VHLGM
Validation of high Load Capacity Gear Material

State of the art – Background

The demand for higher performance and reliability requisites for aeronautical gears besides the strong requirement about lightweight design, which imposes safe margins to be as low as possible, is constantly increasing.
High applied loads, high speeds and extreme lubrication conditions that gears usually experiments in aeronautical engines lead them to be subjected to severe stress at the tooth root, high contact pressure and contact temperature with a consequent need of a more accurate evaluation of bending, scuffing and pitting capability.
Besides to the normalized traditional standards, recently new design strategies, based on the implementation of new models and on the use of advanced software able to perform FEM analysis or Load Tooth Contac Analysis (LTCA), for the evaluation of load distribution, contact pressure and root stress have been introduced.
To achieve an accurate evaluation of gears performances however a precise estimation of these physical quantities is not sufficient and an experimental assessment of the material strength that takes into account specific design and manufacturing conditions (i.e. material cleanliness, case depth and hardness, tooth root shape and roughness, compressive residual stresses) through a systematic testing program is essential.

Objectives

The project VHLGM aim is to integrate the currently available knowledge of the strength properties of the high load innovative aeronautical gear's material used into the Power Reduction Gearbox of Geared Open Rotor demonstrator (SAGE 2) through an optimized characterization process with potential benefits on future applications.

To achieve this object the project is divided in two main tasks. The first task covers the validation of the Single Tooth Bending Fatigue (STBF) testing technique as a leaner and alternative approach to tests on components for the study of the gear bending fatigue. As a matter of fact nowadays the only accepted practice in the aeronautical gear industry is still that accurate design data are derived from running gear tests. STBF technique can up to now be judged as a suitable methodology to perform screening experiments or comparative analysis (e.g. to compare the bending strength of different materials or different surface treatment). Nevertheless the STBF approach could offer a number of advantages like the less amount of samples required to collect the same number of data (since with the same gear an high number of experiment can be carried out), with consequent costs reduction, and the fact that there is no risk that tests intended to evaluate bending strength have to be terminated due to surface failures (wear, scuffing, pitting). This gives the big advantage that very performing materials can be tested at very high load without the risk of any unwanted other damage mode.
The second task deal with the bending and scuffing strength performance evaluation and with the study of experimental and statistical approaches for the pitting strength characterization. The bending performance evaluation is carried out applying the methodology developed and validated in the first task, while the scuffing limits is determined by carrying out tests on components through the identified optimized experimental and statistical approach.

A project goal is also to provide robust and reliable statistical and experimental methodologies for the determination of bending, scuffing and pitting limits that may be introduced as a standard approach to characterize in the future further new materials.

The project was carried out by AM Testing with the collaboration of the Topic Manager.

Description of work

The work plan is structured into 6 technical work packages, a Management work package and a Dissemination / Exploitation work package.

WP1 - STBF validation
WP2 - Test articles procurement
WP3 - Bending characterization
WP4 - Scuffing characterization
WP5 - Pitting characterization
WP6 - Global material characterization results
WP7 - Management
WP8 - Dissemination and exploitation

The first work package (WP1 – STBF validation) is focused on the validation of the STBF testing methodology for the bending fatigue characterization of aeronautical gears.
In order to achieve the project objective a test rig was purposely designed, procured and commissioned. The design of the STBF equipment reproduces root stress conditions representative of power gearboxes and is optimized to:

- minimize the uncertainty on the applied load magnitude
- minimize the uncertainty on the position of the load application point
- minimize the uncertainty on the direction of the load (the load is perpendicular to the involute profile gear tooth at the loading location)
- avoid surface damage at the tooth – load anvil interface.

The tooth root stress conditions have been determined using FEA and experimentally verified by means of cross correlation of experimental gear strain measurements on STBF machine and gear power circulating rig. Figure 1 and figure 2 show the instrumented gear.

Figure 1: Instrumented gear with strain gauges

Figure 2: Detail of an instrumented gear tooth root fillet

An innovative approach has been identified for the statistical data analysis. The same approach has been used in order to define an optimized experimental test plan with the object to maximize the achievable results.

The third work package (WP3 – Bending characterization) relates with the determination of the Pyrowear 53 bending strength through the optimized process developed and validated in the previous WP1.

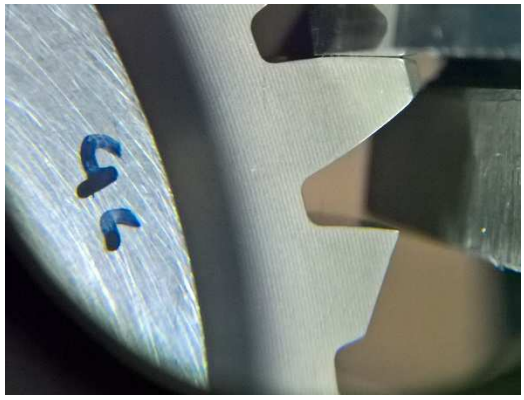

Figure 3: Picture showing a bending crack on the tooth root fillet

In WP4 – Scuffing characterization an extensive test campaign for the experimental determination of the Pyrowear 53 gears scuffing performances has been carried out on power circulating gear test rig.

