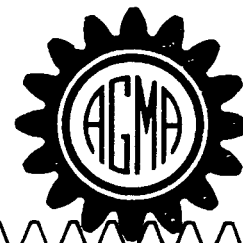


Mesh Friction in Gearing

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TECHNICAL PAPER

Mesh Friction in Gearing

Clifford M. Denny, Consultant

[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

Gear tooth sliding friction appreciably increases the magnitude of tooth root bending stresses in both the driving and driven gears. Compared to situations devoid of friction, these stresses are decreased in the approach portion of the mesh but are increased in the recess portion. Even coefficients of friction as low as 0.06 can change the point of tooth-load application for maximum bending stress in the driven gear from the highest-point-of-single-tooth-contact to the pitch point at the beginning of recess action.

An analytical approach is described in the case where the driven load is constant and the coefficient of sliding friction remains unchanged throughout the mesh's entire contact zone. Equations are derived and effects demonstrated.

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

October, 1998

ISBN: 1-55589-720-7

MESH FRICTION IN GEARING

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Introduction

The objective of this study is to show the potential effect of friction on tooth bending stresses. These can be severe in cases where ideal lubrication conditions are absent. Included are applications where no lubrication is provided, where there is only initial greasing, where tooth quality is low and surface finish is poor. Only in applications where the highest standards of gear technology are observed can these friction effects be ignored. In intermittent operation, lubrication films may have no opportunity to form that would prevent metal-to-metal contact. This can also be the case where operating speeds are too low, loads too high, tooth faces too narrow, or shaft alignment too poor. In cases such as these, friction coefficients could become higher than 0.2 where boundary lubrication is lost^[3].

The significance of frictional effects in the operating efficiency of small mechanisms has been recognized^[7]. In gearing that transmits fractional horsepower, frictional efficiencies are very important considerations. The cost of power supplies and driving motors contribute heavily toward final product costs, so every effort needs to be expended to increase the driving efficiency of the gear trains transmitting power to drive the expected loads.

Included in these considerations is the significant effect of friction on the bending stresses of teeth brought into mesh, as they are loaded through a full mesh cycle. This effect has been noted, verified experimentally, and published^[9].

The procedures of AGMA gear rating are followed in the calculation of the effects on tooth bending strength. These calculations, included in the appendix, simply supplement the AGMA rating system; they are *not* intended to replace it. They may be applied to other rating systems and to Finite Element Analysis as well and render similar adjustments to the calculated bending strength.

Background

In a gear mesh, there is a combination of sliding and rolling between contacting tooth pairs. The locus of points of contact is a line that starts at the beginning of contact and ends at the secession of contact. This line passes through the *pitch point* where it (the line) intersects the line of centers connecting the two gears' centers of rotation.

Assuming contact begins before the pitch point and ends after the pitch point, the line is divided into two parts: *approach* and *recess*. Approach action occurs in the mesh in advance of the pitch point. Recess action occurs after the point of contact passes through the pitch point.

During approach, the sliding of one tooth upon the other is toward the other's base or root. Conversely, in recess, the sliding is reversed, being toward the tips of the meshing pair. At the pitch point, there is no sliding; only pure rolling is present.

It is during this sliding of one tooth upon the other where friction forces are generated. The direction of this force acting on one tooth will be that of the opposing tooth sliding upon it. Therefore, in approach, friction forces are directed toward a tooth's root; in recess, toward its tip. In both cases, the direction will be normal to the line of contact and located where contact occurs.

In the case of gear teeth with involute profiles, the line of contact, called the *line of action*, is straight, and crosses the line of gear centers at an angle, called the *operating pressure angle*. Only spur gears with involute tooth profiles are considered in this analysis.

In plastic gears especially, sliding friction is known often to be higher than in steel, and material properties are not as well understood. Calculation serves only to estimate performance roughly. Application-specific testing *remains* an essential step in the gear-design process regardless of the materials employed.

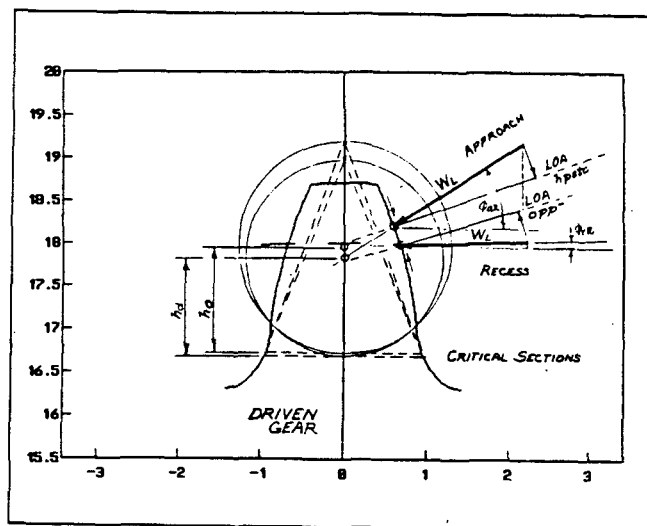
Model Studied

Table 1 provides the critical rolling angles for the mesh. Tables 2 and 3 provide the specifications for the particular gears studied in this paper. The AGMA PT basic rack^[2] is the origin of the tooth proportions used.

