Problem Solving for the Gear Industry

Aaron Isaacson, Managing Director, Gear Research Institute

If you've got a gear performance problem, the Gear Research Institute (GRI) is here to help you. Since inception in 1982, GRI has been a primarily industry sponsored, experimentation driven research facility. Whether establishing the fatigue life of gears or evaluating the impact of manufacturing processes on the performance of gears, GRI has pioneered methods and procedures for characterizing such properties that are accepted by the aerospace, vehicle and other industry sectors. This industry sponsorship and experimental tradition has continued and grown at the Applied Research Laboratory of Penn State since 1996, when GRI relocated to the campus of The Pennsylvania State University in State College, PA. We continue our relationship with the AGMA and the ASME, organizations which were instrumental in the creation of GRI, with a governing board of trustees whose members are nominated by these trade associations.

Most gear engineers like to say that their designs never fail. At GRI, we say the opposite. The challenging part is to design gears to fail by a specific mechanism, whether that means contact fatigue (pitting), bending fatigue (tooth breakage), scuffing, micropitting, wear, etc. Our mission is to accurately duplicate all gear failure mechanisms in a controlled manner, allowing factors affecting these mechanisms to be understood and characterized individually. Thorough characterization enables optimization of performance, cost or a balance of each. In order to accomplish this mission, we are very well equipped with testing hardware — from a series of universal test stands to conduct tooth bending fatigue tests to several roller on roller testers for rolling/sliding contact fatigue evaluation. Eight high- and low-speed power recirculating gear test machines perform fatigue tests on running gears. We are very well equipped to test at both the coupon and component levels. Further, we have an array of custom test stands, designed and built for specific sponsors to test their particular drive train components for durability and life.

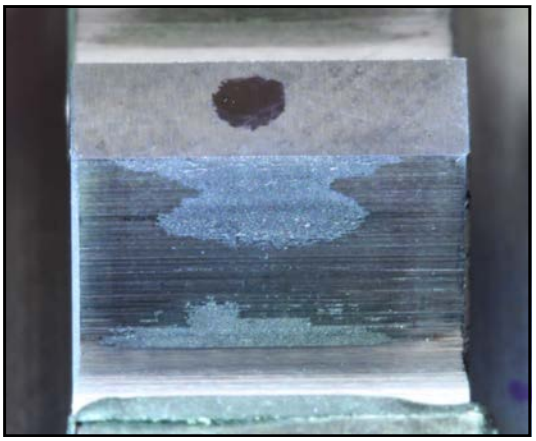

Figure 1 Test gear tooth with micropitting damage in both addendum and dedendum.

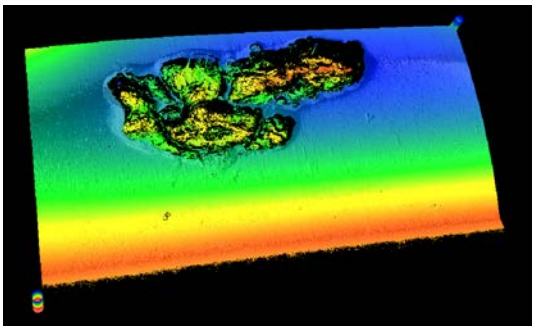

Figure 2 Optical interferometry characterization of pitted gear tooth flank.

Accompanying this experimental hardware is an attitude emphasizing attention to detail. Experimental data can be meaningless unless the test conditions are very carefully controlled. Invalid data is also very expensive, both in time and cost. A crew of skilled technicians, who have a combined work experience of almost a hundred years in gear testing, ensure that the experiments are conducted meticulously and flawlessly. While we do involve undergraduate and graduate students in our experimentation, they are always supported by one of our technicians until they are satisfied that the student has developed an aptitude to the relevant details. The process of gathering data is currently being automated to minimize the potential for random and observational error occurrence during data gathering and analysis.

