

The Effect of Spacing Errors and Runout on Transverse Load Sharing and the Dynamic Factor of Spur and Helical Gears

by: H. Wijaya, D.R. Houser and J. Harianto,
The Ohio State University

American Gear Manufacturers Association



TECHNICAL PAPER

The Effect of Spacing Errors and Runout on Transverse Load Sharing and the Dynamic Factor of Spur and Helical Gears

Husny Wijaya, Donald R. Houser and Jonny Harianto, The Ohio State University

[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

This paper addresses the effects of two common manufacturing errors on the performance of spur and helical gears. The first error to be considered will be tooth spacing error. First the transverse load sharing for two types of worst case scenarios, one where one tooth is out of position and the second where there is a step index error is applied (all subsequent teeth are out of position). The results of these analyses are then used as input to a simulation program that predicts gear dynamic loads, dynamic contact stresses and dynamic root stresses and generalized dynamic factor information is generated. Runout, which results in a sinusoidal spacing error is the second type of error that is analyzed. When the dynamic simulation is run with runout, there is much modulation of the meshing forces and again dynamic loads and stresses are presented as a function of rotating speed.

In all cases, results are run for gears that have profile modifications that initially minimize dynamic load, thus minimizing dynamics due to mesh stiffness variations. This allows the isolation of spacing error effects while at the same time minimizes tooth corner contact. Since it is difficult in these situations to separate the transverse load sharing effects from the dynamic effects, they will be simultaneously considered in all of the analyses.

Copyright © 2001

American Gear Manufacturers Association
1500 King Street, Suite 201
Alexandria, Virginia, 22314

October, 2001

ISBN: 1-55589-787-8

The Effect of Spacing Errors and Runout on Transverse Load Sharing and Dynamic Factor of Spur and Helical Gears

Dr. D. R. Houser
Professor, Department of Mechanical Engineering
The Ohio State University
Columbus, OH 43210

and

Husni Wijaya
Graduate Research Associate, Department of Mechanical Engineering
The Ohio State University
Columbus, OH 43210

and

Jonny Harianto
Research Engineer, Department of Mechanical Engineering
The Ohio State University
Columbus, OH 43210

INTRODUCTION

The dynamic factor used in gear design has been the subject of many studies, most of them being analytical in format. Buckingham's first formulation [1] of a dynamic factor was based on entering contact impacts due to spacing errors and subsequent work by Tuplin [2], and Houser and Seireg [3, 4] continued applying this approach. However, in modern gear design, these impacts are eliminated through the use of tip relief and lead crowning so that the later formulations of Harianto and Houser [5, 6] and Lin [7] have been based on errors in the tooth form that result in a transmission error excitation.

Three types of dynamic factors defined by Harianto and Houser [5] are the "dynamic load factor" which is the same as the factor used by AGMA [8], the "dynamic root stress factor" and the "dynamic contact stress factor". In this paper, spacing errors and runout will be introduced and further analyzed using these three dynamic factor definitions. However, the static changes in the transverse load sharing (*TLS*) sometimes are much greater than the dynamic effect, so we shall define two new factors that combine the static and dynamic effects as follows:

$$\text{Spacing Factor} = \text{Dynamic Factor} \times \textit{TLS}_{\text{Spacing}}$$

$$\textit{TLS}_{\text{spacing}} = \frac{\text{Maximum static value with spacing error}}{\text{Maximum static value without error}}$$

$$\text{Runout Factor} = \text{Dynamic Factor} \times \textit{TLS}_{\text{runout}}$$

$$\textit{TLS}_{\text{runout}} = \frac{\text{Maximum static value with runout}}{\text{Maximum static value without runout}}$$

The "static value" depends on the type of analysis, namely load, pinion root stress, gear root stress or contact stress, and these two factors give the net static and dynamic effect of the respective spacing errors and runout.

The procedure for determining these factors is first to use the Load Distribution Program (LDP) [9] to obtain the static transmission error and mesh stiffness as functions of gear rotation. These parameters are then used as excitations to the Dynamic Transmission Error Program (DYTEM) that uses a six degree-of-freedom

non-linear time domain model to simulate gear dynamics [10]. Dynamic loads are predicted from the DYTEM program and then fed back to LDP to calculate the values of both root and contact stresses at each contact position. The procedures used in this paper for predicting dynamic load, root stress and contact stress are similar to those presented by Harianto and Houser [5, 6]. A description of each of these programs is provided in the APPENDIX.

