Worm Gears

Email your question—along with your name, job title and company name (if you wish to remain anonymous, no problem) to: *jmcguinn@geartechnology.com*; or submit your question by visiting *geartechnology.com*.

QUESTION #1

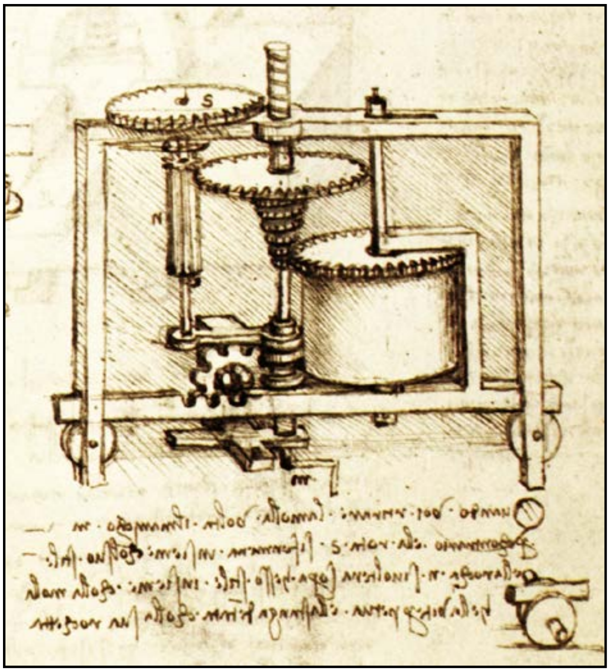
How does one determine the center of a worm and a worm wheel?

First response provided by Joe Mihelick, *Gear Technology* Technical Editor:

The center of the single enveloping worm is straightforward, as it is at a plane passing through the axis of the worm at its outside diameter. The center of a double enveloping worm gear is a bit more involved. It is nominally located at a plane passing through the worm gear at its root diameter. If the worm gear is throated, the location of the minimum diameter of the throat will locate the nominal center of the worm gear. This is more useful for the manufacturing process but is less important in the successful operation or the worm – worm gear pair. The successful operation of worm gearing involves the actual contact pattern between them. The observed contact pattern is to be from the nominal center of the worm gear towards the leaving side of the worm gear as determined by the direction of the worm rotation.

Second response provided by Charles D. Schultz, PE, Chief Engineer for Beyta Gear Service, and *Gear Technology* Technical Editor *(gearmanx52@gmail.com):*

Short answer: It depends upon who is asking and what the intended application is. If you are specifying an off-the-shelf solution, you can rapidly determine the appropriate size from supplier catalogs. Commercially supplied worm gear speed reducers are available in a wide range of sizes, ratios and assembly configurations — from both U.S.-based and off-shore companies.



The study of worm gears has come a long way: 16th century worm gear illustration (courtesy Leonardo daVinci).

Worm gearing is not as standardized as spur, helical and bevel gearing. Several different 'systems' coexist in the marketplace, and each has its proponents. In the smaller gearbox sizes (less than 4-inch center distance), exterior and mounting dimensions have become 'standard' and users can easily interchange between brands. Larger units have no such commonality, and users are well advised to carefully consider all factors of supply (initial cost, availability, service factor and after-sales support) before selecting a vendor. Published ratings can be based on AGMA, DIN, ISO or other methods, and have generally been applied with few problems.

While each manufacturer will tout their particular tooth design as having performance advantages, the key factor in power capacity remains the physical size of the parts and the mechanical properties of the materials used to make them. Worm gears have some unique capabilities that can be used to good advantage in machinery design. They are the only gear system where gear ratio does not affect the outside diameter of the rotating parts; this means a machine can easily be supplied with a wide range of ratios — say 5:1 to 70:1 — without a center distance change or multiple reductions. Another capability — self-locking — can be a boon or a bane, depending upon your goals. Understanding these aspects of worm gearing can be a lifelong project, but users should ask the suppliers about it before ordering.

