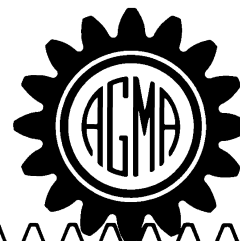


The Gear Dynamic Factor, Historical and Modern Perspectives

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American Gear Manufacturers Association



TECHNICAL PAPER

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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

The dynamic factor has been included in gear design and rating formulas since the 1930's. Its original formulation was based on an assessment of entering tooth impacts, but in modern gear design procedures, where tip relief and lead modifications are common, these impacts may be virtually eliminated. With this elimination, one finds that gear dynamics are mainly excited by steady state phenomena such as transmission error, friction and axial shuttling of the mesh force. This paper first provides a historical progression of the dynamic factor equations that are based on impact theory and then discusses when this methodology is appropriate. A sophisticated dynamic finite element simulation of a gear pair with significant spacing errors is used to describe the entering impacts of a spur gear pair. A new steady state dynamic modeling approach is used to demonstrate the effects of the different excitations as well as manufacturing deviations on the predicted dynamic loads.

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Background:

Impact dynamics

Dynamic tooth loads have been the subject of numerous investigations over the past century. Fisher [1] provides a wonderful summary of the initial studies on dynamic factors (15 references prior to 1950) and Walker [2] provides a very cogent discussion and calculation of dynamic factors in which he also introduces the concept of tip relief in order to minimize impact effects. Houser and Seireg [3,4] update references through the 60's and Bradley [5] presents a discussion of dynamic factor models and some of the more recent concepts used in the ASME/ANSI standards[6].

Literally all of the early dynamic factor equations were based on the fact that there will be an entering impact when the gear teeth first come into contact. This impact occurs whenever the sum of the mesh deflection plus the sum of the two worst case spacing errors of the respective mating gear teeth is greater than the sum of the tip relief of the driven member and the root relief of the driving member (for helical gears, the amplitude of lead crown or end relief should be added to the tip and root relief val-

ues). This impact, which occurs well in advance of the usual entering contact point (point D versus point E) as characterized in the Fig.1 (this figure will be cleaned up in the final paper version), creates an impact force that is proportional to the difference in the instantaneous velocities of the respective contact points (tip of driven member and a position above the SAP [start of active profile] of the driving member). Early analyses simulated this impact with a linear cam [7,8] that drives the simple single degree of freedom torsional model. This model has often been used to simulate gear dynamics [5].

The original entering impact equations that were developed did not consider accuracy, however, as accuracies in gears improved, the equations were adjusted so that they provided lower values of dynamic factors. Some of the equations that have been developed are given below.

$$DF1 = 1 + \frac{v}{600} \quad \text{Walker [1,2]}$$

$$DF2 = 1 + \frac{\sqrt{v}}{78} \quad \text{Ross [7]}$$

$$DF3 = 1 + \frac{\sqrt{v}}{50} \quad \text{Gear Handbook [8]}$$

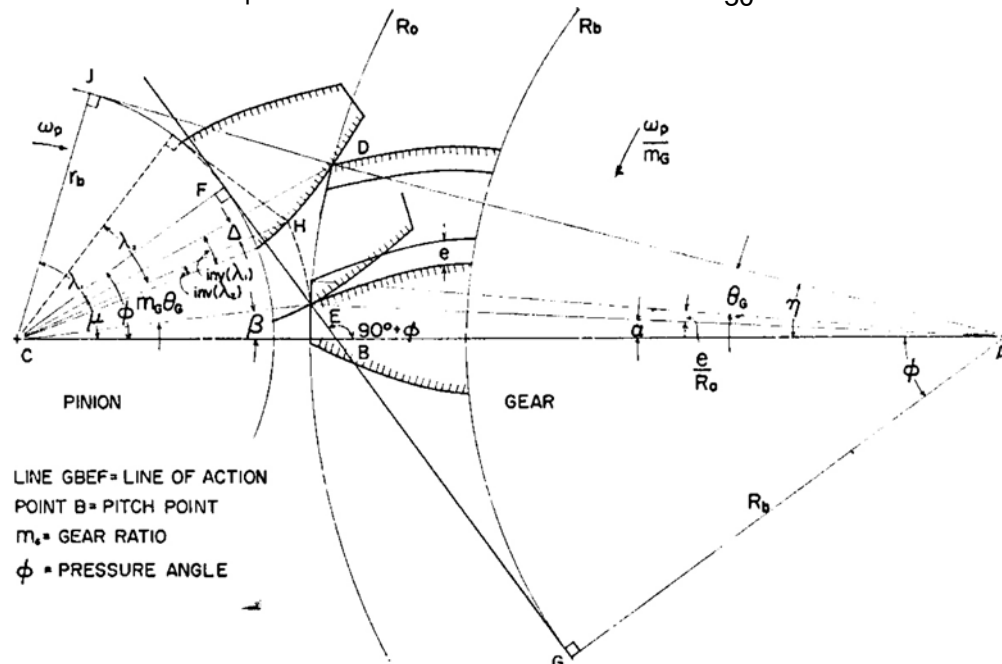


Figure 1. Gear geometry needed to predict the entering impact of gears with spacing errors

