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How Are You Dealing with the Bias Error in Your Helical Gears?

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John Lange, The Gleason Works

[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

The paper initially defines bias error (“the twisted tooth phoneme”). Using illustrations we explain that bias error is a by product of applying conventional radial crowning methods to produced crowned leads on helical gears. The methods considered are gears that are finished, shaped, shaved, form and generated ground. The paper explains why bias error occurs in these methods. It then addresses what techniques are used to limit/eliminate bias error. Some times there may be a possibility to apply two methods to eliminate bias error. In those cases the pros/cons of these methods will be reviewed. Profile and lead inspection charts will be used to detail bias error and the ability to eliminate it.

The paper details the simultaneous interpolation of multiple axes in the gear manufacturing machine to achieve the elimination of bias error. It also explains that the CNC machine software can be used to predict bias error. Equally important that it could be used to create an “engineered bias correction” to increase the load carrying capacity of an existing gear set.

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Introduction

Bias error or correction (also known as “The Twisted Tooth Error” and topological correction) was understood and addressed in the mid 1970’s. It was not used by designers to increase a transmission’s gear load capacity and noise reduction, but rather in a manufacturing process to finish automatic transmission gears to a quality level similar to a shaved finished quality. The finish rolling process required the use of dies that required bias error correction. Without bias correction the rolling dies and the working pressure of the process would produce errors similar to bias. The bias correction process was applied to a finishing tool. However, there was little chance to apply bias correction economically to conventional gearing.

The push in almost every gearing field is to increase the durability, load carrying capacity and a reduced noises level for given gear set. It is stated as the need for higher power density, we need more torque capability, we need a quieter gear box, and we need longer life and so on. From the aerospace industry it might be twisted around a bit (pun intended). They want a smaller lighter gear set but having the same load carrying capacity. Dealing with the loss of involute contact ratio and tooth face width bearing pattern contact because of bias error, reduces the load carrying capacity of a given gear set. So “dealing with it” just might make it possible to meet the demands of higher power density without an entire redesign of the gear set.

Discussion

Bias error is a non uniform profile and lead geometry across the facewidth of a helical gear. “The twisted tooth” appears as if one end of a gear tooth was rotated one clockwise and the other counter clockwise. It is the direct result of making a lead crown correction using the conventional method of the radial displacement of the “tool” (cutting or otherwise) as it moves along the facewidth of the gear. Pinions, the lower number of teeth component in a gear set, are more prone to “inherit” this unique

manufacturing error. The pinion, being the smaller gear component, is more apt to deflect under heavy loads. That deflection occurs in the lead and involute planes. It is ironic that gear designers, in an effort to maintain a reasonable face contact pattern at peak loads; specify lead crowns that in reality can have an adverse affect. There is a need to understand a lead crown correction with bias error compensation will achieve the goals of the designers.

The contributing factors creating bias error and those increasing the amount of bias error are:

- The helical aspect relates the line of action contact pattern of two helical gears in mesh, see Figure 1.

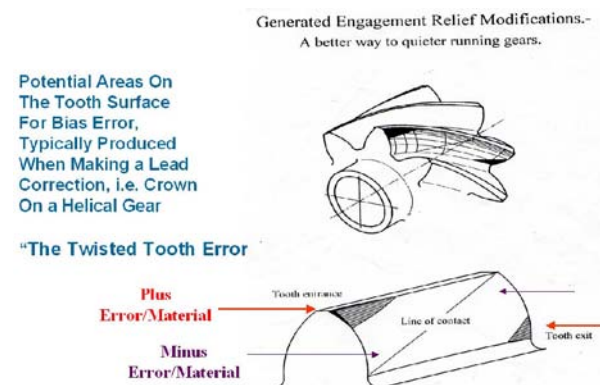


Figure 1. Line of action contact

- The pinion is the gear normally modified and it has the highest degree of tooth curvature. The higher the tooth curvature, lower number of teeth, the greater the potential for bias error, see Figure 2;

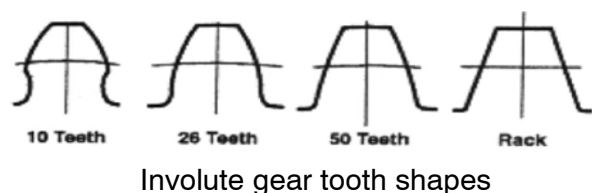


Figure 2. Curvature of the involute

- Figures 3, 4 and 5 illustrate bias error and a corrected bias error. The red section of the plotted tooth represents unwanted plus error; yellow signifies the transition zone to beginning of tooth contact; and green, the ideal tooth geometry along the line of contact.



