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Determination of wear volumes by chromatic confocal measurements during twin-disc tests with cast iron and steel

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ABSTRACT

A novel method for in situ profile measurements on rolling contact test specimens has been demonstrated. A chromatic confocal probe was integrated into a twin-disc machine and used for disc profile measurements during periodically interrupted wear tests. The arrangement allowed detailed studies on the progress of the wear during a test without the removal of discs from the tribometer. Data from the interrupted tests was compared with the results of continuous tests. Both types of tests were run with two grades of cast iron dicsc in lubricated contact with steel. The results of this new method were in good agreement with those of a conventional diamond stylus probe method applied before and after the tests.

1. Introduction

Rolling contact fatigue and rolling contact wear are common material deterioration mechanisms that occur in many different types of tribological contacts, like rolling contact bearings, gears, wheel–rail contacts and cam-roller mechanisms.

A twin-disc tribometer is a piece of equipment intended for the testing of two sample discs in rolling contact with each other under a given radial load. The rolling contact comprises either pure rolling or rolling with partial sliding due to a difference between the periphery velocities of the two discs. The most important mechanical features investigated in twin-disc tests are the coefficient of friction, the rolling contact wear or fatigue, and the change in the surface quality of the discs. Common research objectives employing twin-disc tribometers have been related to the development of materials, coatings, surface finishes and lubricants for gears, rolling bearings and wheel-and-rail contacts [1–3].

The progress of the wear of the disc samples during the twin-disc tests is a feature of particular interest. Traditionally, the monitoring of the volumetric wear of the discs has been performed on removed discs using a profilometer. The detachment and re-installation of samples during tests is time-consuming and adds uncertainty to the experimental procedure, and for this reason there is certain interest in methods for on-line wear determination during tests.

Non-contact probes have been used in surface topography measurements for several decades, but their use is currently negligible in comparison with the use of stylus instruments. For a tactile instrument the interaction between the probe and the sample is mainly depending on the tip shape and the hardness of the material. For a non-contact probe, the reflectivity and the local angle of the surface to be measured seems to change the behaviour of the probe much more than for its tactile competitors. The chromatic confocal microscopy (CCM) is a quite new type of non-contact probe. In the past decade, the CCM has become a well-known tool for the measurement of surface topography [4–7]. Mingard and Gee have previously used a CCM probe in a pin-on-disc tribometer investigation [8].

The present study is part of a larger investigation on the wear of steel wire ropes and cast iron rollers for rope drives. For enabling laboratory tests with steel wire and cast iron in rolling contact, sample discs coated with high-tensile steel wire and cast iron discs were used as test specimens. In order to develop a useful procedure for disc wear monitoring, the wear during a set of twin-disc tests was assessed by the use of a non-contact, CCM profilometer that was mounted on the tribometer.

2. Experiments

2.1. Equipment

The present tests were performed using VTT's twin-disc tribometer (Fig. 1). In the test set-up, a lower disc was driven by a

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drive motor, and an upper disc was connected to a brake motor. The normal force on the test disc couple was achieved by compressing a coil spring. Lubrication of the discs during the tests was carried out by a motorized syringe.

By taking into consideration the diameters of the discs, and by applying specific rotational velocities, a desired difference between the periphery velocities of the discs was achieved. The torque from the drive motor to the lower disc was measured by a torque transducer. The transducer was located between the drive motor and the support bearings of the shaft for the lower roll, for which reason the bearing loss torque under the set normal force had to be subtracted from the recorded torque values.

Optical, non-contact chromatic confocal microscopy (CCM) was used for measuring the surface topography of the lower disc samples and for assessing geometrical changes in the surfaces of the discs during selected tests. CCM exploits the chromatic dispersion of an objective lens that focuses different colours at varying distances from the lens. The distance between lens and surface can be retrieved by spectral analysis of the light reflected from the target surface, that is, there is no need for mechanical scan of the depth profile (Fig. 2).

The probe used in this work was a commercial CCM probe (Digital Surf, Nobis OEM) having a 400 μm (μm) working range and about 5 μm spot size [9]. The topography of the disc was measured after mounting a motorized translator stage on the tribometer frame and by moving the probe over the disc. The measured profiles were approximately 11 mm long and the measurement data contained up to 32,000 data points at 0.34 μm spacing and at least 7000 data points at 1.7 μm spacing. For the evaluation of the wear volume, the latter point density is sufficient but profiles with a high point density were measured to make texture analyses of short wavelengths possible. A specific Python programme was written for the data acquisition and initial evaluation of the profiles. The performance of the CCM set-up was checked by measuring optical flats, steel gauge blocks, groove standards (Types A2 (groove) and C (sine wave) standards from Halle KNT2060/01 and Mitutoyo 178-601, respectively) and a surface roughness standard (Type D (unidirectional irregular profile), Halle KNT2058/01). The different standard types are defined in Ref. [10]. The relative error in the depth profile measurements using the CCM set-up and the reference samples within the working range of 1–10 μm was below 10%. The calibration using the optical flat showed a straightness error of less than ±0.3 μm at a 10 mm profile length.

