

## Got a Gear Question?

## Ask the Expert!

Welcome back to *Gear Technology's* Ask the Expert—a regular feature intended to help designers, specifiers, quality assurance and inspection personnel in addressing some of the more complex, troublesome gearing challenges that never cease to materialize—whether on the drafting table or the shop floor. Simply e-mail your question—along with your name, job title and company name (if you wish to remain anonymous, no problem)—to: [jmcguinn@geartechnology.com](mailto:jmcguinn@geartechnology.com); or, you can submit your question by visiting [geartechnology.com](http://geartechnology.com).

### QUESTION #1

#### Profile Shift

Regarding profile shift: What kind of data must be considered when we grind a gear with shift profile?

A few days ago we received a series of gears that need to be corrected (profile shift). Our engineering department had a question about this topic; they tell me that they do not know how to calculate the gears with profile shift and that they have big doubts over whether—with each profile shift factor—the pressure angle also changes.

A friend in Texas told me that you cannot make a profile shift gear with a cutter in a traditional way. For each correction factor, you require a cutter according to the modification. Is this is correct?

**Ing. David Ruiz**, production manager  
Grupo Meusnier S.A. de C.V.

Dear David,

AGMA 913–A98—Method for Specifying the Geometry of Spur and Helical Gears—gives all the equations you need for calculating profile shift.

The reference pressure angle measured on the generating pitch diameter (the same as the standard pitch diameter or reference pitch diameter) is determined by the cutter pressure angle and is usually 20° for most gears. It is independent of profile shift. The operating pressure angle is determined by the operating center distance of the mating gears and is again independent of the profile shift.

You can think of profile shift as simply shifting the teeth outward or inward so that the active profile of the teeth uses a different sector of the same involute curve.

Profile shift does not require special cutters if straight-sided hobs are used (the usual case). The hob is simply shifted outward or inward to shift the profiles, and the outer diameters of the gears are changed to accommodate the profile shifts. Therefore, the advantages of profile shifting are achieved with no cost consequences. Only form cutting such as milling requires a different cutter for profile shifted gears. That's because form-cutting or form-grinding require a cutter or grinding wheel with a profile that matches the shape of the tooth space. Since profile shifting changes the shape of the tooth space, the shape of the form cutter must change.

One of the most important parameters in any gear design is the number of teeth in the pinion, and profile shift has its greatest relevance when the pinion has a small number of teeth. In fact, the first use of profile shift was to avoid undercut in pinions with less than 17 teeth. It was later realized that profile shift improves most aspects of gear operation, and today it is used for many reasons including:

- Avoiding undercut
- Avoiding narrow top-lands to avoid case/core separation in carburized gears
- Balancing specific sliding to maximize wear resistance and Hertzian fatigue resistance
- Balancing flash temperature to maximize scuffing resistance
- Balancing bending fatigue life to maximize bending fatigue resistance

Gears with few teeth are more sensitive to profile shift, and their tooth shape changes more dramatically, whereas profile shift changes tooth shape only slightly for gears with a lot of teeth. In fact, the teeth of a rack (with theoretically infinite number of teeth) do not change shape as the teeth are profile shifted. These effects can be seen in Figure 4 of AGMA 918–A98. It's best to design gear sets with pinions with at least 20 teeth—and preferably 25—in which case the

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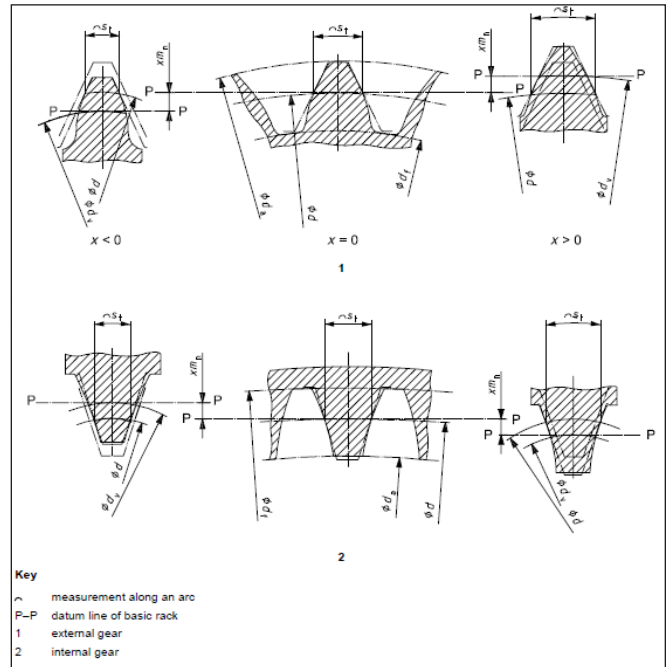


