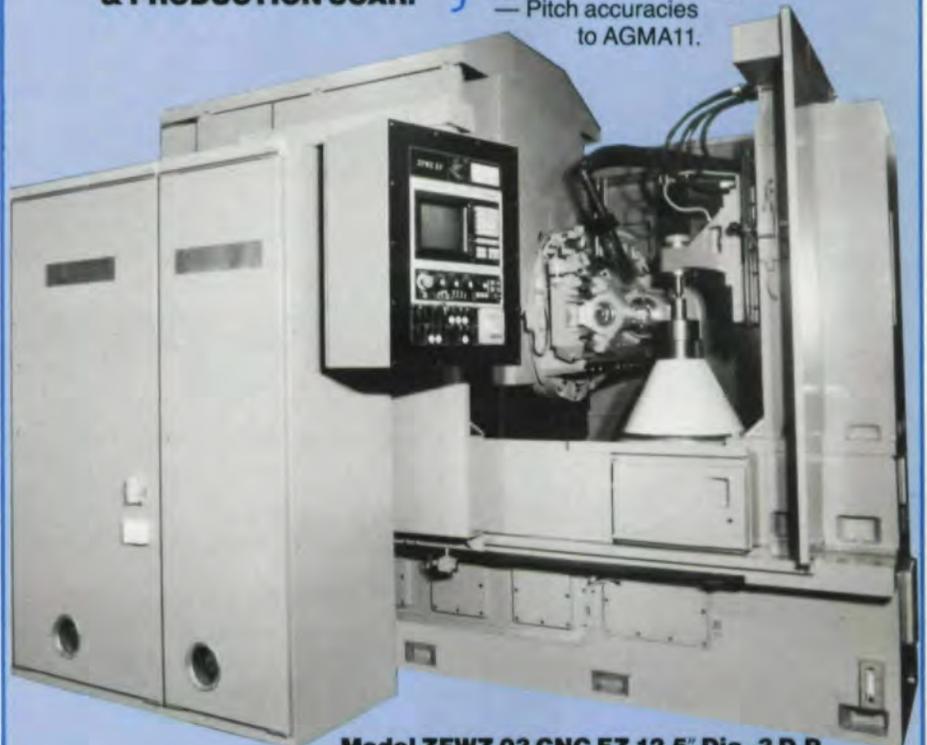
WITH GENERAL NUMERIC 3MB/4B-6 AXIS CNC

**WHAT IT DOESN'T HAVE
WILL ASTOUND YOU!**

- No gears to change.
- No limit switches to set.
- No mechanical cycles to adjust.

**WHAT IT DOES HAVE WILL
MAKE YOUR QUALITY
& PRODUCTION SOAR!**

- 70% Savings in set-up time.
- All the canned cycles you need at the touch of a button.
- Pitch accuracies to AGMA11.



Model ZFWZ 03 CNC EZ 12.5" Dia.-3 D.R.
(Full range of models up to 72" Dia. available)

SEE WMW MACHINERY, AT BOOTH 4454
McCORMICK PLACE EAST



IMTS 86

Distributor for WMW Machinery



GMW MACHINERY INC.
700 Route 46, P.O. Box 1729, Clifton, NJ 07015
Phone (201) 772-3000-Gear Division, Chicago, IL (312) 364-4530

CIRCLE A-2 ON READER REPLY CARD

September/October 1986 59

speed ratios. Consider the following equation.

$$\tan \lambda = \frac{L}{\pi D_w} = \frac{p_a N_w}{\pi D_w} \quad (12)$$

A large efficiency requires a large lead; therefore the worm should be multithreaded. Consequently, when worm gearing is designed primarily for transmitting power, it should be multithreaded, as is common practice.

To obtain a given ratio, some number of worm wheel teeth divided by some number of worm threads must equal the ratio. Thus, if the ratio is 6:

$$m_G = \frac{6}{1} = \frac{12}{2} = \frac{18}{3} = \frac{24}{4} = \frac{30}{5} = \frac{36}{6} = \frac{42}{7}$$

Any of these combinations may be used. The numerators represent the number of worm wheel teeth, and the denominators are the number of worm threads. As the total number of teeth increases, so does efficiency, but only at higher initial cost.