The long answer: Many 'systems' have been developed for worm gearing over the past 100 years. Each of them has its proponents and, oddly enough in the normally polite world of gear engineering, opponents. If off-the-shelf components won't work for your applications, you have to pick one of these competing systems and wade through the often confusing recommendations to develop your gear set. Custom-made tooling is expensive and takes critical lead time to obtain, so designers are encouraged to use existing hobs and fly cutters. I recommend the design system found in Daryl Dudley's *Gear Handbook,* along with the worm hob charts on Ash Gear and Supply's web site. AGMA's standards are the most reliable rating method for the independent designer.

If your requirement is for instrument gearing or plastic gearing, it is recommended that you work with a supplier of such parts or an experienced design engineer. Tooling costs can be very high, and the performance of prototype sets can vary depending upon manufacturing method. Molded plastic teeth do not have exactly the same topography as cut gears; veteran suppliers of plastic gearing understand the changes needed to make sample parts that will work reliably without skewing test results.

Worm gearing design is an iterative process which can be frustrating the first few times you work through it. Standard worm hobs may not converge on the solution you would prefer. Some suppliers can make worm gears using 'fly tools' — a custom single-point cutter that allows more flexibility in design than the standard hobs. The cutting process is, by necessity, much slower than hobbing, but for one-off or low-volume requirements it is often the best solution. Regardless of the tooling ultimately employed, custom worm gearing design requires compromises on center distance, face width and numbers of teeth/threads. More than any other gear type, 'your results may vary' is an appropriate disclaimer.

QUESTION #2

A gear handbook in my possession states: The ZI worm is identical to an involute helical gear whose tooth number is the number of worm threads. Equations of tooth surfaces of an involute helical gear are the same as for an involute worm. Knowing that a ZI hob cutter is identical to a ZI worm, I conclude that the mesh of the ZI worm and involute helical gear is identical to a cross involute helical gear mesh; and even identical to the hobbing process of an involute helical gear with a ZI hob cutter.

I would like to know whether I am correct and what is their difference.

Response provided by Hermann J. Stadtfeld, vice president - bevel gear technology - R&D for Gleason Corporation.

Worm Gear Generation and their Manufacturing Tools

The question will be answered considering the different possibilities in profile form, kind of mesh, and type of tools. Figure 1 contains the general nomenclature used to define the geometry parameters.

Worm gear drives can be separated in three categories:

Case A. Crossed helical worm gear drives

Case B. Cylindrical worm gear drives

Case C. Double-enveloping worm gear drives

Cylindrical worm gear drives "B" are the most common form. Their tooth profiles of the worms depend on the manufacturing method. The different profile forms according to DIN 3975 are:

ZI: Tooth profile in face section is an involute; manufactured, for example, by hobbing, like a cylindrical pinion. The hob for the worm gear manufacturing is a "duplicate" of the worm (however serrated and considering clearance and backlash).

ZA: Profile is a trapezoid in an axial section; manufactured, for example, by turning.

ZN: Profile is a trapezoid in a normal section; manufactured, for example, by turning with cutting blade tilted to lead angle of worm.

ZK: Profile with crowning. Tool is disk cutter with trapezoidal profile, which is tilted to lead angle of worm. Profile crown generated depending on disk cutter diameter.

ZH: Disk cutter with convex cutting edges, causing hollow flank profiles in axial section on worm teeth. Disk cutter axis is parallel to worm axis (not tilted like ZK).

A. Crossed helical worm gear drive. This is a special case of crossed helical gears, where the worm is a helical gear with one to six teeth, and the worm gear has a high number of teeth (e.g., above 30). The pitch elements of a crossed helical worm and worm gear are cylinders (Fig. 2). Both members—worm and worm gear—are manufactured like helical gears, with standard hobs, for example. The profile of both members is involute. The hobbing tool in Case A is not identical to