profile shifts for balanced specific sliding, balanced flash temperature and balanced bending fatigue life are all nearly the same.

See AGMA 901–A92—A Rational Procedure for the Preliminary Design of Minimum-Volume Gears—for a method to design gears with maximum-load capacity by balancing the macropitting resistance and the bending fatigue resistance.

Figures 1 and 2 demonstrate how profile shift dramatically improves specific sliding. Figure 1 shows the specific sliding for a gear set with no profile shift. Figure 2 shows the same gear set after the pinion and gear have profile shifts designed to balance and minimize the specific sliding. Profile shifting has greatly reduced the specific sliding from -4.03 to -1.28. This improves the meshing characteristics of the gear set by reducing the frictional loss, lowering the contact temperature and increasing the resistance to wear, macropitting, micropitting and scuffing.

**Robert L. Errichello**, a longtime Gear Technology technical editor, is owner-operator of Geartech—a gear industry consultancy. Bob also is a current member of the AGMA Nomenclature, Helical Gear Rating, Epicyclic Enclosed Drives and Wind Turbine committees.



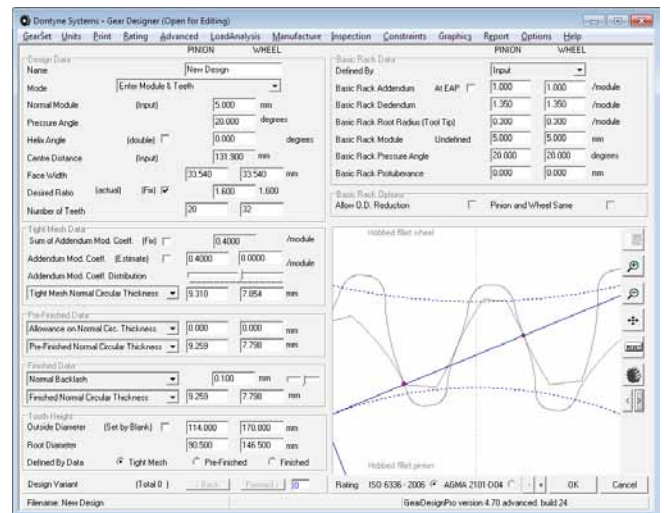
**Figure 1—Profile shift for external and internal gears, as defined by ISO 21771:2007. Gears: Cylindrical Involute Gears and Gear Pairs—Concepts and Geometry.**

Dear David,

Profile shift—sometimes known as ‘addendum modification’ or ‘correction’—is the displacement of the basic rack (or cutting tool) datum line from the reference diameter of the gear. The size of the profile shift (mm or inches) is usually made to be non-dimensional by dividing it by the normal module (or multiplying by the DP), and it is then defined by the profile shift coefficient ‘x’. A positive profile shift increases the tooth thickness while a negative profile shift reduces tooth thickness (this applies to internal and external gears alike). This is illustrated in Figure 1, which is copied from ISO 21771:2007, i.e., Gears: Cylindrical Involute Gears and Gear Pairs—Concepts and Geometry.

The only difference in machine setup required for cutting profile shifted gears is to change the radial position of the cutting tool by an amount defined by the profile shift. The cutting tool module or DP, cutting tool pressure angle and number of teeth on change gears on manual machines, remain unchanged. This in turn means the base diameter (and base helix angle on helical gears) remain the same. A key benefit from using involute gears is that we don’t need to change the cutting tool to make gears with a different diameter and tooth thickness.

