Got a Gear Question?
Ask the Expert!

Welcome to *Gear Technology's* latest installment of 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.

Here's how it works: Have a standards question? Design query? How about a backlash or tooth profile problem that needs fixing? Or maybe you need a material recommendation or are wrestling with a tricky contact ratio. And just which lubricant is best for those open-gearing applications?

Look no further. *Gear Technology* will call upon its deep reserve of industry experts from around the world to help solve your dilemma and get you back on track.

So stop fretting (no pun intended) about that nagging gear conundrum. Simply e-mail your question—along with your name, job title and company name (if you wish to remain anonymous, no problem)—to: Jack McGuinn, senior editor, *jmcguinn@geartechnology.com.*

High Ratio Hypoid Gear Efficiency

Our question this issue deals with high-ratio hypoid gears, and it should be noted here that this is a tricky area of gearing with a dearth of literature on the topic. That being the case, finding "experts" willing to stick their necks out and take on the subject was not a given.

Nevertheless, we have indeed for your edification responses from no less than four intrepid men in the industry—names probably familiar to most of you. Two of our guest experts—Dr. Hermann Stadtfeld and Robert Wasilewski—appeared in the March/April Ask the Expert. Also taking on the question are George Lian of Amarillo Gear; Ted Krenzer of Gleason Corp. and *Gear Technology* technical editor Bill Bradley.

THE QUESTION

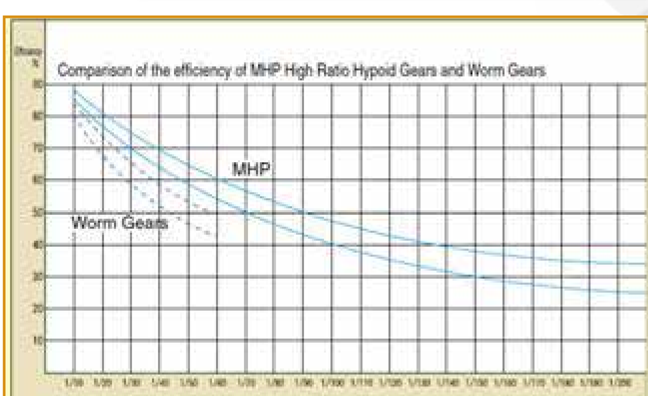
We are studying a gearmotor with high-ratio hypoid gears (HRHGs) and I would like to ask you if you know who manufactures this kind of gear.

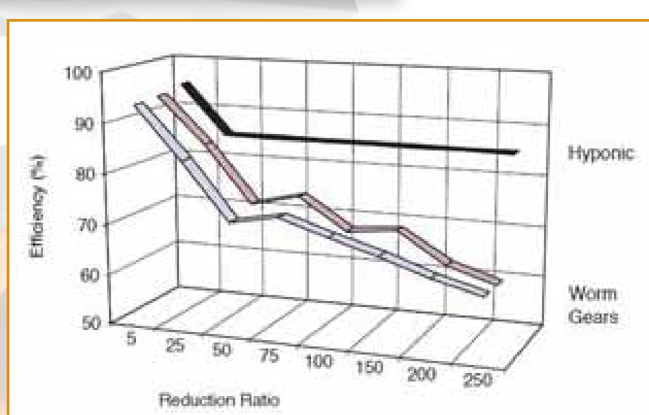
I found that there is some confusion about their efficiency: some say that the efficiency is near 90%—even for high-ratio; others say that the efficiency decreases with the ratio, i.e.—the higher the ratio, the lower the efficiency (see two graphics below).

Could you help me with this question? Are there high-ratio hypoid gears with high efficiency—even at the highest ratio?

Thank you.

Walmir Fernandes Navarro, mechanical engineer and R&D manager, *WEG-Cestari Redutores e Motorredutores,* Brazil





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The Answer is Yes—and No

Mr. Navarro,

There are (only) a few companies that manufacture high-ratio hypoid gears (HRHGs) and gearmotors:

Kohara Gear (KHK) manufactures HRHGs, which consist of bevel wheels and conical mating pinions. The company makes catalog HRHGs for ratios in the 15:1 to 200:1 range.

ITW Heartland manufactures spiroid gears (similar to KHK HRHG) and helicon gears, which consist of bevel wheels and cylindrical mating pinions. Spiroid and helicon gears can have a gear ratio up to 400:1.

Sumitomo Drive Technologies manufactures gearmotors under the brand name Hyponic. The gear drives use HRHGs for the input stage.

You asked a very good question about the discrepancy in the efficiency of HRHGs reported by various sources. One reported the efficiency of HRHGs decreases as the gear ratio increases, while another indicated that the efficiency of HRHG gears remains the same—at about 90%—over the full range of ratios.

Can both be correct?