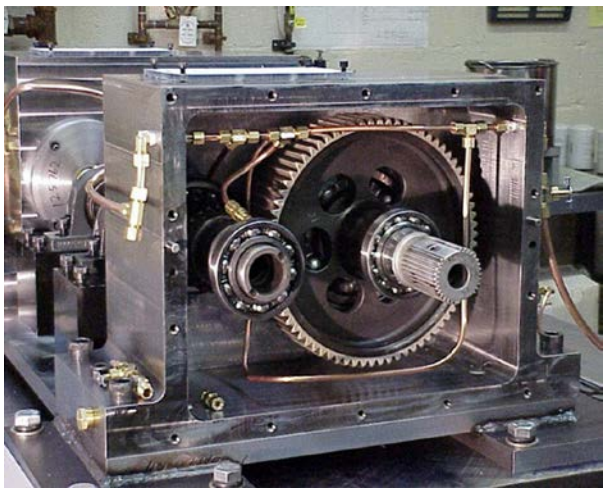

Figure 3 Custom designed power recirculating (four square) test rig for 7.5-inch center distance spur gears. Testing was conducted at various speeds, up to 6,500 rpm using a 100 HP drive motor resulting in circulation of approximately 1,600 HP in the test loop.

Further supporting this experimentation effort is a suite of rigorous analysis tools, some generic and some internally developed, to make physical sense of the collected data. A vast array of the latest materials characterization techniques, such as scanning electron microscopy, transmission electron microscopy, energy dispersive spectroscopy, Auger electron spectroscopy, X-ray photo-electron spectroscopy, X-Ray diffraction, optical interferometry, hardness testing (macro, micro and nano-indentation capabilities), etc. , that are unique to a large research institution like Penn State, add to GRI's ability to provide rational and meaningful results to our sponsor community. In a similar manner, experienced and nationally recognized academic faculty in a host of specialized

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disciplines are available for consultation and collaboration to address specific sponsor-related issues at Penn State, when they arise.

The combination of these resources has resulted in some exciting results in the recent past. We have completely characterized the gear related fatigue properties of AMS 6308, a steel that is being increasingly utilized in the aerospace sector of industry. We have compared this material to other more exotic, high hot hardness (temper resistant) steels such as Pyrowear 675, CSS-42L, Ferrium C64, etc. We have quantified the impact of processes achieving very high surface quality on gear fatigue life, to the point that these processes have now become the norm in many gear applications. Current and ongoing projects are related to characterizing methods to mitigate micropitting and the fatigue behavior of triple vacuum melt, ultra clean steels. Also of note is a continuing project characterizing the fatigue behavior of gears subjected to a billion load cycles. We are also heavily involved in establishing methods and procedures for evaluating the behavior of gears and lubricants in a "loss of lube" condition. These research activities are sponsored by industrial heavyweights like Boeing, Bell Helicopter, GE, Pratt & Whitney, Rolls Royce, Honeywell, John Deere, Sikorsky, and Carpenter Technology Corp. The majority of our test data is kept proprietary at the request of our sponsors. We also support small businesses in many government funded Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs, all geared toward making transmissions lighter, cheaper, more efficient and/or more durable.