Tooth Loading with Friction

In the presence of tooth sliding friction, the direction of the tooth-loading force and its magnitude change significantly at the operating pitch point. Figure 1 shows a *driven* gear tooth. In the approach section from tooth tip to operating pitch point, the magnitude of loading force, W_L , is high, as is its vertical (compressive) component. At the pitch point, the force changes abruptly in magnitude and

direction, its magnitude significantly decreases, and its compressive component all but disappears. In approach, the compressive component decreases tensile bending stresses in the tooth's root. In recess, there is little such decrease. Loading just to the recess side of the pitch point produces the greatest tensile tooth bending stress in roots of driven teeth – not at the highest point of single tooth contact. This is true despite the greater magnitude of tooth loading forces in approach.

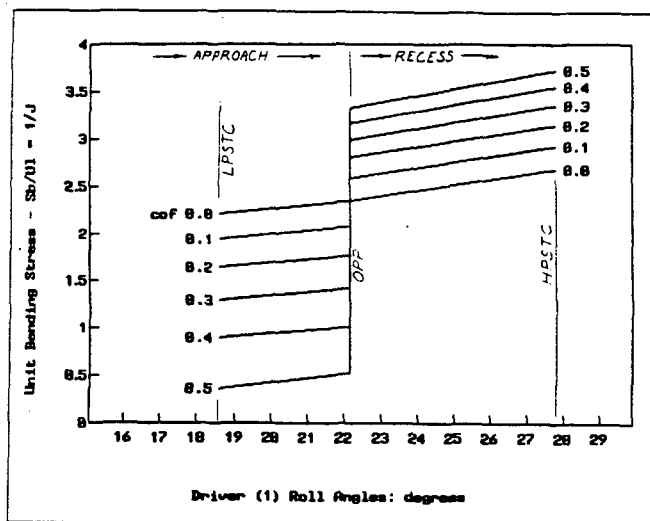


Loading effects on Critical Section
Figure 1

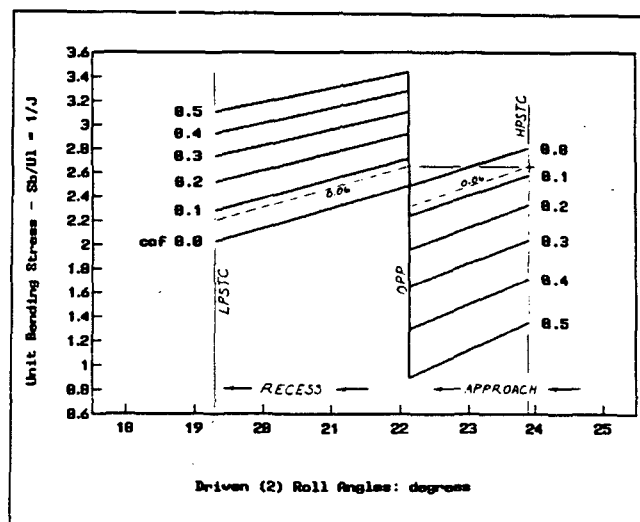
Tooth Bending Stress

Maximum tensile tooth bending stresses increase as the point of tooth loading goes from the LPSTC (lowest point of single tooth contact) to the HPSTC (highest point of single tooth contact). In "frictionless" applications, this increase is uninterrupted. But where friction is present, even to a 'small' degree, there is an abrupt change at the pitch point. The direction of this change depends on which tooth is involved, driving or driven. If *driving*, the change is an abrupt *increase* in bending stress. If the tooth is the *driven* one, the change is an abrupt *decrease*. From there, both resume their smooth upward climb. Figures 2 and 3 show the progression through the single-tooth contact part of the mesh cycle.

In the case studied, any frictional coefficient above 0.06 will maximize the bending stress for loading at the *operating pitch point* on the *driven* tooth. The maximum bending stress still occurs on the *driving* tooth when loading is at the HPSTC.



Bending Stresses on Driving Tooth
Figure 2



Bending Stresses on Driven Tooth
Figure 3

Coefficients of Friction

Values of the coefficient of sliding friction depend on the materials in contact, the contact pressure, the velocity of sliding, and the degree of wear among other things including the actual test conducted and the controls placed upon it. Understandably, there is generally wide variance in test results even when well controlled. The value can be estimated somewhere within the range of test results. Typical values of the friction coefficient of materials against steel follow ^{[6][8][12][13][14]}.