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High Contact Ratio Gearing: A Technology Ready for Implementation?

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(The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.)

Abstract

Today's competitive industrial gear marketplace demands products with excellent reliability, high capacity, and low noise. Surface hardened ground tooth gearing predominates but the legacy tooth forms handicap further improvements in capacity and noise generation. Vehicle and aircraft equipment use tooth forms not found in the standard tables to achieve better performance at little or no increase in cost. This paper will propose adopting these high contact ratio forms to industrial use.

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Discussion

I first became aware of deeper than standard tooth forms in 1979. The venerable company had been through tough times but its staff of engineers and designers came up with some creative solutions in the effort to remain competitive. When competitors started to shift to carburized gearing and invest in gear grinding equipment, the owners did not have the cash to follow suit. Some clever engineer decided to use teeth that were 20% deeper than standard and nitride them. The rating methods then in effect gave them competitive power densities with only the purchase of custom cutting tools.

The 1.2 addendum combined with the 25 degree pressure angle did not result in true high contact ratio geometry (see Figure 1). Poor tool life, especially when cutting hard pre-nitriding blanks, made for some production challenges. Coming from a through hardening background I was very skeptical but over time found the tooth form provided good results in the field. Replacing the special hobs wasn't possible in the reduced order volume of the early 1980s, however, and we did not use the 1.2 addendum system in new design standard products.

My next exposure to high contact ratio gearing came eleven years later during a tour of the Saturn automobile plant in Spring Hill, Tennessee. The Society of Automotive Engineers (SAE) organized the event and we were keen to see the compact, integrated gear manufacturing cell that had been set up to produce all the components needed for a front wheel drive transaxle. It was an impressive achievement in 1990 to begin with raw forgings at one end of the line and have complete carburized, hardened, and ground helical gears ready for assembly at the other end. General Motors spent plenty of money on the project and it challenged the best equipment builders in the world to participate.

The gear line included an automated inspection station after the gear grind operation. While watching the charting of parts in the cue, I noticed that the teeth were much deeper than "normal" but did not think to ask our guide a question about it. The equipment supplier gave out sample charts and when we debriefed back at our office we tried to run the geometry shown on it through our gear analysis software. The home brewed code "blew up" at the dimensions entered and when we dug into the error codes it was found to have exceeded the "allowable" profile contact ratio of 1.99. We didn't at first understand the significance of this limit in conventional gear design but after scouring our engineering library we came across a great paper by Leming [1] that explained things very well. Despite the many advantages of high contact ratio gearing that Leming pointed out, we put the concept aside and continued to design products with "standard" teeth.