SPACING ERROR AND RUNOUT

Spacing error is the circumferential position error of one gear tooth with respect to the previous tooth. Runout is an eccentricity that can be described over one revolution of the gear as a sinusoidal spacing error function.

Spacing errors and runout have a significant effect on gear dynamics, and many studies have been conducted in this area. Houser and Seireg [3, 4] have done experimental and analytical studies on the influence of different pitch errors and profile modifications on the dynamic factors of spur and helical gears. The studies were limited to gear systems that operate at low speed or non-resonant speeds and concentrated on the entering tooth impact that occurs due to corner contact. Today, this corner contact effect can be avoided or minimized by providing adequate tip relief and lead crowning. Umezawa, Sato and Kohno [11] studied the rotational vibration of gears with pitch errors on every other tooth and on every third tooth, and their results show that low contact ratio gears are more sensitive to pitch error than are high contact ratio gears. Kohler [12] examined the effect of spacing error on the gear transmission error. Padasolala and Lin [13] investigated the effectiveness of profile modification for reducing dynamic loads on the gears using long span and short span spacing error over several teeth, but the magnitudes of spacing errors used are very low and are close to the highest quality (quality 15) rated gear tolerances prescribed by AGMA. Briere and Sabot [14] investigated the eccentricity faults in spur gears and their results show amplitude modulation and a resulting periodicity of kinematic transmission errors.

The proper means of simulating spacing errors would be to apply the errors over the total rotation of both pinion and gear. This would require running the gears through their total hunting period. Instead, we have found that the worst-case spacing errors occur when the respective worst-case errors of the pinion and gear match up. Therefore, we are only going to study the worst-case combinations of spacing errors, first with errors in the positive direction and second with errors in the negative direction. Even so, there are two ways errors can occur

that give high dynamic responses. The first, called case A, is when one tooth is out of position and all other teeth are in their original locations. This means that if one tooth is given a spacing error, then the opposite magnitude spacing error is applied to the next tooth to relocate the next tooth back to its original position. The second, called case B, is a step index error. This means that if a tooth is out of position because of a spacing error, then all subsequent teeth are also out of position by the same amount. Positive spacing error means the tooth with error is closer from the previous tooth (added material), and negative means the tooth is farther from the previous tooth. Since only the worst-case is considered, the magnitudes of spacing error and runout used for all simulations will be taken as double the tolerances prescribed by AGMA quality standards. In this study, gears of AGMA quality 10, 12, and 14 are used in the simulations. Schematics of negative spacing errors modeled as case A and case B are shown respectively in Fig. 1.

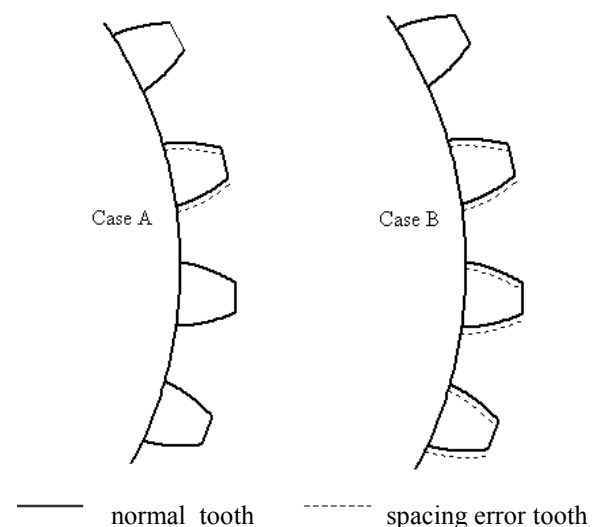


Fig. 1 Schematic of teeth with negative spacing error

OPTIMIZED PROFILES AND LEADS

In order to isolate the effects of spacing errors and runout from other factors such as profile errors, it is important to start with gears that have minimum dynamic effects due to profile errors. It is assumed that the effect of each type of error must be superimposed in order to obtain a complete dynamic factor. In Fig. 2, the dynamic load factors are shown for a perfect involute spur gear and a spur gear whose profile has been optimally modified. The geometry of the spur gear pair is given in Table 1. The dynamic factor of the perfect involute spur gear pair exceeds 2.0 for several operating speeds and the

dynamic factor for the optimally modified spur gear pair is virtually 1.0 at all operating speeds.