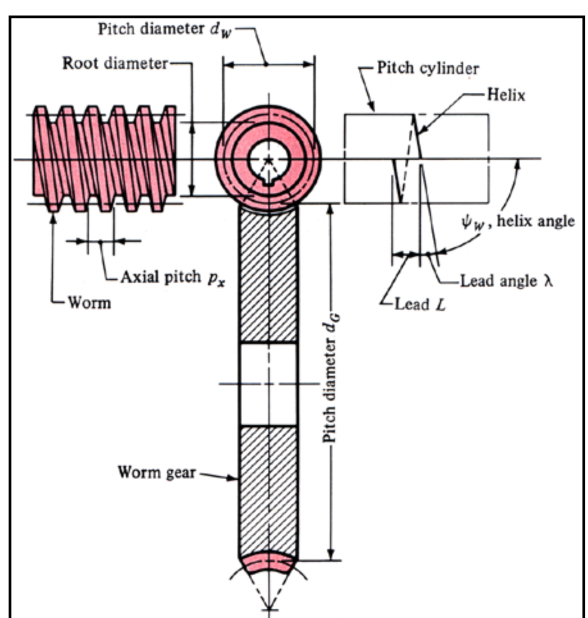


Figure 1 Worm gear drive nomenclature, single-throat example (graphics courtesy of Gleason)

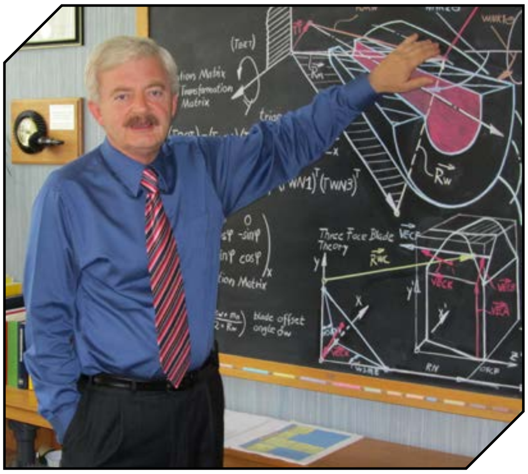
the worm. The two members have line contact, which appear instead as point or small contacting zones.

B. Cylindrical worm gear drives (single-throat worm gear drives). A typical worm gear drive; here the worm also has one to six teeth (starts), and the worm gear has a high number of teeth (e.g., 30 to 300). The pitch elements of a single-throated worm and worm gear are shown in Figure 3. The worm is manufactured on a lathe or with a disk milling cutter. The profile is not a generated involute but a straight line. The geometry of a cylindrical worm therefore is similar to an ACME screw. The worm gear is manufactured with a hob and the hob's enveloping surface *is identical to the mating worm*. This enveloping surface generates the same involute profile on the worm teeth as seen in Case A. However, the tooth thickness of the hob is thicker by the desired backlash amount. The difference in the gear in Case A is the shape of the pitch element, which in Case B has a hyperbolic form known as "throat." The throat is formed merely by plunging the hob cutter at the center of the face width. The two members have line contact that appears on the worm gear member like slim ellipses with a major orientation (if projected in an axial plane) parallel to the worm gear axis.

C. Double-enveloping worm gear drives (double-throated worm gear drives). These are special types of worm gear drives with a very high contact ratio and high torque transmission abilities. Again, here the worm has one to six teeth (starts) and the worm gear has a high number of teeth (e.g. 30 to 300). The pitch elements of worm gear and worm have a hyperbolic appearance which is why Case C is called "double-throated" (Fig. 4). The worm is manufactured on a lathe, where the cutting blade profile rotates around a center point while it moves along the face width. The distance between the cutting blade pitch point and the center of blade rotation is identical to the pitch radius of the worm gear. The profile is not a generated involute, but in a straight line. The worm gear is manufactured with a hob that has the pitch diameter of the worm at the center of the throat and the same number of starts, unlike the number of worm teeth. Also, here the worm gear is cut (as in Case B) by plunging with the hob cutter at the center of the worm gear's face width. The two members have line contact that appears even under light load, as with large elliptical zones—even in single angular positions.