The answer is Yes, both can be correct! The following attempts to explain why the HRHG efficiency could be constant in one case and variable—according to gear ratio—in another.

Hypoid gear mesh efficiency is affected by the amount of tooth lengthwise sliding; i.e., the higher the tooth sliding, the higher the resultant friction loss, in turn lowering mesh efficiency. The lengthwise sliding is a function of hypoid offset. Larger offset will cause higher lengthwise sliding.

The lengthwise mesh efficiency can be calculated with the following equation (*ISO/TR 22849 Technical Report,* "*Design Recommendations for Bevel Gears*," *April 2011*).

$$\eta_{\mathrm{ffl}} = \frac{T_{\mathrm{o2}}}{T_{\mathrm{i2}}} = \frac{1+\mu_{\mathrm{m}}\dfrac{\tan\beta_{\mathrm{m2}}}{\cos\alpha_{\mathrm{n}}}}{1+\mu_{\mathrm{m}}\dfrac{\tan\beta_{\mathrm{m1}}}{\cos\alpha_{\mathrm{n}}}}$$

where:

η_{ffl} = Lengthwise sliding (mesh) efficiency

T_{o2}, T_{i2} = Gear output and input torque, respectively

μ_{m} = Coefficient of friction

β_{m1}, β_{m2} = Mean spiral angle, pinion and gear, respectively

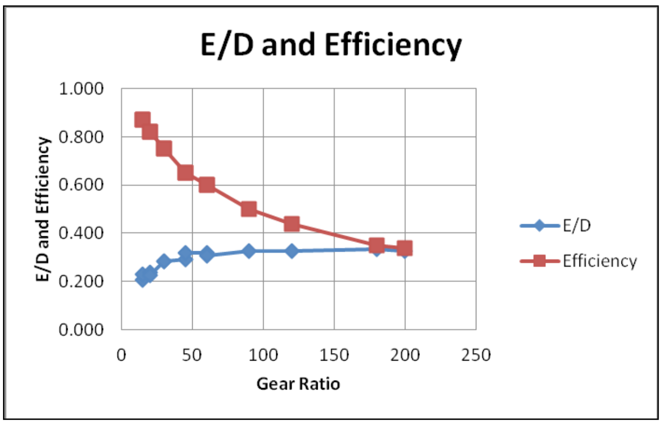
α_{n} = Normal pressure angle

For efficiency comparison of similar gears, we can consider them to have the same coefficient of friction, μ_{m}, and normal pressure angle, α_{n}.

For HRHGs, the difference between wheel and pinion spiral angles, β_{m1} and β_{m2}, is loosely related to the ratio of offset E to wheel pitch diameter D. As the $\frac{E}{D}$ increases the difference between β_{m1} and β_{m2} becomes greater. Since $\tan\beta_{\mathrm{m1}}$ is in the denominator and $\tan\beta_{m2}$ in the numerator of the mesh efficiency equation, the calculated mesh efficiency, η_{ffl}, will decrease when $\frac{E}{D}$ increases, and η_{ffl} will increase when $\frac{E}{D}$ decreases.

The first graph included in your question—Comparison of the Efficiency of MHP High-Ratio Hypoid Gears and Worm Gears—showed the efficiency of HRHGs decreases as the gear ratio increases. The graph data was apparently from KHK. In the figure below, the efficiency of KHK HRHGs (in red) and $\frac{E}{D}$ ratio of HRHGs (in blue) were plotted against the gear ratio. It is seen that as $\frac{E}{D}$ increases, the KHK/HRHG efficiency reported by the KHK figure decreases.

Based on the mesh efficiency equation presented above, increasing $\frac{E}{D}$ will cause mesh efficiency to decrease. Therefore, it is true that the HRHG efficiency can vary over the full range of ratios.



Your second figure showed efficiency of hypoid gears (some in HRHG-ratio range) to remain constant for all gear ratios. The source of the figure was apparently from a paper by Stefanie Burns (*Stefanie Burns; "Hypoid vs. Worm Gear Efficiencies;" whitepaper, Sumitomo Drive Technologies, November 2009*).

(It appears that) the efficiency calculation for the paper could be based on a series of Sumitomo HRHG gearmotors. For the same series of gearmotors, the offset and the wheel pitch diameter would be the same due to gear housing constraints. Consequently all the HRHGs compared by Ms. Burns could have the same $\frac{E}{D}$ ratio. As discussed earlier, gears with common $\frac{E}{D}$ would have the same mesh efficiency. This explains the case where all HRHGs had the same efficiency.

Summing up the above discussions, we can say that HRHGs could have identical gear efficiency over the range of ratios, and also could have decreasing efficiency as gear ratio increases.

Finally, you asked if there (are) 'high-efficiency' HRHGs—even at extremely high ratio.

