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Bending Fatigue Tests of Helicopter Case Carburized Gears: Influence of Material, Design and Manufacturing Parameters

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Bending Fatigue Tests of Helicopter Case Carburized Gears: Influence of Material, Design and Manufacturing Parameters

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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

A single tooth bending (STB) test procedure has been developed to optimally map the AgustaWestland gear design parameters and a test program on case carburized, aerospace standard gears, has been conceived and performed in order to appreciate the influence of various technological parameters on fatigue resistance, and to draw the curve shape up to the gigacycle region.

In a first phase, tests up to 10 million cycles have been performed on four test groups differing by material (VAR and VIM-VAR 9310, and VIM-VAR EX-53) and by manufacturing process (ground fillet versus unground fillet); in the second phase, VIM-VAR 9310 ground fillet specimen have been tested up to 100 million cycles. All the gear types were shotpeened.

FEM analysis, strain gauge measurements and rating formula of AGMA standard are used to express test loads in terms of tooth root stresses.

The program has been completed by failure analysis, based on SEM, on failed specimens and by ultimate load tests.

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Introduction

The safety, performance and reliability required to helicopter gearboxes are constantly increasing and gears are therefore subjected to increasing bending fatigue loads at the tooth root while at the same time longer lives are demanded.[1]

Many aspects of gear design and manufacturing must be controlled in order to obtain such results, like material cleanliness, case depth and hardness, tooth root shape and roughness, compressive residual stresses. Gear design and manufacturing processes, developed and optimized during many years, are therefore the key of the increasing performances of helicopter transmissions and a deep knowledge of the influence of each single design and manufacturing parameter on the fatigue strength is also required. Moreover, helicopter gears are designed to withstand loads in the very high cycle field ($> 10^8$ cycles) but are also subjected to short duration overloads and therefore a precise knowledge of the shape of the S-N curve is of great importance for precisely assessing their in service life.

Rating Standards, like AGMA 2101-D04 [2] and ISO 6336 [3], provide methods to assess gears bending fatigue performances, based on the com-

parison between the stress induced at the tooth root and the material allowable stress. Both terms are calculated in detail, taking into account with appropriate factors many influencing aspects, like tooth geometry, gear mounting conditions, contact ratio, overloads, velocity, number of cycles, roughness, dimensions, etc., but some limitations can be pointed out, and in particular:

1. Material data provided are lower limits, which can be granted if the conditions specified by the Standard are respected, but cannot take into account the actual performances which can be achieved through appropriate design, development and manufacturing.
2. The stress cycle factor/life factor, which represents the shape of the S-N curve, is not specified in the highest number of cycle region, that is represented as a range by a shaded area. In that area the actual value of the factor depends on such items as material cleanliness, ductility, fracture toughness and pitch line velocity (Figure 1). Therefore the responsibility of selecting a value is left to the designer, based on his specific knowledge. The range between the lower and the upper limit of the factor, at 10^{10} cycles, varies from 0.8 to 0.9 according to AGMA and from 0.85 to 1.0 according to ISO.

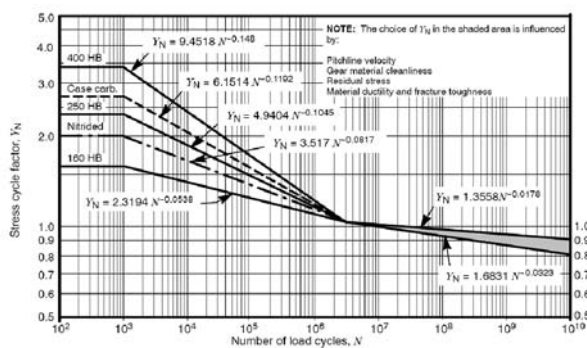


Figure 18 - Bending strength stress cycle factor, Y_N

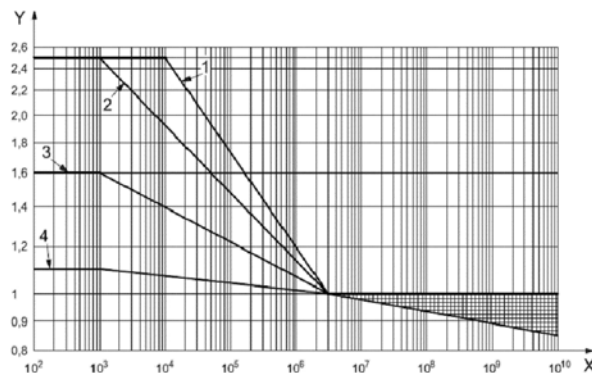


Figure 1. AGMA stress cycle factor (left) and ISO life factor (right)

