A Split Happened on the Way to Reliable, Higher-Volume Gear Grinding

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In the past 15–20 years, gear grinding has evolved into a stable, much-used process in industrial production, especially for making high-quality automotive transmission gears.

During this evolution, though, a split occurred between U.S. and European bevel gear manufacturers. Today, they live in one of two camps: the face-hobbing/lapping camp and the face-milling/grinding camp.

In the mid- to late 1980s, when gear grinding was introduced for industrial production, gear manufacturers already knew that gears ground to a very high AGMA quality level didn't have particularly low noise emission levels. The reason was the high spacing and flank form accuracy, which generated tooth meshing impacts during operation. These impacts occurred in angular intervals with very little variation.

The precise impact frequency created a so-called pure frequency tone that was emitted as part of the structure and air-borne noise. In the automotive industry, this pure tone noise could be easily distinguished from other sounds, such as noise from the wind, the engine and the tires. Moreover, the pure tone noise felt disturbing.

Gear manufacturers, however, were still attracted to grinding. Its beauty lay in its ability to achieve a low amount of variation in gear flank geometry within a production batch and in its ability to achieve such low amounts from batch to batch regardless of different levels of heat treat distortion resulting from steel variations.

For cylindrical gears, some manufacturers tried to reduce or eliminate the excitation from the tooth mesh impacts by grinding their gears, then honing at least one of the rolling members. But, this honing was difficult to justify economically.

Also, the manufacturers had another option: power honing. This highly economical finish honing process didn't require a previous grinding operation to take advantage of a gear's defined flank surface with minimum variation in production. The advantage of honing was the surface structure. It had a different orientation than the contact lines between pinion and gear, reducing the dominant mesh frequency peaks in the noise emission.

The problem with the pure tone frequency noise of strictly finish-ground gears was also reduced when flank modifications were developed. These modifications resulted in low motion error, even if the gears were displaced from their theoretical positions.

These developments helped spread the use of grinding for cylindrical gears, but not for bevel gears. There was still a five- to eight-year delay for the bevels.

In the early to mid-1990s, though, there were a number of advances in bevel gear manufacture. A breakthrough promised to spread the use of bevel gear grinding in Europe; the other advances led many bevel gear manufacturers in the United States in another direction.

The result was today's split between U.S. and European bevel gear manufacturers.

Until the early 1990s, most bevel gear grinding was done in the aircraft industry in single setups for convex and concave pinion flanks. But a breakthrough occurred in the completing cutting and grinding process for face-milled bevel gears.

The breakthrough resulted from a series of advances: improvements in the completing tooth design, especially in the tooth taper; a new generation of free-form machine tools with the higher stiffness and accuracy needed for a completing cutting and grinding process; new machining cycles that greatly reduced grinding time; and higher-order machine motions able to make flank form modifications that increased strength and reduced noise.

The breakthrough changed the economics of bevel gear grinding. The aircraft industry's single setups hadn't been affordable for automotive applications, but the new completing setups were. Bevel gear grinding became popular for mass-produced automotive gear sets.

Consequently, European bevel gear manufacturers turned away from lapping and toward grinding as a finishing process.

But grinding as the only and final hard finishing operation was a struggle for many years. It wasn't until the new millennium that all the elements of this technology worked as a stable process in an industrial production environment.

Also in the early to mid-'90s, though, many U.S. bevel gear manufacturers chose lapping over grinding. The reason: a number of innovations in face hobbing. The innovations convinced them that face hobbing had the most potential to be a stable, economical process for making bevel gears with high strength and low noise.

But face-hobbed gears couldn't be—and still can't be—ground with today's gear grinders. The flank lines' epicyclical shape makes grinding impossible. Lapping works efficiently, though. It also delivers better results when used on face-hobbed gears than it does on face-milled gears.

In the Far East, China, Japan and South Korea knew about the technological advances affecting grinding and lapping, but they change their bevel gear manufacturing processes only slowly. Most gear manufacturers in those Far East countries decided to retain the practice of five-cut face milling with lapping after heat treatment—the cutting-and-finishing combination that prevailed around the world before the 1980s.

Whether the U.S.-European split will continue is an open question. Just as advances led to the separation, other advances may lead one camp into the other or may lead both into a third camp. In all cases, though, a successful finishing process has to provide economical advantages and result in gears of high strength and low noise.