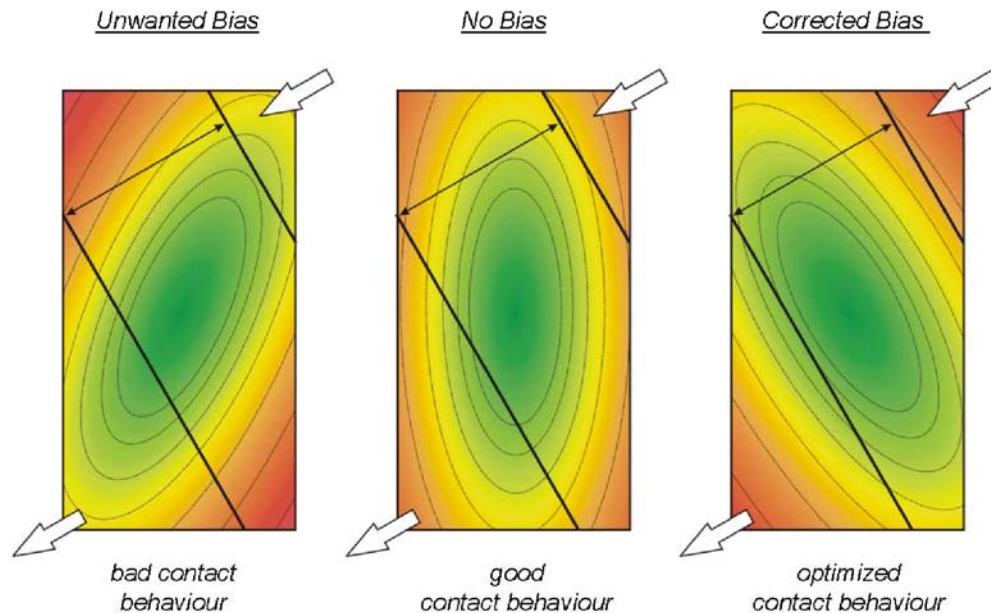


Figure 5. Impact of bias on tooth contact

What does a gear designer consider and how does bias error affect those decisions?

Three significant factors figure into the load carrying capacity rating and noise of a gear set:

- **Involute contact ratio:** A theoretical calculation of an average number of teeth in contact as mating gears roll in mesh, 2 or greater is desirable;
- **Load distribution:** Distributed across the face-width of the gear which can also simultaneously affect the involute contact ratio negatively if the two gears in mesh are not contacting each other along the designated facewidth, normally 80% or more when under load, see Figure 6;
- In the finished gear plus error needs to be avoided. If not high contact stress could lead to tooth pitting in those areas of plus error.

Because of varying load, tooth and gear blank/shaft bending under severe loading, there is a need to create gear tooth modifications.

- Involute tip relief and / or root relief
- Lead crown
- Lead evaluation typically over 80% of the facewidth but in newer designs moving to 90 %!

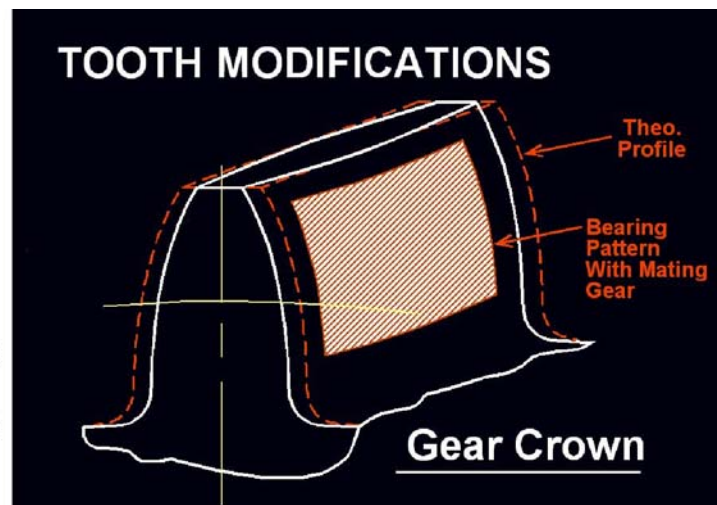


Figure 6. Load distribution