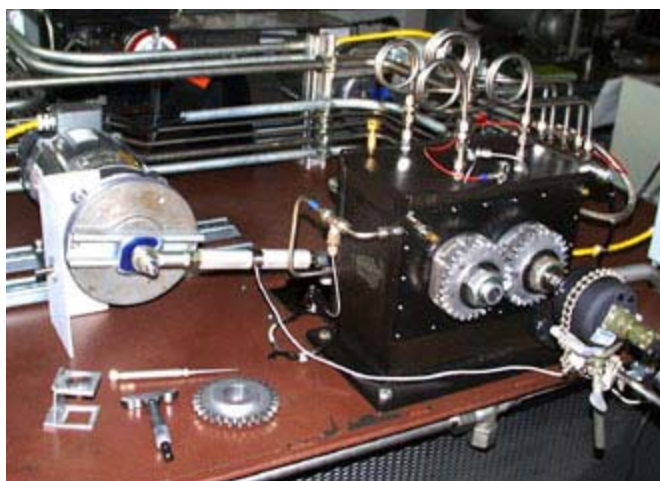


Spur Gear Wear Investigated in Support of Space Shuttle Return-To-Flight Efforts

As part of NASA's Return-To-Flight efforts, the Space Operations Program investigated the condition of actuators for the orbiter's rudder speed brake. The actuators control the position of the rudder panels located in the tail of the orbiter, providing both steering control and braking during reentry, approach, and landing. Inspections of flight hardware revealed fretting and wear damage to the critical working surfaces of the actuator gears. To best understand the root cause of the observed damage and to help establish an appropriate reuse and maintenance plan for these safety critical parts, researchers completed a set of gear wear experiments at the NASA Glenn Research Center.

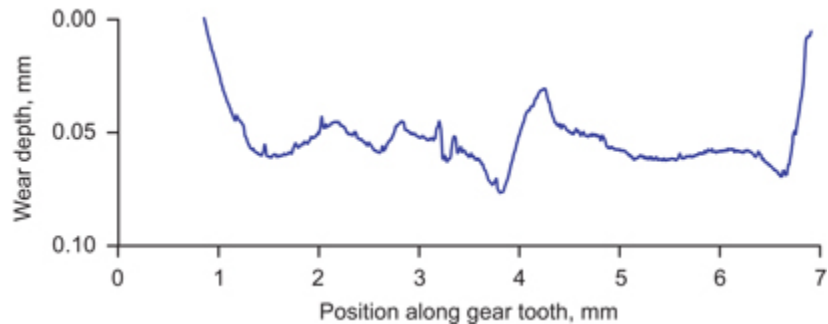
Wear of sufficient magnitude can weaken the strength of a gear tooth, particularly if the hardened surface layer is worn thin. Furthermore, gear tooth wear can accelerate other modes of failure, such as surface pitting fatigue. In addition, wear and pitting debris can be detrimental to the proper operation of bearings within the gearbox. An assessment of technical literature reveals that accurate predictions of gear wear require dedicated laboratory experiments that closely duplicate the gear tooth loads, motions, material, surface topography, and lubrication method for the particular application. A set of gear wear experiments were performed to support the assessment of space shuttle rudder speed-brake gearing. The experiments were completed using Glenn's spur gear test rigs. In the past, these rigs were used to study the performance of high-speed, oil-lubricated gears. The rigs were modified to provide grease lubrication, low-speed operations, and direction reversal (dithering motions), like that which occurs within the orbiter's rudder speed-brake actuators (see the photograph).



Glenn's Spur Gear Test Rig setup for gear wear experiments.

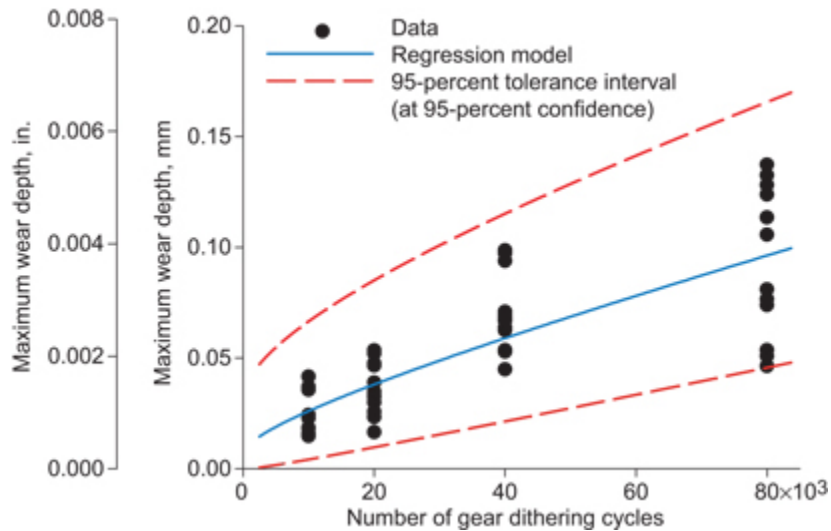
Long description of figure 1. The Spur Gear Test Rig is a torque-regenerative type rig driven by an electric motor to cause a back-and-forth dithering motion for gear wear experiments.

Gear wear was measured with high accuracy by employing a stylus profilometer using a specially devised fixture that allowed accurate mounting and orientation of the gear on the measuring machine. In this manner, profile traces of new and worn gear teeth were compared and processed using a computer algorithm to determine wear amounts. A plot of typical wear data (see the next graph) shows how the wear depth varies along the tooth profile. One important measure of the severity of gear wear is the maximum wear depth. The final graph summarizes the measured maximum wear depths as a function of gear operating cycles.



Typical gear wear trends and depths for gear tooth positions from low on the tooth (1-mm position) to high along the tooth (7-mm position). The wear shown occurred after 80,000 gear dithering cycles and torque producing a 1.1-GPa (160-ksi) hertzian contact pressure at the pitch-line position on the gear.

Long description of figure 2. Wear depth in millimeters versus position along gear tooth in millimeters. The wear profile shows peaks and valleys on the order of 0.5 mm wide and 0.05 mm deep.



Test results for spur gear wear, including regression model and statistically based tolerance interval.

Long description of figure 3. Graph of maximum wear depth in inches and millimeters versus number of gear dithering cycles for data, regression model, and 95-percent tolerance interval (at 95-percent confidence). Wear depths on the order of 0.10 mm occurred after 80,000 gear-dithering cycles. The trend of wear was approximately linear with depth. The statistical 95-percent tolerance band at 95-percent

confidence shows an anticipated scatter band for a large population of parts that is nearly equal to the mean value.

The data were modeled to provide intervals to capture the likely range of wear amounts that can be anticipated for a large population of parts operated in identical fashion. The data show an approximately linear trend for the range of cycles and wear depths investigated, an important finding that will provide confidence in projecting wear rates for gears that are proposed for inspection, assessment, and potential reuse on space shuttle orbiters. This work was completed as part of the NASA Engineering Safety Center's Independent Technical Assessment of Orbiter Rudder Speed Brake Gear Margins.

Find out more about this research at <http://www.grc.nasa.gov/WWW/5900/5950/>

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Headquarters Program Office: OSF, NESC

Programs/Projects: Space Operations, NESC