The answer would depend on your definition of high-efficiency. If you consider 90% efficiency being high, then the answer would be in the affirmative. One HRHG example mentioned in this letter showed 90% efficiency for HRHGs, even at high gear ratio. Efficiency higher than 90% could be possible, but difficult to attain, because HRHGs always have some tooth sliding that reduces efficiency.

Hope the above helps.

George Lian, *engineering supervisor, Amarillo Gear Company LLC and member of the AGMA Bevel Gearing Committee.*
and **Ted Krenzer,** *Gleason Corp. and member of the AGMA Bevel Gearing Committee.*

Super Reduction Hypoids

High-ratio angular drives can be realized with worm-shaped pinions that mesh with Formate ring gears. The Gleason Corp. HRH system (high-reduction hypoids) has existed in the field for many decades. HRH teeth are face-milled and have parallel depth. The whole depth of HRH is limited to about 5 mm.

"But there is now a more modern system—Gleason Corp. SRH—or *super-reduction* hypoids. The whole depth of SRH is now only limited by the tool and machine capacity. SRH allows the application of universal motions and an "artificial" pinion diameter reduction. Both can be used as tools in order to maximize efficiency; all high-efficiency HRH and SRH gear sets are ground.

"If the number of pinion teeth is above 5, the efficiency of hypoid gears depends on the offset. If the number of pinion teeth is below 4, the number of teeth and offset have relatively equal influences on efficiency."

(*Following are some graphics in support of Dr. Stadtfeld's response, with additional comments.*):

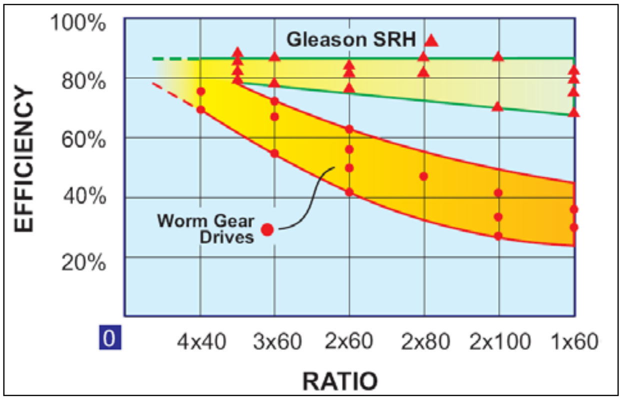


Figure 1—Efficiency comparison between worm gear drives and SRH drives.

"Figure 1 shows an efficiency comparison between worm gear drives and SRH drives. The diagram shows that average optimized SRH gear sets have efficiencies between 80% and 65%. Highly optimized SRH gear sets can almost be constant at the 83% to 87% level—even for ratios of 1x60. However, the reduced number of teeth and the higher ratio deliver the lower efficiency. A better sense of the dependencies between the parameters ratio and number of teeth is provided in Figure 2.

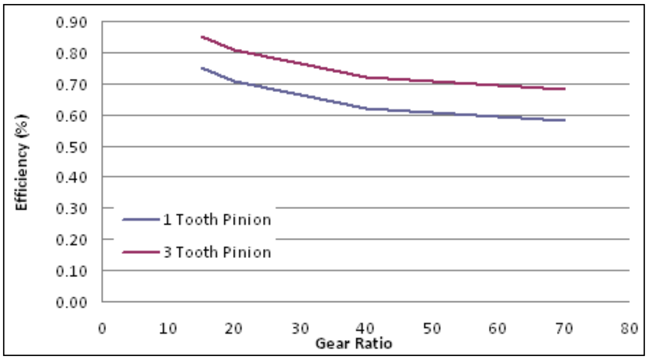


Figure 2—Dependency between number of teeth, ratio and efficiency.

"The graph in Figure 2 shows two qualitative diagrams, which imply that a lower number of teeth results in lower efficiency (red graph vs. blue graph). Both graphs show that as the ratio increases a drop in efficiency is noticed. Ninety-percent efficiency can be achieved with three pinion teeth if the ratio is below 10.

"The belief that with ratios greater than 25 the hypoid efficiency is constant at about 83% is incorrect. A reduction ratio of 250 will most likely be realized with one pinion tooth and 250 ring gear teeth. Such a transmission will show an efficiency of 45–53%. But don't be mistaken: a worm gear reduction is still 5–10% below that.

"Manufacturing of HRH and SRH gearsets is offered by Sumitomo, Nissei, Ningbo and by the Specialized Gear Services Department of The Gleason Works."

Figure 3—HRH gearset; HRH gearset with wormgear drive (courtesy Gleason Corp.).