The expression for λ also indicates that a small worm diameter D_w is most desirable because it lowers rubbing velocity. As can be seen in Fig. 13, the

worm diameter is small relative to the thread height.

Example 2

A right-angle speed reducer has a triple-threaded worm and a 41-tooth gear. Find the speed ratio, lead, lead angle, helix angle, pitch diameter of gear, center distance, efficiency, power output, and transmitted force for the following data.

$$p_c = 32 \text{ mm} \quad n = 900 \text{ rpm}$$

$$D_w = 44 \text{ mm}$$

$$f = 0.05 \quad P = 0.75 \text{ kW (input)}$$

Will the unit back-drive?

Solution

$$m_G = \frac{N_G}{N_p} = \frac{41}{3} = 13.67$$

From Eq. 4:

$$L = N_w p_a = 3(32 \text{ mm}) = 96 \text{ mm}$$

From Eq. 8:

$$\lambda_w = \arctan \frac{L}{\pi D_w}$$

$$= \arctan \frac{96 \text{ mm}}{\pi(44 \text{ mm})} = 34.78 \text{ deg}$$

For proper mesh, the lead angle of the worm must equal the helix angle of the gear. Thus $\psi_G = \lambda_w = 34.78 \text{ deg}$

As can be seen in Fig. 12

$$\psi_w = 90 \text{ deg} - \lambda_w = 55.22 \text{ deg}$$

From Eq. 6:

$$D_G = \frac{p_a N_G}{\pi} = \frac{(32 \text{ mm})41}{\pi} = 417.62 \text{ mm}$$

From Eq. 9:

$$C = \frac{L}{2\pi} (m_G + \cot \lambda_w) = \frac{96 \text{ mm}}{2\pi} (13.67 + \cot 34.78 \text{ deg}) = 230.86 \text{ mm}$$

From Eq. 10:

$$e = \frac{\tan \lambda_w}{\tan(\lambda_w + \theta)}$$

The High-Accuracy Gear Tester

FOR TWO-FLANK ROLL TESTS, SINGLE-ERROR TESTS AND GEAR PITCH TESTS

Now you can make your gear testing Mahr-accurate, too, with the peerless Mahr No. 898 universal gear testing machine. Designed primarily for two-flank roll tests to find total composite error, tooth-to-tooth error and torsional backlash on external and internal spur gears with straight and helical teeth, bevel gears and worm gears. Also performs single-error tests for concentricity and uniform tooth thickness on spur, bevel and worm gears. Plus gear pitch tests. Modular design with add-on units available. Three models offered. Quality Mahr construction throughout.

Write for more details to Mahr Gage Co., Inc., 274 Lafayette St., New York, NY 10012. Tel. 212-966-3277.