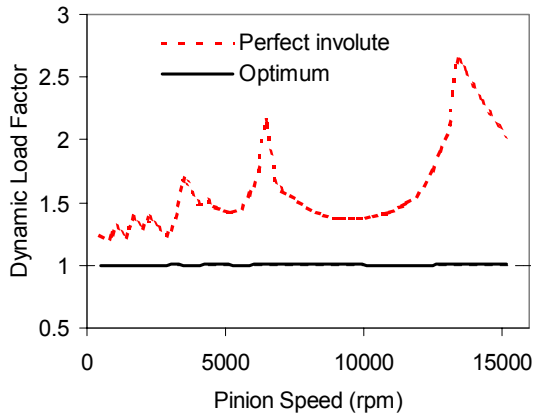


Fig. 2 Dynamic load factors comparison of the perfect involute spur gear pair and the optimum spur gear pair

SPUR GEAR RESULTS

A spur gear pair whose geometry data is given in Table 1 is used for this analysis. The gear pair has the same 1:1 ratio geometry as was studied by Harianto and Houser [5] and by Rebbechi [15]. The tolerances of

spacing errors and runout for quality 10, 12 and 14 gears are also given, respectively, in Table 1.

Table 1 Spur Gear Data

Number of teeth pinion/gear	28
Normal diametral Pitch	8 (1/in)
Center distance	3.5 in
Face width	0.25 in
Helix angle	0 °
Pressure angle	20 °
Theoretical contact ratio	1.64 in
Outside diameter pinion/gear	3.75 in
Root diameter pinion/gear	3.1875 in
Torque	1128 lb-in
Mesh frequency	0.467*RPM
Quality 14: spacing error / radial runout	100 μ in / 379 μ in
Quality 12: spacing error / radial runout	202 μ in / 744 μ in
Quality 10: spacing error / radial runout	408 μ in / 1457 μ in

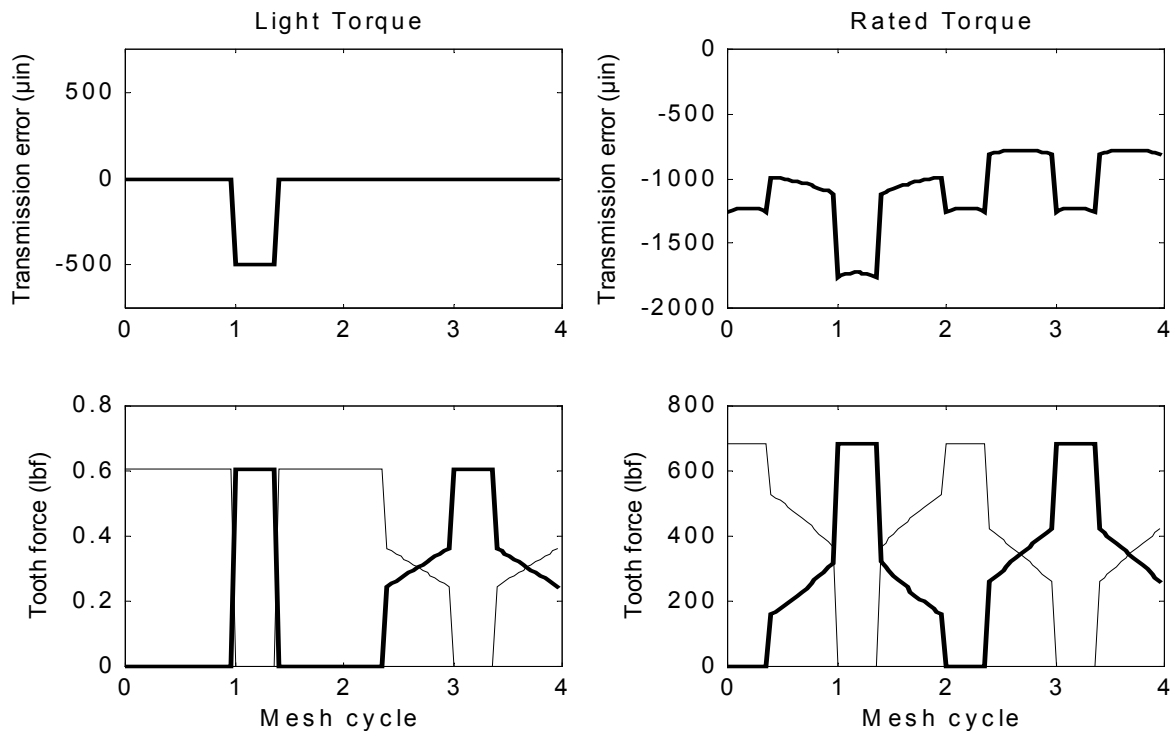


Fig. 3 Light torque (1 lb-in) and rated torque (1128 lb-in) comparison for the perfect involute spur gear pair with case A, negative spacing error