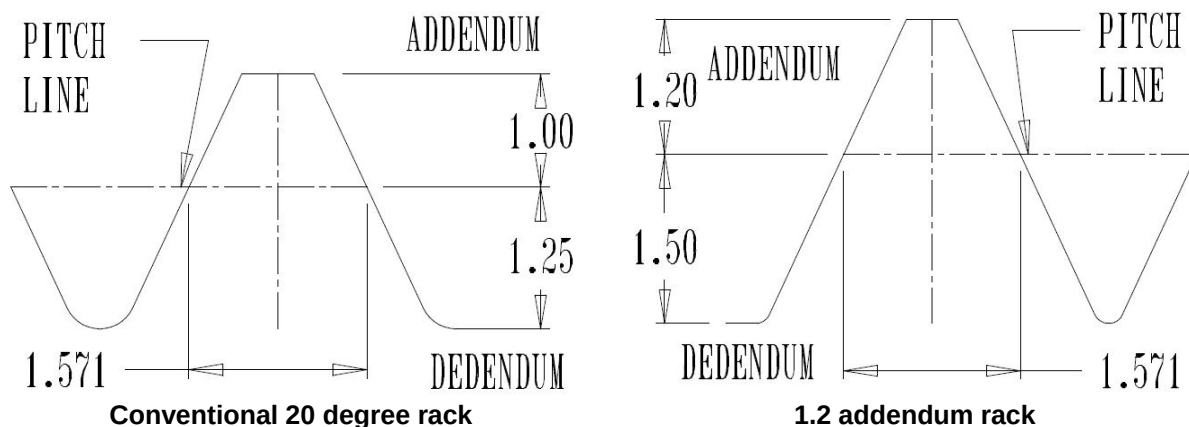


Figure 1. Deeper than standard tooth form

A couple years later, though, one of our salesmen asked us to help a potential customer resolve a noise problem with his equipment. Our firm had a well-deserved reputation as a supplier of high quality ground tooth gears and we went to work reviewing a consultant's telephone book thick report on the customer's "problem." Unfortunately, the solutions suggested were things we had tried before without much success and we told the salesman we did not think the project was worth pursuing. This salesman was a very persistent man and he refused to take no for an answer. Under the guise of giving the client a tour of our facility, he arranged for a couple of engineers to meet with my boss and me. We explained our dismal prognosis for quieting his gearbox and figured we were done with the matter. These engineers were just as persistent as our salesman and they knew we wouldn't be able to resist a well-argued challenge. Especially after they told us their project motto was "We won't fail because we didn't spend enough money."

During the brainstorming that followed the Saturn tour, the Leming article came up. While I went to retrieve the reference book with the Leming paper in it, my boss committed to me designing a set of high contact ratio gears in less than a week. There was, after all, a three day weekend coming up and there would be fewer distractions. Six days later we met again and reviewed the proposed design. We had no way of predicting the possible noise reduction but the geometry worked out and we were ready to make drawings. The customer started expediting delivery of prototypes before the review meeting was over. We thought perhaps two weeks after the hobs arrived, maybe eight to ten weeks total.

This was not acceptable and the customer promised to use his influence to get the hobs made more quickly. The next day, when the drawings were done, he called back to report that there could be no rush hob delivery. What other options were there? Jokingly reminding him of his project motto, we suggested wire cutting the parts. He didn't find the attempted humor funny and asked for blanks to be ready for his pick-up in two days. Said blanks were back to us three days later with Q9 quality teeth cut in them using tooth plots we provided. The sample gearbox was put on test two weeks later and the results were excellent. Noise reduction goals were easily met with no tooth modifications required.

Knowledgeable observers could not let go of the long thin teeth appearing to be so delicate. Surely those skinny teeth will break, they insisted. Upon the completion of the sound tests, the prototype gearbox was subjected to the same breakage test used many years earlier to approve the previous gearbox for production. It was still running flawlessly after completing the test three times. The conventional gearbox seldom survived extended testing. A modified version of the high contact ratio gearbox has now been in production for over 20 years.

Tooling budgets and production schedules prevented me from using high contact ratio tooth forms often while a gear company engineer. We managed to purchase a few HCR hobs for specific projects where there simply was not enough room for conventional gears to transmit the load but, regrettably, there was not the will to implement this technology in a widespread way. Now that I have my own consulting firm I hope to change that situation and assist clients in developing HCR geared products.

The history of high contact ratio gearing

The official "history" of high contact ratio gears begins with aircraft gearboxes in World War II. Leming's excellent summary of the development work on aircraft systems was published in 1977 but there is also some unofficial history dating back much further that bears study.

We take the "standard" involute tooth forms for granted as they were adopted long before any of today's working engineers were born. The 14-1/2 degree "full depth" involute was the first to gain official recognition in April of 1921, but even back then there was an effort to switch to 20 degrees, first at stub depth and shortly thereafter at full depth, to meet increasing load requirements for automobiles and trucks. A "composite" 14-1/2 degree system which combined an involute and cycloidal form into a single reference rack was also adopted in the 1920s, a recognition that not everyone was completely sold on the involute system either.

So where did the "standard" form come from? If you look at old photographs or drawings you will see a variety of tooth proportions, especially prior to the widespread use of hobbing and shaping machines in the late 1880s. Many gears had cast teeth and there is some evidence that the 14-1/2 degree system became popular in part because the sine of 14-1/2 degrees is 0.25 and that makes it easier to draw the tooth shape into the pattern than other pressure angles. A more plausible reason, based upon my limited foundry experience, is that 14-1/2 degree teeth have wider top lands which would be easier to maintain in the foundry conditions of that time.