Make your QC Mahr-accurate

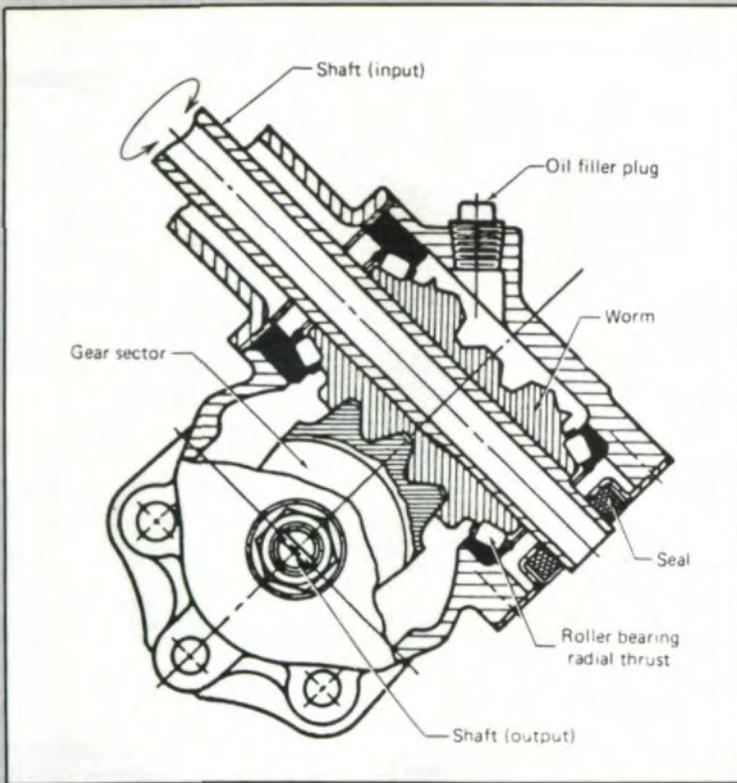


Fig. 14—Steering mechanism. Note that only a gear sector is needed. (Courtesy The Timken Company.)

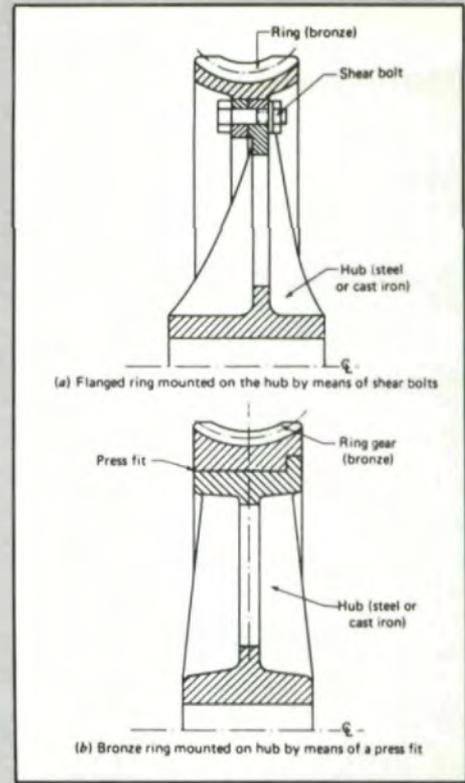


Fig. 16—Design of a large worm gear.

