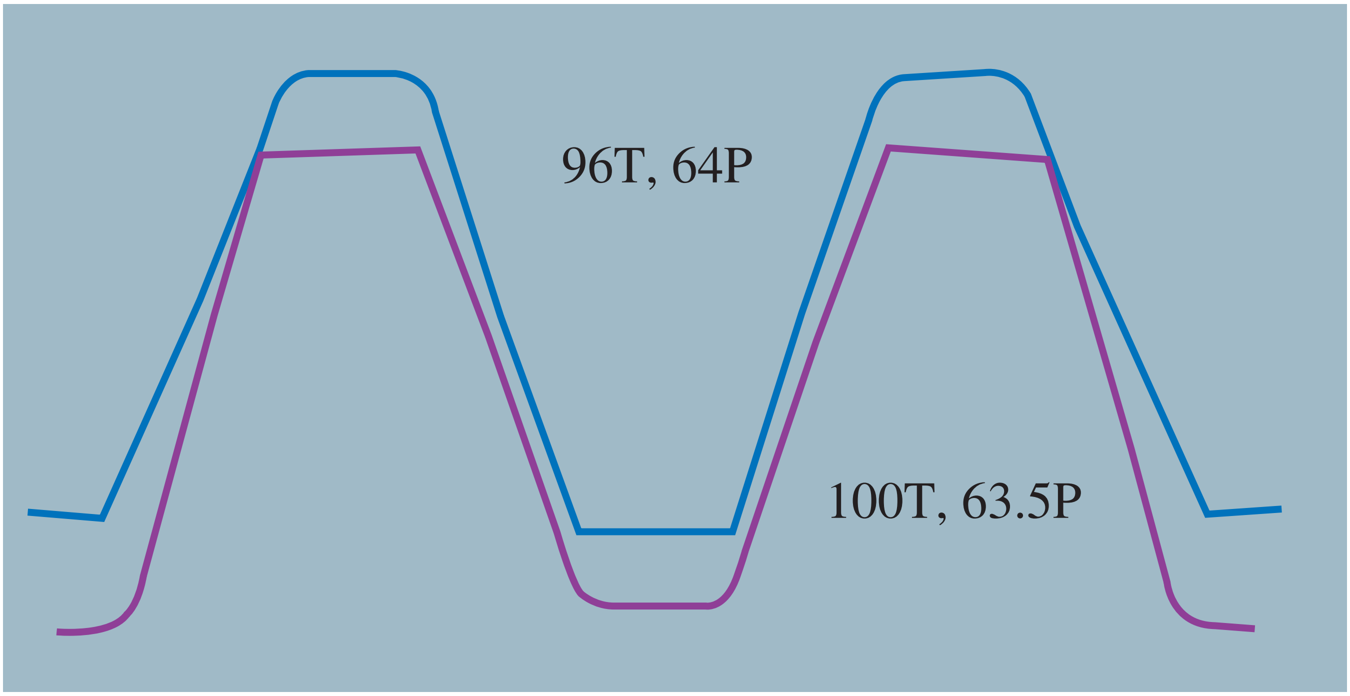

Figure 1—Computer plot for a master gear tooth on the line of centers.

Characteristics of Master Gears

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Management Summary

The two-flank roll test (a work gear rolled in tight mesh against a master gear) measures kickout (also known as tooth-to-tooth composite error) and tooth thickness. In this article, it will be shown that the measured values for kickout and tooth thickness vary with the number of teeth on the master gear, and that the errors in measured values become greater with the number of teeth on the master gear.

Introduction

To show that the measured value for kickout varies with the number of teeth on the master gear, a work gear is meshed against master gears of various tooth numbers. For example, the author has a 100-tooth, 48 diametral pitch, 20° profile angle, molded plastic gear—drawn at random from a production line—that has kickouts of 0.0003". and 0.0010" against 96- and 30-tooth master gears, respectively. Another way to show the variation in kickout values is to mesh high grade work gears of various tooth numbers against a master gear of slightly different diametral pitch (Ref. 1).

For example, when a 180-tooth, 120 diametral pitch master gear is meshed against a 192-tooth, 127 diametral pitch (0.2 module) master gear, 20° profile angle on both, the kickout is only about 0.0002", despite the fact that the difference in base pitch is 0.0014". But when 120 diametral pitch high-grade work gears of various tooth numbers are meshed against the 127 diametral pitch master gear, the kickout increases as the tooth number decreases, to about 0.0019" for a 12-tooth work gear (Ref. 1).