Profile shift is used by designers for many reasons including the elimination of undercut when hobbing or shaping gears with few teeth, minimizing sliding at the gear pair start of active profile, increasing bending strength, increasing or decreasing the center distance and changing tooth thickness



**Figure 2—Example geometry software package with graphical display illustrating the effect of profile shift (addendum modification) on tooth shape and operating pressure angle.**

or backlash. In fact all gears have some profile shift when you consider that we normally move the cutting tool radially to change the tooth thickness.

A common perception is that profile shift changes the ‘pressure angle’ of a gear.

This is wrong.

The pressure angle we specify on the drawing is the pressure angle of the cutting tool. The actual gear flank pressure angle changes from root to tip and the working pressure angle (the angle of the line of contact) of a gear pair depends on gear center distance and gear base diameters only. If



the sum of the pinion and wheel profile shift is zero, the gears operate at the reference center distance. If this sum is negative the gears have smaller center distance and thus they have a smaller operating pressure angle, while a positive sum requires a larger center distance increased operating pressure angle.

For further information on this subject I recommend a document published by British Standard PD 6457—Addendum Modification to Involute Spur and Helical Gears, and also ISO 21771:2007, published by ISO. These references contain the calculations and recommendations for minimum profile shift to avoid undercutting and maximum profile shift that can be applied before the tooth crest thickness become too thin. Most commercial software packages provide options for specifying profile shift; the effects can be demonstrated graphically and improvements in gear performance can be quantified, as seen in Figure 2.

**Dr. Robert Frazer**, a Gear Technology technical paper contributor, heads the U.K. National Gear Metrology Laboratory and as such is responsible for gear design and analysis within The Design Unit at the University of Newcastle-Upon-Tyne. Rob is also actively involved with delivering the British Gear Association (BGA) training seminar program and is an active member of the AGMA Gear Accuracy and Calibration committees.



Dear David,  
Profile shift, also known as  $x$  factor, is just a method for specifying tooth thickness. If the gear drawing has a “measurement over pins” or “span over a given number of teeth” or other tooth thickness specification that you are familiar with, you can just grind the gear to meet the specified tooth thickness and safely ignore the profile shift.

Many of those familiar with profile shift find it very easy to use during the design of a gear pair. However, the resulting gear is not fundamentally different from one designed by other methods. Cutters do not need to be modified to create gears with different amounts of profile shift.

The concept of profile shift is quite simple: as a gear cutter is shifted radially towards the center of an external gear, the tooth profile will of course also be shifted towards the gear center. At a given diameter, such a shift of the tooth profile results in the teeth appearing thinner. Since the actual pressure angle varies with diameter, a shift in the profile changes the pressure angle at a given diameter. But this change in pressure angle does not mean there was a change in tooling; it is the natural result of sinking a given tool deeper into the part.

The symbol for profile shift is  $x$ , and it is a coefficient; i.e., it is normalized so it is non-dimensional. The sign convention for profile shift is that a positive profile shift results in thicker teeth. So shifting a cutter towards the center of an

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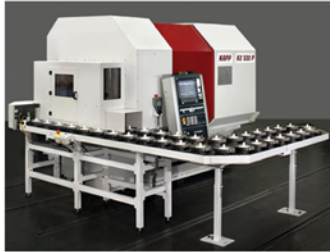
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ASK THE EXPERT

external gear is a negative profile shift, since it makes the teeth thinner.

The profile shift usually used by gear designers is for a zero backlash gearset. To provide some backlash, some designers increase center distance while others reduce the profile shift. When you subtract an additional small shift as a backlash allowance from the non-dimensional zero backlash profile shift, and multiply by module to get millimeters, the result is called the "rack shift."

In Europe, some gear designers specify only the zero backlash profile shift and the manufacturer will thin the teeth according to tables in the DIN standards. If you receive such a drawing that does not specify an actual measurement of the finished gear teeth, then you should discuss with your customer what is actually expected.

For more information, see AGMA 913-A98. This information sheet was written to introduce profile shift to engineers in the United States. There are also many computer programs, such as AGMA's Gear Rating Suite, that will allow you to easily convert from profile shift to other forms of tooth thickness specification.

John M. Rinaldo, senior development engineer at New York-located Atlas Copco Comptec LLC, is also a current member of the AGMA Computer Programming (vice-chair), Nomenclature, Gear Accuracy (vice-chair) and Helical Enclosed Drives High-Speed Units committees.



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