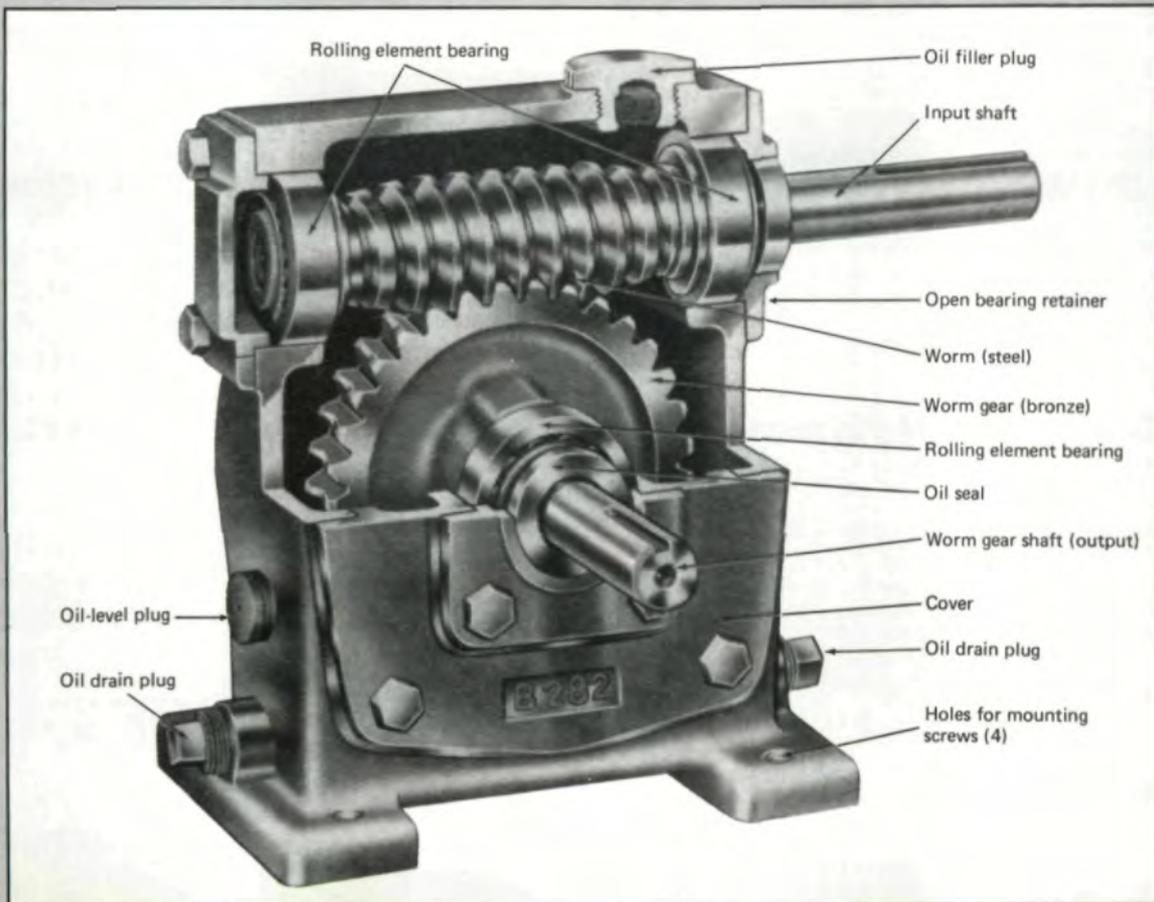


Fig. 15—Typical medium-size worm gear speed reducer. (Courtesy of Morse Industrial Corp., subsidiary of Emerson Electric Co.)

CLASSIFIED

Rates: Classified Display—\$100 per inch (minimum 3") Type will be set to advertiser's layout or *Gear Technology* will set type at no extra charge. **Word Count:** 35 characters per line, 7 lines per inch.

Payment: Full payment must accompany classified ads. Mail copy to *Gear Technology*, P.O. Box 1426, Elk Grove Village, IL 60007. **Agency Commission:** No agency commission on classifieds.

Closing date: Ads must be received by the 25th of the month, two months prior to publication. **Acceptance:** Publisher reserves the right to accept or reject classified advertisements at his discretion.

HELP WANTED

GEAR ENGINEER

Spur and helical production gear manufacturing company has opening for engineer and manager of engineering.

Ideal candidate will have experience in manufacturing, project and process engineering, as well as automation and state-of-the-art technology.

These positions are being created by internal growth.



Reef Industries
50903 E. Russell
Schmidt Blvd.
Mt. Clemens, MI 48045

SUBCONTRACT WORK

SPRIAL BEVEL GEARS

Coniflex bevels to 34" diameter
Prototype or production up to 60" diameter

Breakdown work — fast turnaround
Complete machining, heat treat,
lapping and testing
CALL US!



B&R MACHINING
PO Box 536
Sharon, TN 38255
1-800-238-0651

CIRCLE A-34 ON READER REPLY CARD

FOR SALE

AVAILABLE:

Rebuilt galvano meters for
EPSCO, BRUSH and
SANBORN tube type
recorders.



PRECISE INSPECTION
27380 Gratiot Avenue
Roseville, Michigan 48066
313-445-6959

CIRCLE A-32 ON READER REPLY CARD

THE DRIVING FORCE

The drive to excel in technology is a prime motivator at **Rockwell International's Automotive Operations**. It's evident at our Troy Technical Center, the largest and most advanced of its kind. Our technical professionals continually strive to perfect automotive components technology. This is proven by the number of our Engineers who have won Rockwell International's prestigious "Engineer of the Year" award. If you're driven to excel, consider our current opportunity.

GEAR DESIGN ENGINEER

The ideal candidate would possess a BSME with a minimum of 5 years hands-on gear design experience. Specific knowledge of Hypoid/Spiral Bevel gear design required, along with a working knowledge of gear manufacturing techniques. Familiarity with Spur and Helical gear design a plus.