It is pertinent to note that an error of 0.001" in base pitch is not uncommon in formed gearing (molded plastic, die cast, powder metal, stamped, cold drawn).

And to show that the measured value for tooth thickness varies with the number of teeth on the master gear, a work gear of slightly different diametral pitch is meshed against master gears of various tooth numbers.

The general way in which tooth thickness varies with the number of teeth on the master gear has been known for a long time (Ref. 2). Now, with the advent of the computer plot, it is feasible to calculate values for both the tooth thickness and the kickout.

Numerical Example

Given two master gears: 96- and 20-tooth, 64 diametral pitch, 20° profile angle, basic tooth thickness (π /128). Also given a work gear: 100-tooth, 63.5 diametral pitch (0.4 module), 20° profile angle, basic tooth thickness (π/127). Accordingly, the error in base pitch, relative to the 96- and 20-tooth master gears, is:

$$\left(\frac{\pi}{63.5}-\frac{\pi}{64}\right)\cos 20° = 0.00036''$$

Since only the effect of an error in base pitch is being investigated, the outside diameter of the 100-tooth work gear is (100 + 2)/64 = 1.5938", not (100 + 2)/63.5 = 1.6063".

When the 100-tooth work gear is meshed against the 96-tooth master gear on the computer plot, it is seen that the center distance is maximum for a master gear tooth on the line of centers and minimum for a work gear tooth on the line of centers. Also, it is seen that both center distances exceed the basic center distance of (96 + 100)/128 = 1.53125".

Thus, to bring the maximum center distance down to the basic center distance, it is seen (via trial and error) that the tooth thickness on the work gear must be 0.0498" less than the basic π/127".

From Figure 1, which is the computer plot for a master gear tooth on the line of centers, it is seen that the master gear tooth is not in contact with the adjacent work gear teeth and that contact is on the tips of the work gear teeth, not on the line of action.

For a work gear tooth on the line of centers, the center distance on the computer plot is 1.53092" for a tooth thickness of 0.00498" less than basic. Thus, the kickout is 1.53125–1.53092 = 0.0003".

Further, for two work gears with 0.00498" reduction in tooth thickness, their tight mesh center distance is 1.5606" (Refs. 3 and 4), not the (100 + 100)/128 = 1.5625" indicated by the 96-tooth master gear.

Conversely, when the work gear is meshed against the 20-tooth master gear on the computer plot, the reduction in tooth thickness is 0.00487" (versus 0.00498" for the 96-tooth master), the kickout is 0.0005" (versus 0.0003" for the 96-tooth master) and the tight mesh center distance between the two work gears is 1.5609" (versus 1.5606" for the 96-tooth master), not the 1.5625" indicated by the 20-tooth master gear.

Lacking the computer plot, nearly the same results can be obtained with gears made to the above dimensions, using 64 diametral pitch and 0.4 module hobs.

Excessive backlash (arising from unknown reductions in tooth thickness) can be avoided when both members of a gear pair are generated (hobbed, shaped). Specifically, all parts for one member of the gear pair are cut to mesh against a master gear. Then, these parts, drawn at random to simulate the assembly process, are used to cut parts for the other member of the gear pair to a specified center distance (Ref. 5).

Optimum Tooth Number

In the foregoing example, both kickouts were determined for a known error in base pitch. In practice, however, the gear defects are not known. Consequently, the optimum tooth number for a master gear (that for which the kickout is maximum) must be determined by experiment.

The optimum tooth number is likely to be determined by work gears with high tooth numbers and is likely to be lower for formed gearing than for generated gearing.

Measurements

It is imperative that the experimental measurements for optimum tooth number not be conducted by different companies. For example, Michalec and Karsch conducted a correlation study (Ref. 6), wherein an assortment of 100 fine-pitch precision gears were inspected at 20 different facilities for total composite error, tooth-to-tooth composite error (kickout) and testing radius. In their report, in addition to finding a "wide variation of measurements among companies," they decided to eliminate the study of kickout because "the readings contained considerable uncertainty."

It is interesting to note that the study was conducted during the heyday of the analog computer (Ref. 7), when the participants had a special interest in obtaining state-of-the-art gears.

If a similar correlation study were to be conducted today, the discrepancies probably would be similar since there have been no marked improvements in inspection practice and test equipment.

In short, it is imperative that the search for optimum tooth number be conducted at one location by personnel who are well acquainted with the measurement errors in gear roll testing (Refs. 8 and 9).

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