Dr. Hermann J. Stadtfeld, *vice-president/bevel gear technology/R&D, Gleason Corp.*

Efficiency is Determined Case by Case

Traditionally, high-ratio hypoids needed to be cut on hypoid generators that have special modifications to adjust for the very low numbers of teeth and the amount of movements necessary to cut the extreme spiral length. (While) CNC generators (require) software to overcome these deficiencies, not every hypoid manufacturer has this equipment. Tooth contact development is (also problematic).

But whether your hypoid requires special machinery or not really depends on the specifics of your design.

The subject of efficiency is not as simple as saying 'All hypoids are 90% or better.' Technically, spiral bevel gears are hypoids and their efficiency is much higher. We have seen typical (i.e., not high-ratio) hypoids below 90%.

The key here is that a hypoid gear is normally considered to have an offset between the pinion and the mating gear. As this offset is increased, the pinion gets larger in diameter and the spiral angle can get bigger too. As you increase the ratio you typically need to reduce the number of teeth on the pinion, and the pinion spiral angle approaches the thread-like appearance of a worm gear. The result is a larger percentage of lengthwise sliding, similar to a worm gear set—and greater losses. You can adjust some of the geometry to reduce losses, but as the number of teeth and offset approach those of the equivalent worm, so does the efficiency.

Without a specific set of parameters it is difficult to say what efficiency you will have. There are calculations that can be done both in manufacturing software and industry standards that give efficiency predictions. ISO TR 22849 (proposed for AGMA adaptation) has a calculation procedure for hypoids that also takes into account windage and churning. These are calculations and you need to actually verify your efficiency in your application.

So in short, it would be best to compare a specific hypoid to a specific worm to see how different they really are.

Robert F. Wasilewski, *design engineering manager, Arrow Gear Company*

Typically, There Are No High-Ratio Hypoid Gears with High Efficiency—But Read On

Gearbox efficiency is a very complex topic as there are many sources for the loss of power into heat. When thermal losses of a gearmotor are considered, the major sources are the motor; bearings; gear mesh; shaft seals; windage; and churning.

In the past (the days of cheap energy), the efficiency of a gearmotor or a gear mesh was not a big concern, as industrial energy consumption was not a big concern. When it in fact became one (and continues today), there was confusion when efficiency was quoted, as the methods for its determination were not the same. Also, it is very difficult and expensive to accurately measure differences in efficiency of a gearmotor. In the world of international gear standards the calculation of losses has taken the form of standardized methods for the determination of thermal rating of a gearbox.

Specifically, for right-angled gearing, (bevel, hypoid and worm) the mesh friction losses are an important consideration. The designer can theoretically evaluate friction losses based on relative sliding between the teeth in mesh—in both profile and lengthwise direction. Generally, for similar size and ratio, bevel gears will have the best efficiency and wormgears the worst—with hypoid in the middle. This is because the relative sliding tends to increase, going from bevel-to-hypoid-to-worm.

In general, with these gears the relative sliding increases as the ratio increases. Therefore, relatively speaking, there are no high-ratio hypoid gears with high efficiency. The efficiencies can vary considerably with right-angle gearmotors—generally between 95% – 75%, depending on design and lubrication.

If you want more detail, a reference standard is AGMA ISO 14179: Gear Reducers—Thermal Capacity Based on ISO/TR 14179–1:

"This information sheet utilizes an analytical heat balance model to provide a means of calculating the thermal transmittable power for a single- or multi-stage gear drive lubricated with mineral oil. The calculation is based on standard conditions of 25C maximum ambient temperature and 95C maximum oil-sump temperature in a large indoor space, but provides modifiers for other conditions. Differences from ISO/TR 14179–1 are: a) errors were identified and corrected; b) text was added to clarify the calculation methods; and c) an illustrative example was added to assist the reader."

A reference technical paper of interest is AGMA 05FTM06: "A Model to Predict Friction Losses of Hypoid Gears," by H. Xu, A. Kahraman and D.R. Houser. Quoting here, "In it a model to predict friction-related mechanical efficiency losses of hypoid gear pairs is proposed, which combines a commercially available finite element-based gear contact analysis model and a friction coefficient model with a mechanical-efficiency formulation. The contact analysis model is used to provide contact pressures and other contact parameters required by the friction coefficient model. The instantaneous friction coefficient is computed by using a validated formula that is developed based on a thermal elastohydrodynamic lubrication (EHL) model. Computed friction coefficient distributions are then used to calculate the friction forces and the resultant, instantaneous mechanical efficiency losses of the hypoid gear pair at a given mesh angle. The model is applied to study the influence of speed, load, surface roughness and lubricant temperature as well as assembly errors on the mechanical efficiency of a (sample) face-hobbed, hypoid gear pair."

Bill Bradley, longtime AGMA gearing expert, Bevel Gear Committee member and *Gear Technology* technical editor