Rockwell International offers an outstanding compensation and benefits package including relocation assistance. For further information, please send resume, including salary history, in confidence to: **Technical Services Personnel (GT9/10), Rockwell International, Automotive Operations, 2135 W. Maple Road, Troy, Michigan 48084.** Equal Opportunity Employer M/F.



Rockwell International

... where science gets down to business

GEAR MANUFACTURING ENGINEER

Cloyes Gear is a rapidly expanding manufacturer of automotive gears and sprockets. Our growth requires that we seek an engineer with knowledge in gear manufacturing processes to join the staff of our manufacturing plant in Arkansas. We are in need of an individual with a strong hobbing and shaving background willing to take a "hands on" attitude toward troubleshooting gear manufacturing processes.

For a chance to work with state of the art gear machinery including 6 axis CNC hobs and CNC gear inspection equipment, please submit your resume and salary history to:



CLOYES GEAR & PRODUCTS, INC.
P.O. BOX 511
WILLOUGHBY, OHIO 44094

(continued from page 60)

$$= \frac{\tan 34.78 \text{ deg}}{\tan(34.78 \text{ deg} + 2.86 \text{ deg})} = 0.90$$

Output: $P = 0.90(0.75 \text{ kW}) = 0.675 \text{ kW}$

The unit will back-drive because the lead angle of the worm ($\lambda_w = 34.78$ deg.) is much greater than the friction angle Θ where

$$\begin{aligned}\Theta &= \arctan f \\ &= \arctan 0.05 = 2.86 \text{ deg.} \ll 34.78 \text{ deg.}\end{aligned}$$

From the power equation:

$$\begin{aligned}W_i &= \frac{9550 P}{(0.5 D_w)_n} \\ &= \frac{9550(0.675 \text{ kW})}{0.5(0.044\text{m})(900 \text{ rpm})} = 326 \text{ N}\end{aligned}$$

Applications

As indicated in Fig. 12, worm gear efficiency varies widely from 0.5 to 0.98. It also varies inversely with speed ratio or mechanical advantage. Thus, single-threaded worm gear drives yield large

reduction ratios, but at the expense of efficiency. In contrast, a multithread speed reducer will have high efficiency, but a somewhat lower reduction ratio. This fact leads to three major areas of application for worm gearing.

1. *Intermittent, infrequent* operations where a small, low-cost motor moves a heavy load, as in small hoists. Efficiency, of minor importance, is thus

(continued on page 64)

GEAR DESIGN WITH YOUR PERSONAL COMPUTER

Enjoy convenience and time savings by using your personal computer for gear design. Reduce gear design from 3-4 hours to under 30 minutes!!!

Gear redesign is easy . . . recall previous design from the electronic library; change just the revised factors and you're finished . . . complete with a record of the design specifications and a gear profile drawing!!!!

Programs satisfy most external helical or spur gear specifications for . . .

- Standard or non-standard gears.
- Various gear material properties.
- Gear size or gear ratios.
- Bending/surface stresses with varying load/speed conditions.
- Contact ratio calculates potential for meshing interference.



ENGINEERING SOFTWARE COMPANY

Three Northpark East, Suite 901
8800 North Central Expressway, Dallas, TX 75231
(214) 361-2431

CIRCLE A-21 ON READER REPLY CARD

HOBBER REBUILDING SPECIALISTS

Having trouble meeting today's demand quality control tolerances?

Let our factory trained and experienced staff return your machine to optimum operating condition.

We specialize in repairing, rebuilding and modernizing all makes of hobbbers.

- Cleveland Rigidhobbbers
- Gould & Eberhardt
- Barber Colman

PRESSMATION INC.

522 Cottage Grove Road
Bloomfield, Conn. 06002
(203) 242-8525

CIRCLE A-24 ON READER REPLY CARD

WANTED:

GEAR MANUFACTURER WITH FOLLOWING CREDENTIALS:

- Certifiable quality control system GM-Spear 2, Ford Q2, mil spec 45208 or better,
- 2) Current use of SPC/SPS techniques,
- 3) Capability to manufacture gears to class 11 or better,
- 4) Experience in prototype as well as high volume runs,
- 5) Ability to assimilate large volume of work in a 6-12 month period,
- Bevel and spiral bevel capability a plus but not required.
- Respondents should be willing to enter into a representation agreement.