For these reasons, in applications which require an accurate evaluation of gear performances, like helicopter transmissions, manufacturers must perform a systematic testing program in order to determine material fatigue limits, which must take into account specific design and manufacturing conditions, and the shape of the S-N curve in the range of interest.

Initial bending fatigue tests are generally performed using a STF (single tooth fatigue) scheme, instead reproducing gear meshing. The data for actual running conditions can then be determined by means of an appropriate factor, which can be explained as a consequence of a different load ratio R and of statistical considerations depending on the teeth number loaded during the tests [9]. The load ratio R , which is defined as the minimum test load versus the maximum test load in a load cycle, is $R = 0$ in running gears and typically $R = 0.1$ in STF tests.

Test setup

STF tests are usually performed by means of hydraulic machines or resonance machines. Two basic load application schemes, with several variations, are known:

1. In a “true” STF scheme, like in SAE J1619 [4] test rig for instance (Figure 2), the gear is supported by a pin, one tooth is tested while a second one, which is loaded at a lower position along the profile, acts as a reaction tooth. Such scheme is more common in the United States. With this scheme, some problems can arise if the tests are performed on mechanical resonance machines and the test are not stopped before reaching the final breakage
2. A second test scheme, more common in Europe [12][11], in which actually two teeth are loaded at the same time, is a consequence of the involute profile properties, and of the span measurement (the so called “Wildhaber span”) in particular. In this case the gear blank can be left unsupported since the two equal and opposites applied forces are perfectly balanced (Figure 3).

The test fixture (Figure 4) designed specifically for the present research program can be used for both testing schemes. By changing the length of the anvil on the left side, the position of the load along the flanks of the tooth can be varied, thus changing the stresses on the two loaded teeth. With an appropri-

ate length of the anvil the symmetric condition can be obtained and the pin, which in this case is used only for the positioning of the gear, can be removed: in this way no load can be absorbed by the pin and the load and stress on the two teeth are the same.

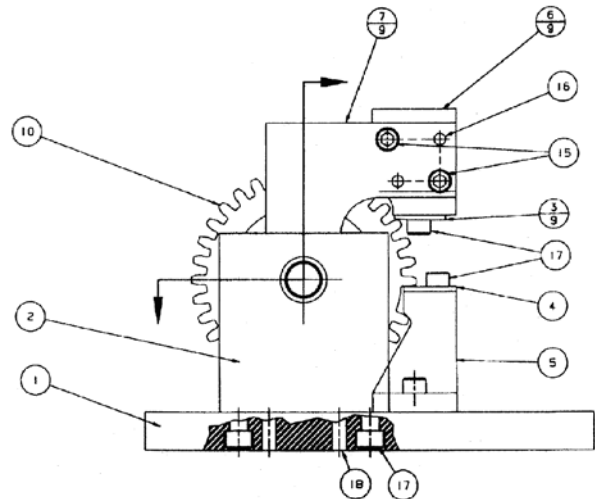


Figure 2. SAE J1619 test scheme

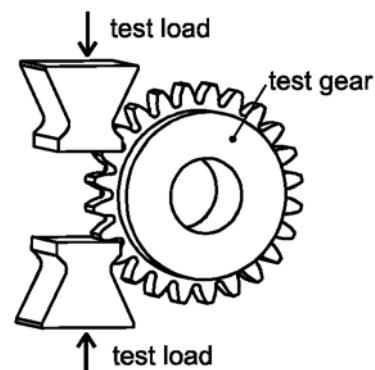


Figure 3. Testing scheme without supporting the gear blank (from [11])



Figure 4. Fixture designed for AgustaWestland tests