$$DF4 = \sqrt{1 + \frac{\sqrt{v}}{78}} \quad \text{AGMA [9]}$$

$$DF5 = \left(1 + \frac{\sqrt{v}}{C}\right)^B \quad \text{AGMA [6]}$$

where B and C are constants that are related to the accuracy of the gear set. The AGMA equation has upper pitch line velocity limits that increase with increasing quality.

$$DF6 = 1 + \frac{K_v \sqrt{\frac{e_e}{C}}}{T_g} \quad \text{Seireg and Houser [4]}$$

where K is a constant related to the gear geometry and type, e_e is the effective spacing error, C is the center distance and T_g is the driven gear torque. This equation is appropriate up to a high speed limit that occurs when the duration of the impact force becomes much shorter than the natural period of the main torsional natural frequency of the gear drive (to be briefly discussed later).

The DF6 equation was developed from tooth strain data taken from operating spur and helical gears that had intentionally large spacing errors manufactured in them. A typical tooth strain plot for a 0.006 inch spacing error is shown in Figure 2, and Figure 3 summarizes the peak strains for several operating loads and speeds [3]. The last tooth strain pulse has a contact duration that would be considered normal for this spur gear pair, and the contact duration of the first pair is cut short, and the middle tooth pair has an elongated tooth strain pulse. Also, one observes that there is an instantaneous rise in the tooth strain that is caused by the entering impact. The peak strain at this particular condition is extremely high with Figure 3 showing the values of the peak strains relative to the static strains. Also, note that following the impact, there is an oscillation at a frequency of about 3 kHz. This frequency corresponds to the main mesh torsional natural frequency. Each of the three torque traces that are shown correspond to one of the tooth strain traces. Torque repeatability can be observed from these traces and one also sees torque oscillations occurring at a much lower frequency.

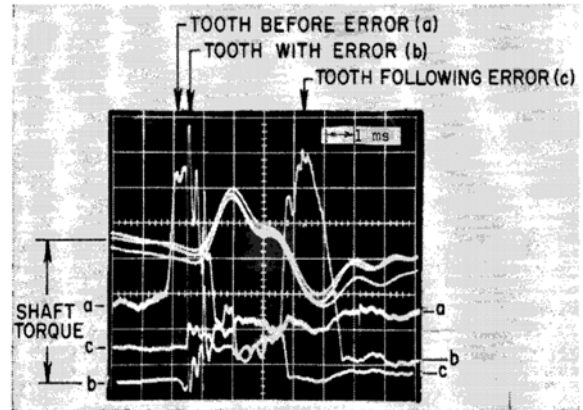


Fig. 13 Strain histories for spur gear teeth in region of positive 0.006-in. error (individual traces do not have same gain)

Figure 2. Strain histories for 106 tooth spur gear teeth in region of positive 0.006 in. error (individual traces do not have the same gain) (taken from Ref. [3])

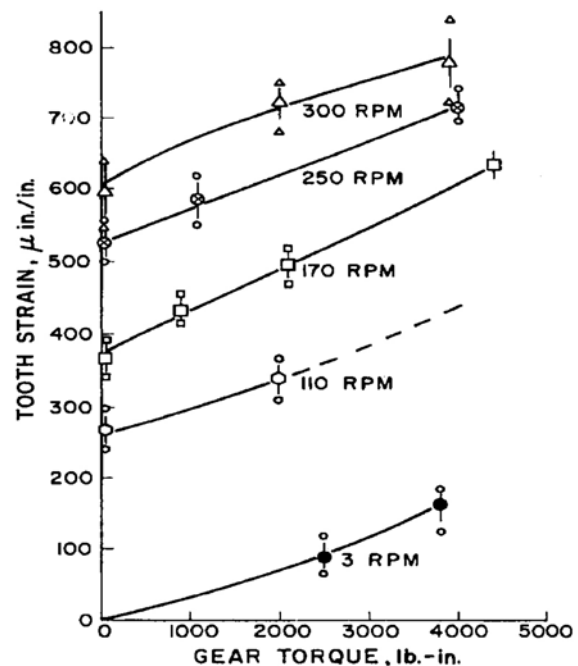


Figure 3. Tooth strain data for central gage of tooth with positive 0.006 in error (106 tooth spur gear) (taken from Ref. [3])

Steady state dynamics

If one applies adequate tip relief, the entering impacts due to spacing errors and profile errors can be completely eliminated. However, that does not mean that dynamic loads are eliminated. Excita-