Several million dollars of gear work available to qualified manufacturer.

Please respond promptly and in confidence to:

Suite 305
4217 Highland Road • Pontiac, MI 48054

CIRCLE A-36 ON READER REPLY CARD



Gears For All Industry

GEAR GRINDING OUR SPECIALTY

Up-through AGMA Class 15 with crowning—
Finest pitches to 5 D.P. including specials—
Maximum diameter 13" —

Full inspection instrumentation with charting
Short lead times

Grind teeth only or complete to your print
Latest Reishauer Gear Grinder
RZ-300E

Grinds low number of teeth (7T)
Fast setup extremely accurate
Excellent for pump gears

NIAGARA GEAR CORPORATION
955 Military Road
Buffalo, New York 14217
(716) 874-3131

CIRCLE A-35 ON READER REPLY CARD

GEARS-SPLINES DESIGN AND TOOLING

- Custom gear design including non-standard pressure angles for more strength.
- Programs to enter tooling data into computer files and search for existing cutters to cut a new gear or spline.
- Gearing computer software for sale.
- Consulting services for gear and spline problems.

VAN GERPEN-REECE ENGINEERING

1502 Grand Blvd.
Cedar Falls, Iowa 50613
(319) 266 4674

CIRCLE A-38 ON READER REPLY CARD

GEAR TOOTH GRINDING & HONING ONLY

Production Quantities
3/4" P.D. to 27.5" P.D.;
3.5 D.P. and 11" Face

We have no turning, hobbing or shaping capability

ALLEGHENY GEAR CORP.

23 Dick Road
Depew, NY 14043
716-684-3811

CIRCLE A-17 ON READER REPLY CARD

IMPROVED GEAR LIFE . . .

(continued from page 18)

References

1. FUCHS, H., Shotpeening Effects and Specifications, ASTM Special Technical Publication No. 196-1962.
2. DALY, J., "Boosting Gear Life Through Shot Peening," *Machine Design*, May 12, 1977.
3. "Shot Peening of Metal Parts," MIL-S-13165B Amendment II, June 25, 1979.
4. *Shot Peening Applications*, Metal Improvement Company, Sixth Edition, 1980, Figs. 2, 6, 8 and 9.
5. McCORMACK, DOUG, "Shot Peen Gears for Longer Life," *Design Engineering*, July, 1981.
6. FUCHS, H.O., "The Effect of Self Stresses on High Cycle Fatigue," *JTEVA* Vol. 10, No. 4, July, 1982.
7. LAWERENZ, MARK, *Shot Peening and its Effect on Gearing*, SAE paper #841090.
8. SEABROOK, JOHN B. and DUDLEY, DARLE W., "Results of Fifteen Year Program of Flexural Fatigue Testing of Gear Teeth," 1963.
9. TOWNSEND, DENNIS P. and ZARETSKY, E.V., "Effect of Shot Peening on Surface Fatigue Life of Carburized and Hardened A151, 9310 Spur Gears," Lewis Research Center, Cleveland, Ohio, NASA 2047.
10. *Lloyd's Register of Shipping*, June 6, 1975, Letter.

Reprinted with permission of the American Gear Manufacturer's Association. First presented at AGMA's Fall Technical Meeting, October, 1985.

The opinions, statements and conclusion presented in this paper are those of the Authors and in no way represent the position or opinion of the AMERICAN GEAR MANUFACTURERS ASSOCIATION.

PRACTICAL ANALYSIS OF HIGHLY LOADED . . .

(continued from page 26)

Conclusion

Based on the DIN/ISO formulae for scoring capacity, a simplified method adopting a modified scoring index has been developed. As can be seen from typical applications, this method works with sufficient accuracy.

The calculation of scoring capacity will become more and more important in parallel with an increasing demand in transmitted power per gear volume. The practical experience with highly-loaded gears with regard to scoring will give more safety in the application of this calculation method and will possibly permit a reduction of the safety margins used today.