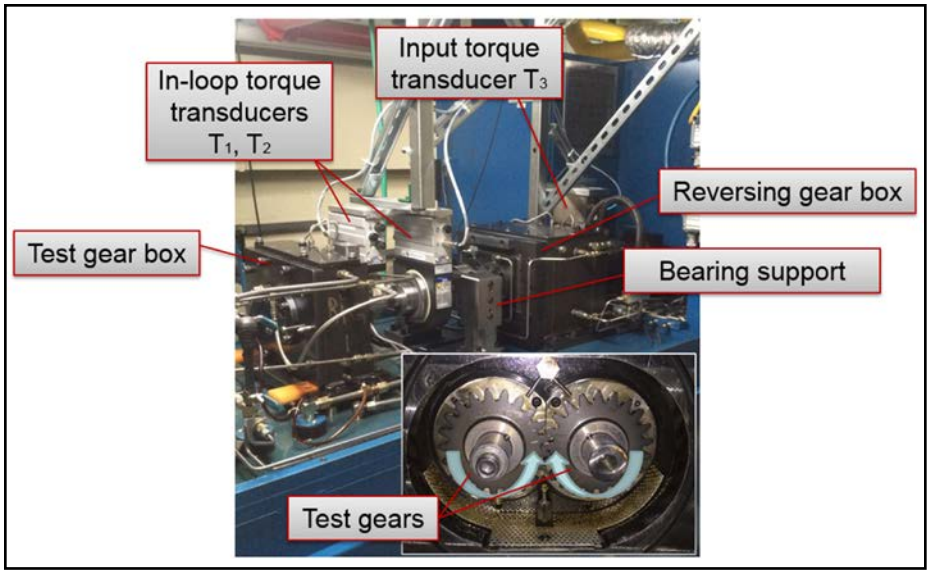

Figure 4 Gear tooth friction measurement test rig.

Due to our location at a major public university, there is a sense of remorse that GRI could be doing so much more in educating the future generation of engineers in gear technology. Through several industry grants, we've been able to give many undergraduate students some hands on, gear related training and experience. This provides an opportunity for students to broaden their engineering foundation in a skillset that is very desirable to companies desperate to maintain gear expertise within their organizations. However, the much larger goal of offering a gear technology curriculum to engineering students remains unfulfilled. This situation is frustrating in light of the fact that it is common knowledge that the nation's gear industry faces the challenge of an aging workforce and most graduating engineers in this country have very little or no exposure to gear technology. While institutional support towards this end has been recently forthcoming, resources to formulate and offer such courses have remained elusive. We intend to keep trying.

The Gear Research Institute has been in existence for 34 years, and geared systems will continue to be utilized in vehicle transmissions for the foreseeable future. We are confident that we have many more projects to formulate and execute for the benefit of this industry and their customers. If your organization has a gear or transmission related issue, GRI has the expertise and the desire to assist you with the problem. If you're interested in learning how you can support the education and training of the next generation of gear engineers — who could become your employees — please consider becoming a corporate or individual member of GRI. For more information about GRI, go to *www.gearresearch.org*.

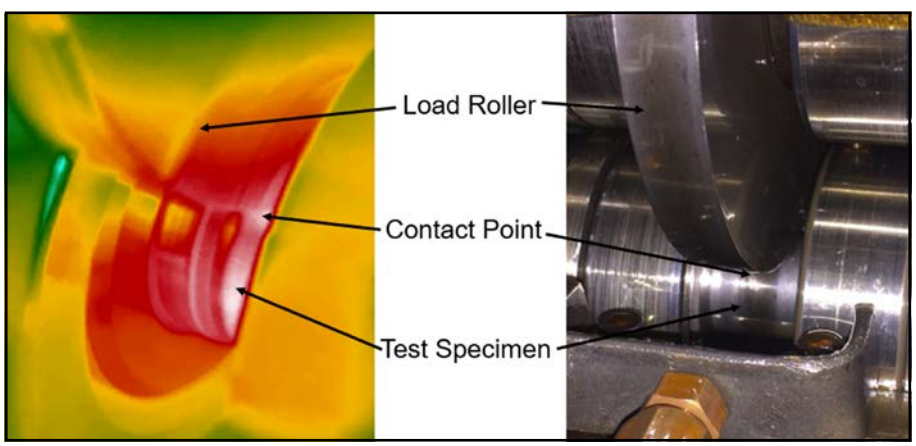

Figure 5 Infrared thermograpy and optical analog showing critical components of a rolling/sliding contact fatigue test during a loss of lube test. Contact temperature and traction force are monitored and recorded throughout the test and used in combination with accelerometer data for failure detection.

Aaron Isaacson is managing director of the Gear Research Institute and Head of the Drivetrain Technology Center at Penn State University's Applied Research Lab. Aaron received B.S. (1998) and M.S. (2009) degrees in mechanical engineering from Penn State and is currently pursuing his Ph.D. in materials science and engineering at Penn State.