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Experimental measurement of strain and stress state at the contacting helical gear pairs

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ABSTRACT

Contact stress evaluation in gears has been a complex area of research, due to its non-linear and non-uniform nature of stress distribution. The high contact stress on gears results in pitting and scuffing, which leads to tooth failure. Furthermore the effects of friction on gear contacts make the problem more complicated. Hence, in this paper, attempt has been made to study contact stress in gears. The experimental testing and analysis of the helical gear was carried out using Gear Dynamic Stress Test Rig (GDSTR). GDSTR is a newly designed test rig to compute the contact stresses on the gear pair contact, under real gear conditions. GDSTR uses the strain gauge and carbon slip rings to measure the surface contact stresses at the contacting points of a meshed gears. The experimental analysis showed promising results which have been verified by the finite element frictional contact analysis. The experimental testing was carried out on 5° and 25° helical gear pairs. Helical gear models with the same specifications and for different frictional coefficient conditions were also generated using FE modelling. The frictional contact stress analysis using FEM has been used for comparison with the experimental results.

1. Introduction

Gears are prominent and would remain so in transmitting power and motion in future machineries due to its high degree of reliability and compactness. While contact problems occur frequently in engineering stress analysis, among which few are simple while others are complex. Johnson [1] provided a useful overview of known solutions for simple general problems. However, most of the contact problems encountered in practice are too complex to be amenable to solution via the classical methods. One such complex problem is the contact mechanics between gears. The reason why researchers have been interested in contact mechanics of gears is due to the increase in contact related problems, e.g. pitting and scuffing. These problems may result in worse conditions, such as rough running gears and contamination of the gear lubricant caused by loose particles, which in turn leads to tooth failure.

Development of a mathematical model to predict the contact stresses between a meshed gears will be difficult because of the involvement of various parameters and their interaction among each other. Therefore, a separate test rig is necessary to evaluate the contact stresses between meshed gears. Velex and Cahouet [2] investigated experimentally and numerically the influence of tooth friction on spur and helical gear dynamics. They noticed that the tooth friction contributes more at low-medium speeds and is negligible at high speeds. Muraro et al. [3] performed experimental tests on spur gear during pitting and studied the influence of contact stress distribution and specific film thickness on wear. The work comprehends the global observation of all such parameters and was carried out to explain the phenomena of wear

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mechanism. The wear test setup used was the FZG (Forschungsstelle für Zahnräder und Getriebebau) test rig. The tests were conducted at two torque levels i.e. at 135 Nm and 302 Nm and at temperatures of 60 and 90 °C. Image analysis was used to evaluate the wear level and tooth surface roughness was calculated to measure the specific film thickness and coefficient of friction. The work showed that the wear on the gear flanks depended on the lubrication film thickness and it was higher for milled gears. In this paper the running - in stage contact stresses in the gear sets were calculated for the conditions mentioned. Jebur et al. [4] investigated the characteristics of an involute gear system including contact stresses between a pair of 3D plastic gears and compared the results with the experimental results. Similar idea has been used to obtain contact stresses in the experimental work presented in this paper. The contact stress results obtained were compared to the FEM results and the results agreed well with each other. Few old literatures on gears show the initial approaches made on the contact analysis [4–7]. Various recent studies on gear contact stress analysis have been made and newer approaches have been reported in technical literature [8–12].

Patil et al. [13] conducted finite element analysis (FEA) on a spur gear pair to study the effect of coefficient of friction on gear contact stresses along the line of action. The FE model was validated by theoretical analysis and the FE results showed an increase in contact stresses with increasing coefficient of friction. They have also determined the change of contact stresses along the line of contact of a spur gear pair. Another piece of work [14] by the same authors involved the study of contact stresses in spur and helical gear pairs using FEA. The results of the work showed an increase of 11–18% in the static contact stress when the friction coefficient was increased from 0 to 0.3. This frictional finite element model was used in this study to simulate the experimental test gears for comparison and verification purposes.

An experimental test setup has been designed to compute contact stresses on gear tooth flanks. GDSTR is a newly designed test rig to compute the contact stresses on the gear pair contact, under actual gear meshed conditions. This experimental analysis employed a new approach, i.e. using carbon slip rings and planting strain gauges on the gear tooth faces. Further, the correlation study between FEM and experimental study has been presented.

2. Experimental work

2.1. Test setup

Experimental testing is one of the best method for determining deflections and stresses. The main purpose of the meshing gear pair experiment is to measure and identify the surface contact stress/strains and the root bending stress/strains that are associated with the gears. Experimental setup can also be utilized for better understanding of various other gear phenomena such as, profile shift parameters, tip relief and tooth crowing effects.

A new experimental setup was designed for this study. It was fabricated by DIXSON FA ENGINEERING SHD. BHD. Malaysia and was named as Gear Dynamic Stress Test Rig (GDSTR). GDSTR is an experimental setup as shown in Fig. 1(a) and could be used for gear analysis studies, namely, contact and bending stress analysis. This can be a useful tool in introducing gear mechanics to engineering students. Also, GDSTR introduced in this work is a novel setup to study mainly contact mechanics of a meshing gear pair. The GDSTR test rig is designed to simulate the gear set loading condition, using gear motor as prime-mover and magnetic powder brake unit as load simulator. On each set of gear a strain gauge is mounted on the surface of the gear. The mounting of the strain gauge has been done carefully on the gear tooth face near the pitch point contact region, as gears are rotating objects and the maximum contact strain is obtained when the pitch line comes in contact. The maximum contact strain is considered to lie around the pitch line contact. The strain gauge placed on the gear tooth face (along the pitch line) will measure this maximum strain when it engages with the corresponding gear pair. An average of 10 peak (maximum contact deflection) readings are taken to get a more accurate estimate of the maximum contact strain and stress. The positioning of strain gauges on the flank would damage the gauges and also the protection for the gauges would distort the smooth gear transmission process.This strain gauge is able to measure the strain and stress under dynamic loading condition. The schematic layout of the test rig is shown in Fig. 1(b).

In order to make the gear test rig more convenient and user-friendly all the measuring items and devices such as the strain gage readings via carbon slips rings, motor speed and torque controller and the dynamometer load controller were integrated using the National Instruments USB-6008/6009 data acquisition device (Fig. 2). Fig. 3 shows the image of the Data Acquisition System's (DAS) LabVIEW user interface. The magnetic powder brake's load and gear motor drive speed can be varied by potentiometer located in the electrical panel.

2.2. Test gear

Two gear sets, 5° and 25° helical gear pairs were selected as the test specimens and the details of the gears are shown in Table 1. The gear material used was structural steel and its properties are listed in Table 2.

The scope of this testing was limited to the investigation of contact stress evaluation on the gear pair under actual gear mesh conditions. Strain gauges (RS 308-102 N11-FA8-120-11) with quarter-bridge circuit (Wheatstone bridge) were used to extract the strain values at the contacting point. The gauge material is compensated for the thermal expansion and additional temperature compensation has been provided by the manufacturer (National Instruments) in the software in the form of polynomial coefficients of the temperature output curve up to fourth order. The strain values are then used to compute the corresponding stresses. The strain gauges are mounted on the gear tooth face in-line with the gear's pitch circle, as shown in Fig. 4. Thus, measuring the strain state or the