References

1. HIRT, M., "An Improved Method to Determine the Scoring Resistance of High Power High-Speed Gearing," Proc. of 1984 Turbomachinery Symposium, Texas A&M University, Houston
2. AGMA 217.0, "Gear Scoring Design Guide for Aerospace Spur and Helical Power Gears."
3. BLOK, H., "Theoretical Study of Temperature Rise at Surface of Actual Contact Under Oiliness," Lubricating Conditions, Proc. Gen. Disc. Lubric. IME London Bd 2(1937) Sh. 225.35.
4. DIN 3990, Part 4: "Basic Principles for the Calculation of Load Capacity of Spur and Helical Gears, Calculation of Scuffing Load Capacity," Draft (1980).
5. DUDLEY, D., *Gear Handbook*, McGraw Hill (1962).
6. HIRT, M., "Design and Calculation Methods for High Speed Gears of Advanced Technology", Proceedings of the Twelfth Turbomachinery Symposium, Texas A&M University, College Station, Texas (1983).
7. NIEMANN, G. and WINTER, H., *Maschinenelemente Part II*, Springer (1983).
8. WINTER, H. and MICHAELIS, K., "Scoring Load Capacity of Gears Lubricated with EP-Oils," AGMA Paper 219.17 (Fall, 1983).

GEARS FOR NONPARALLEL SHAFTS . . .

(continued from page 62)

- sacrificed to obtain a large mechanical advantage. Typical applications are standby pumps, large valves, and gates.
2. *Intermittent, manual* operations requiring a large mechanical advantage, such as in steering mechanisms and opening and closing of valves and gates by means of hand-wheels (Fig. 14).
 3. *Motorized, nearly continuous* operations where worm gearing competes with gear reduction units. When space is at a premium, as in machine tools, packaged, motor-driven worm reduction units are used in preference to gear reducers (Fig. 13). Depending on size and application, the unit may be self-contained or built integrally with an electric motor. Because of silent operation, such units are preferred in machine tools and also in elevators. These units all require multithreaded worms and ratios not exceeding 1:18. Larger ratios are achieved by connecting two units in series.

Design Detail of Worm Gearing

The unit shown in Fig. 15 is a typical, medium-size worm gear speed reducer. Smaller units of this type usually have housings of cast aluminum alloys for maximum thermal rating. For larger units the preferred material is cast iron. The worm is case-hardened and ground alloy steel of integral shaft design. The gear is cast bronze with generated teeth and keyed to the output shaft. Larger worm gears are often composed of a ring of bronze mounted on a center or hub of less expensive material. A common design utilizes a flanged rim mounted on the hub by means of shear bolts (Fig. 16a). Equally common is mounting by means of a press fit (Fig. 16b) assisted by a pin connection. The output shaft is high-quality, medium-carbon steel, ground to close tolerances. The worms and output shafts are frequently mounted on roller bearings. All shaft extensions are equipped with lip style, synthetic oil seals.

Lubrication

Generally, oil is contained within the housing and directed by splash to the bearings and to the zone of tooth and thread contact. Natural splash may be augmented by flingers, scrapers, and cups attached to the gear. Channels or ribs may be furnished inside the housing to help direct oil to the bearings.

Summary

Despite higher initial cost, gears for nonparallel shafts are justified because they often save space and lead to a better design. Kinematically, these gears all perform the very difficult task of changing the plane of rotation. With the exception of crossed helical gears, all have reached a high degree of perfection and a long, useful life of transmitting power. Hypoid gears for automotive differentials, for instance, rarely fail during the life of a car. The versatility of worm gearing is due to the inverse relationship of efficiency to torque and reduction ratio. Table 1 summarizes comparative characteristics of speed reducer gear families.

References

1. BUCKINGHAM, E. K. "Taking Guesswork Out of Worm-Gear Design." *Machine Design*, March 20, 1975.
2. MacFARLAND, W. C. "Straight Talk About Speed Reducers," *Machine Design*, September 18, 1975-October 2, 1975.
3. WILL, R. J. "Selecting Speed Reducers." *Machine Design*, September 8, 1977.