It should be mentioned that in Case B, where the worm gear tool resembles the mating member within the flank surfaces, there remain several differences. The tool face is extended in order to machine sufficient top-root clearance, and the top-land corners to the flanks are rounded with the desired root fillet radius. The dedendum depth of the tool is equal to the addendum of the worm, plus an excess amount to prevent any cutting action at the worm gear top-lands.

The short answer to all conclusions the questioner has posed is "yes."



Hermann J. Stadtfeld

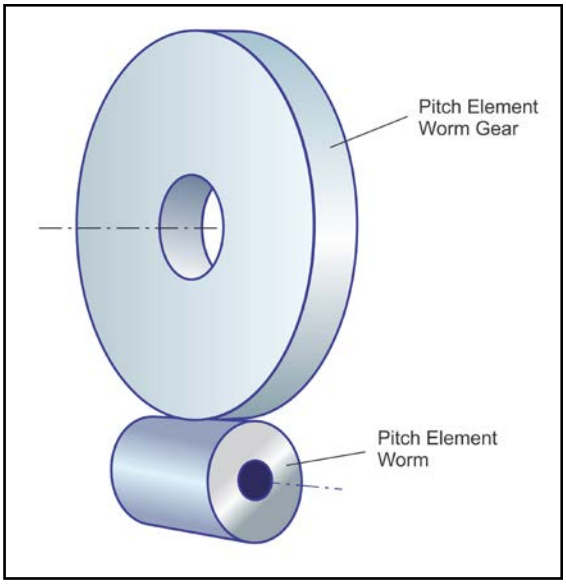


Figure 2 Pitch elements of crossed helical worm gear pair.

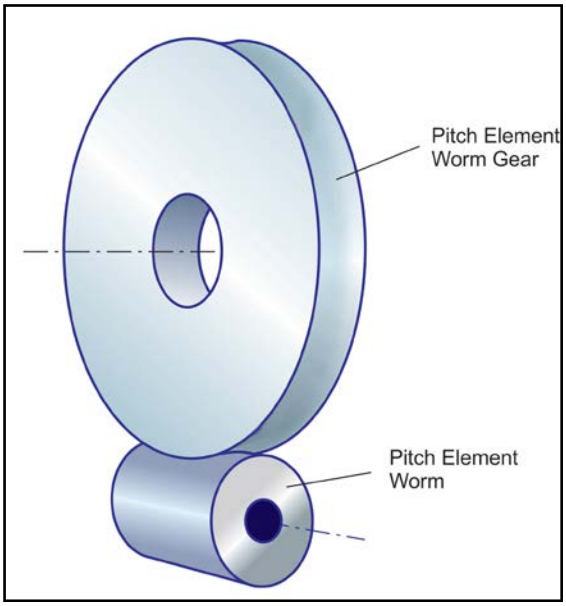


Figure 3 Pitch elements of single-throat worm gear pair.

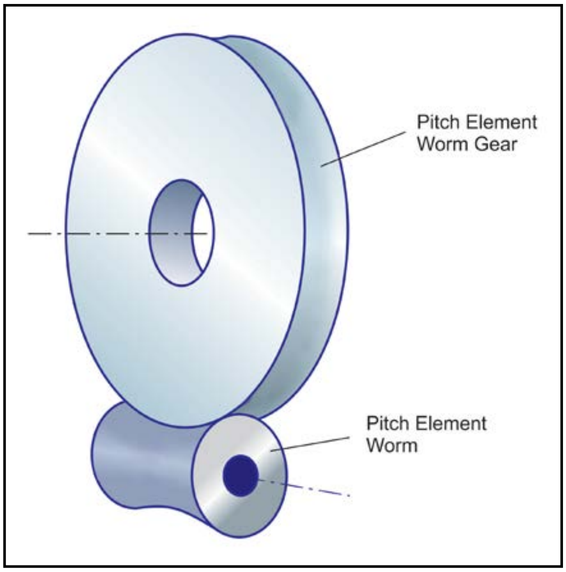


Figure 4 Pitch elements of double-throat worm gear pair.