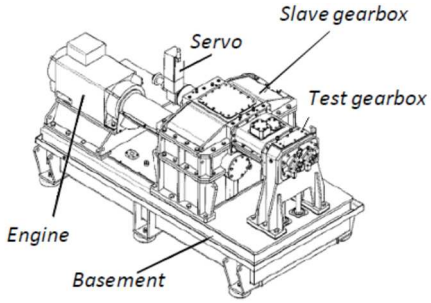

Figure 4: Power circulating test rig

The test rig is able to achieve high performances: the maximum rotational speed is 18000 rpm and the maximum circulating power is about 1 MW.

Torque in the system is achieved using an electromechanical servo actuator that varies the axial position of the load shaft on which are two helical gears (Figure 5). The entity of the motion of the load shaft controls the magnitude of torque in the closed loop system.

The rig is equipped with two torque meters, one on each test gear shaft, of 20 thermocouple installed on the bearing outside ring and in several points of the test and slave gearbox, two flow meters in the slave and test section. An online vibration monitoring system based on 5 high frequency accelerometers is employed to control the damage on the sample gears and to prevent damage of other test rig components.

The lubrication system provides the thermoregulated and independent lubrication of the slave gearbox and of the test gearbox.

A new lubrication system for the test section was procured in order to perform tests in hot oil temperature condition (up to 180°C).
Tests were executed at constant load and constant speed only increasing the inlet oil temperature until scuffing occurred or until the maximum temperature was reached. Out of mesh temperature was measured in order to have an indication of the reached gear bulk temperature.

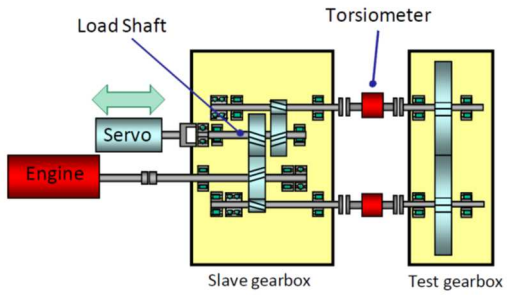

Figure 5: Power circulating test rig layout

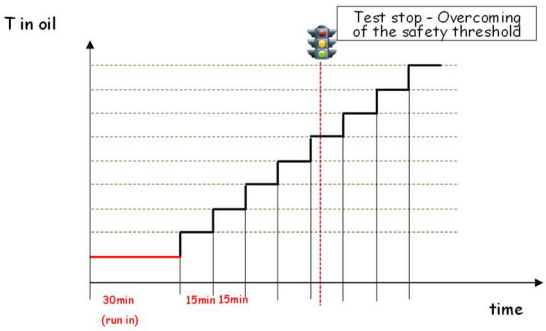

Figure 6: Scuffing test procedure

The test article gear geometry was optimized for functioning at high load minimizing the gear mesh excitation. Moreover, before starting the scuffing characterization tests, vibration survey were executed in order to characterize the rig envelope, identify resonance regimes. Additional tests with gear instrumented at the root fillet with strain gauges were carried out to identify the regimes less affected by dynamic overloads.

Figure 7: Scuffing on the tooth dedendum of a tested gear

The fifth work package (WP5 – Pitting characterization) has provided statistical and experimental methodologies to perform future determination of the material pitting strength. The gears pitting characterization is out of the scope of this project.
In the last work package (WP6 – Global material characterization results) the global results of the material characterization have been assessed.

Results

a) Environmental benefits

VHLGM project contributes to reach ACARE and Horizon 2020 environmental goals.
The employment of the characterized material in future could lead to a reduction of the overall PGB weight, increasing transmission power density, giving a direct contribution to the fuel consumption and emissions reduction targets.

b) Maturity of works performed

A new STBF test rig was developed and commissioned. The carried out experimental activities enabled the characterization of the selected material (i.e. Pyrowear 53). Original experimental strategies and methodologies for data reduction analysis, that could be introduced as a standard approach to characterize in the future further new materials, have been set up.
The participation to this project offered to AM Testing (a SME operating in the gear testing and design) the opportunity to become providers of PGB design services, entering the supply chains of reference players and linking to other SME.s. The results of this research have leaded to further research activities for the development of PGBs.

c) Dissemination / exploitation of results

The following activities were carried out:

- seminaries to the students of University of Pisa
- publications on local newspapers
- publication of news on the AM Testing web site and social networks
- participation at the ASME ESDA Conference 2014 (I. Bartilotta, M. Strambi, E. Ciulli, M. Gravina , A New Methodology for the Experimental Study of Scuffing on Gears for Advanced Applications)
- 2 filings still unpublished (with co-inventor Topic Manager- AM Testing) and 1 defensive publication.

Project Summary

Acronym:	VHLGM
Name of proposal:	Validation of high load capacity gear material
Technical domain:	
Involved ITD:	Sustainable And Green Engine ITD
Grant Agreement:	338510
Instrument:	Clean Sky JU
Total Cost:	522,000.00
Clean Sky contribution:	389,258.00
Call:	SP1-JTI-CS-2012-03
Starting date:	01/05/2013
Ending date:	31/12/2016
Duration:	44 months
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