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The Impact of Surface Condition and Lubricant on Gear Tooth Friction

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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

Frictional losses in gear boxes are of significant interest to gear box designers as these losses transform into heat. The direct result is a reduction in the fuel efficiency of the vehicle involved. Further, in many instances, this heat has to be absorbed and dissipated so that lubricant properties and gear box performance are not significantly compromised. This effort is to measure and document the comparative friction losses in a gear mesh due to gear tooth surface condition and lubricant. Three distinct surface conditions are considered. They are ground, isotropic superfinished (REM ISF®) and tungsten incorporated diamond-like carbon coating (W-DLC) which is a wear resistant coating. Two lubricants, MIL-PRF-23699 (ISO VG 22) and Mobil SHC 626 (ISO VG 68) are considered.

The experimental effort is conducted on a high speed, power re-circulating (PC), gear test rig, which had been specially instrumented with a precision torque transducer to measure input torque to the four-square loop. The torque required to drive the loop is measured under various speeds and tooth loads within the torque loop, with test gears with different surface conditions and with different lubricants. Two operating torque levels within the four-square loop at speeds ranging from 4,000 rpm (pitch-line velocity of 19 m/sec) to 10,000 rpm (pitch-line velocity of 47 m/sec) are evaluated.

Input torque measurements, as measured by the precision torque transducer, on ground test gears operating in MIL-23699 lubricant are used as a base line. The increase or decrease in the input torque to the four-square loop is a measure of the change in friction losses at the test gear mesh due to changing surface condition, tooth load and or lubricant. Based on the collected data, a qualitative analysis of the effect of gear tooth surface condition on frictional losses is presented. Further, the surface characteristics of the tooth flanks of the ground, superfinished and coated gears are also described. Plans for future work, to obtain a quantitative measure of the effective coefficient of friction at the tooth surface, are also proposed.

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Introduction

The impact of gear tooth surface quality and treatments on frictional losses in a gear mesh is of significant interest to the aerospace gear community as these losses are converted to heat that has to be dealt with. Further, the impact of lubricant on frictional tooth mesh losses is also of interest. The most exhaustive experimental study quantifying gear tooth friction is by Yoshizaki [1], in which spur gears with various geometries were operated in a power re-circulating test rig and frictional losses were measured. Various lubricants and additives were also evaluated and tooth surface finishes ($R_{\max}$) ranging from 0.5 to 4 μm were considered. In Britton [2], another experimental study, that specifically evaluated the effect of superfinishing on gear tooth friction on a power re-circulating gear test rig is described. A 30% reduction in frictional losses is measured and documented. In another experimental study on gear tooth friction, Petry-Johnson [3] measured frictional losses in a power re-circulating test rig operating ground and chemically polished gears with two different tooth sizes in three different lubricants. This data was further utilized to define guide lines for the design of gear meshes and transmissions. Martins [4] experimentally measured the friction coefficient in FZG (ground) gears utilizing two lubricants. Several attempts to model and predict the friction losses [5], [6], [7] are also evident in literature, where the experimental effort is utilized to correlate to analytical results.

Based on the available literature, a comprehensive experimental study to compare gear mesh friction losses with different tooth surface conditions, different lubricants and under various operating conditions was considered a worthwhile effort. In this study the special variables being evaluated include superfinishing and a W-DLC coating compared to a ground base line. Two lubricants are also evaluated.

Experimental set-up

A high-speed, power re-circulating (four-square) gear test rig was utilized for the purpose of this experimental study. This rig consists of a test gear box connected to a reversing gear box, as shown in Figure 1. An electrohydraulic torque applicator establishes and measures the torque within the four-square loop and consequently the load on the gear teeth. The motor driving the four-square kinematic loop is only supplying the power to overcome the frictional losses in the test gear box mesh and the reversing gear box mesh. This input torque, outside the four-square loop, was measured with a precision, bearing-less, digital torque-meter, under different experimental conditions to establish a comparative measure of the frictional losses in the test gear mesh under those experimental conditions.

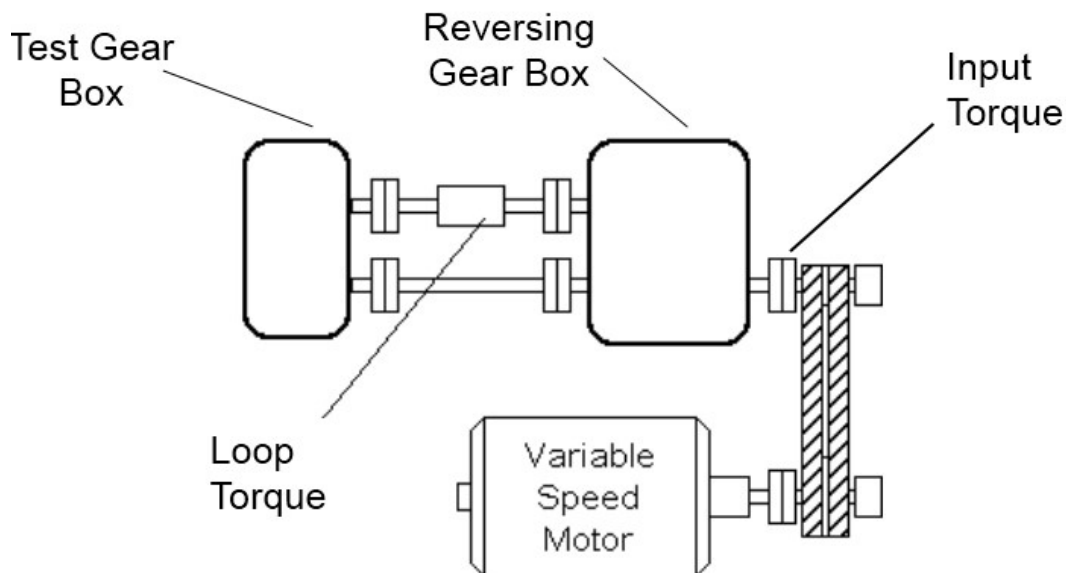


Figure 1. Four-square gear test rig schematic