For comparison, a contact-type Mitutoyo Formtracer SV-C3100 surface roughness analyser was used for profile measurements on the discs before and after the tests. The analyser's measurement head was equipped with a diamond stylus tactile probe. The performance of the Formtracer SV-C3100 was checked by measuring a Type C surface roughness standard (Mitutoyo 178-601). The stylus used in the measurements had a radius of 2 μm and a tip cone angle of 60°. The measured disc profiles were 10 mm long and and the measurement data contained 10,000 data points at 1 μm spacing. The surface roughness on the upper and lower disc samples was measured using the same stylus instrument.

2.2. Samples

Each test was started with a new pair of discs. The upper disc sample of the test set-up represented the outer wires of a wire rope in a rope drive. In order to provide the best possible experimental simulation of the wire rope surface in the disc-to-disc contact, the upper disc was based on a cylindrical steel disc with a round-bottomed spiral groove with a pitch of 1.4 mm, into which a steel wire of 1.4 mm diameter had been firmly attached to form a dense surface of 50 mm nominal diameter, see Fig. 3. The wire was of a commercial grade manufactured by drawing from non-alloyed steel with a pearlitic microstructure, to a tensile strength of 1700 N/mm^2. The wire was uncoated and had a surface roughness of Ra = 0.30 μm and Rsk = −1.0 when measured in the length direction of the wire.

The lower discs of the tests had been manufactured from cast iron into a toroid shape, by turning in a lathe, with subsequent grinding of the rolling surface for a maximum diameter of 50 mm and a radius of 100 mm in the axial direction of the disc. Two

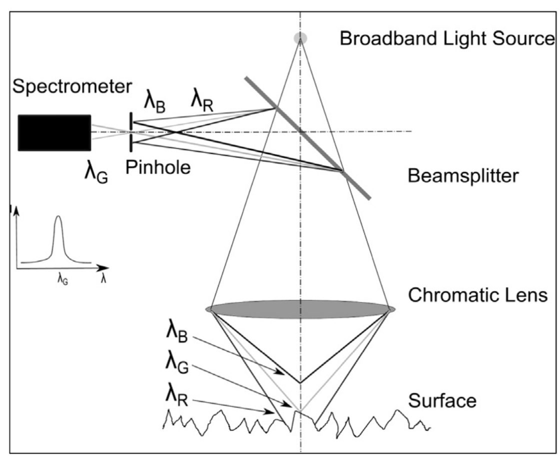

Fig. 2. The working principle of the CCM. The symbols λ_B, λ_G and λ_R refer to the wavelengths of blue, green and red light, respectively.

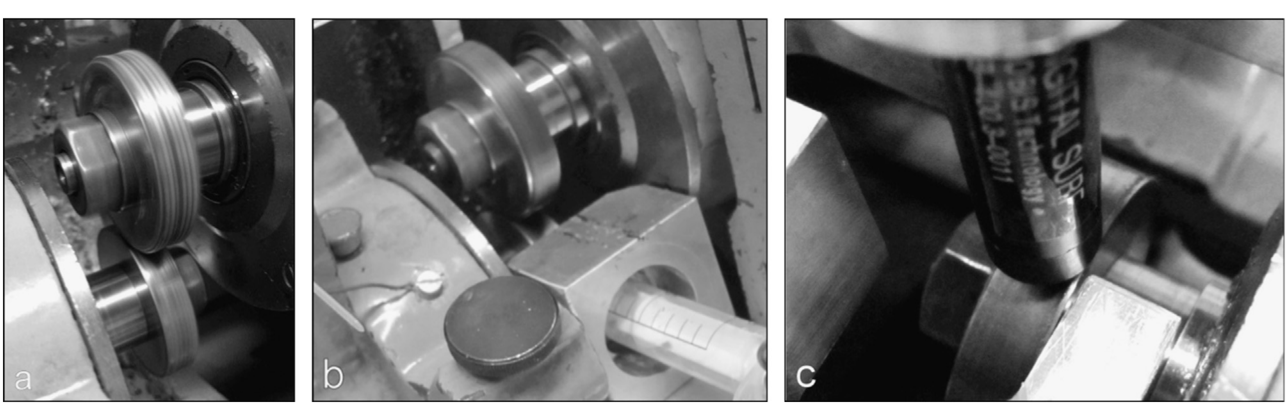

Fig. 1. The twin-disc tribometer; (a) the upper and lower disc samples in operation, (b) the syringe, as installed for lubricant dosing, and (c) the CCM profilometer, as installed above the lower test disc after tilting up the shaft with the upper disc.