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Topography changes observation during running-in of rolling contacts

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ABSTRACT

The automotive industry and the design of engines are strongly ruled by performance and legislation demands. In the valve train, besides the main function (transformation of rotation to translation movements) to fulfill, new requirements in environmental demands and performance in terms of wear are leading to more and more detailed studies of the cams and rollers. Wear reduction studies for prolonging lifetime of these components require decreasing the scale of observation down to roughness. Among the different wear stages of a component, the running-in is a crucial period which will greatly influence the lifetime and performance of components. The aim of this paper is to analyze the topography variations observed during the running-in of a camshaft on a valve train rig test. A truck engine's camshaft is run under realistic conditions and 3D surfaces are measured before and after the test by using relocation techniques. By measuring the very same surfaces before and after the experiment, a deep analysis of the running-in effects on surfaces can be performed. 3D surface roughness parameters are used in parallel with new proposed methods of analysis. As a result, the mechanisms involved during running-in are emphasized and can be used for further simulations and optimization of the cam roller contact.

1. Introduction

1.1. Background

Nowadays, development of engines is strongly pushed by customer and legislation demands [1]. In a heavy duty diesel engine, the cam roller contact (see Fig. 1) is essential to study. Indeed wear issues are critical to study since a loss in geometrical specifications of the elements can lead to serious damages or malfunctioning of the engine.

On the lifetime scale of a component, it is important to delay severe wear occurrence as late as possible. As a matter of fact, the first hours of use of components called running-in has a strong impact on postponing failures [2,3]. The running-in is a beneficial short period of time where mechanical elements and their surfaces adapt to each other and will keep their conformity for most of their lifetime [4]. A good conformity of surfaces will prevent premature failures. The running-in period (a few thousands of kilometers driven) of truck engine components such as camshaft and rollers is very short compared to their lifetime (millions of kilometers driven). However this short stage will modify the topographies in contact which will then stay almost unchanged for the rest of their life. In other words, a bad running-in can generate surfaces able to initiate severe wear. Therefore the running-in stage and in particular the topography changes occurring during this period are the focus of this study. Changes in subsurface microstructure are not addressed in this study which focuses on geometric feature changes.

1.2. Wear and running-in measurements

Before further discussions on wear and running-in characterization, it is necessary to cite the following definitions:

- Wear: "*alteration of a solid surface by progressive loss or progressive displacement of material due to relative motion between that surface and a contacting substance or substances*" [5].
- Running-in: "*The removal of high spots in the contacting surfaces by wear or plastic deformation under controlled conditions of running giving improved conformability and reduced risk of film breakdown during normal operation*" [6]. It is a process minimizing the energy flow between moving surfaces [7]. Some authors mention the running-in and very mild wear as "*zero-wear*" [7–12] since the wear losses are within the limits of the original surface topography.

Different solutions for the characterization of wear exist depending on the volume of material removed or displaced. The less volume removed the more precision in measuring techniques and procedures needed (see Fig. 2). Wear due to plastic

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Nomenclature

Sa	arithmetic mean height (μm)
Sq	root mean square height (μm)
Ssk	skewness ()
Std	texture direction (°)
Str	texture aspect ratio ()
Sal	auto-correlation length (μm)
Sdr	developed interfacial area (%)
Ssc	arithmetic mean summit curvature (1/μm)
Sdq	root mean square slope ()
Sds	density of summits (1/mm^2)
Spk	reduced summit height (μm)
Sk	core roughness depth (μm)
Svk	reduced valley depth (μm)
*Sr*1	peak material portion (%)
*Sr*2	valley material portion (%)
Vmp	peak material volume (μm^3/μm^2)
Vm	material volume (μm^3/μm^2)
Vv	void volume (μm^3/μm^2)
Vmc	core material volume (μm^3/μm^2)
Vvc	core void volume (μm^3/μm^2)
Vvv	pit void volume (μm^3/μm^2)
Spc	arithmetic mean peak curvature (1/μm)
Spd	density of peaks (1/mm^2)
Sfd	fractal dimension of the surface ()
Rdq	2D root mean square slope ()

deformation at macro scales is disregarded in the following survey. Indeed it is assumed that the components are well dimensioned meaning that the mean macroscopic pressure does not reach a certain ratio of the yield strength of the material. As a consequence it is assumed that macroscopic geometries (or bulk) are deforming only elastically.

A survey of methods which are used to characterize the different types of wear and running-in is presented below:

- *Severe wear and mild wear*: Depending on the total weight of the components studied, it is possible to measure a weight variation due to wear [12]. The Thin Layer Activation (TLA) technique produces tracer nuclides on the top layer of surfaces [13]. As a consequence it is possible to measure real time wear by detecting tracers inside the oil. Both techniques only give a numerical value but no qualitative observations can be made. Furthermore it is assumed that wear occurs by a loss of material.

  A commonly used technique is to measure wear tracks by using 2D [12,14] or 3D profilometry [15,16]. A long stylus profile can catch the full width of a wear track and wear volumes can easily be computed.

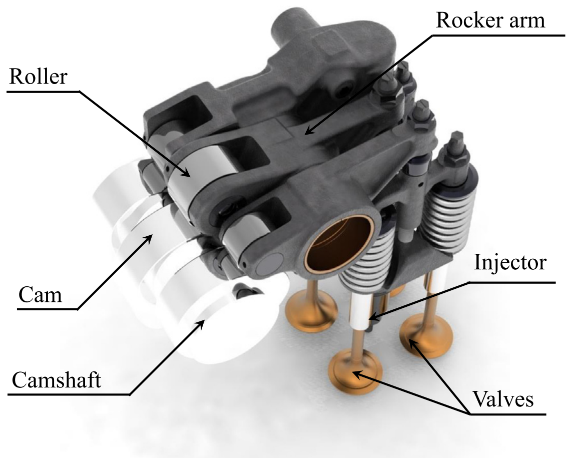

Fig. 1. Valve train of a heavy duty diesel engine.

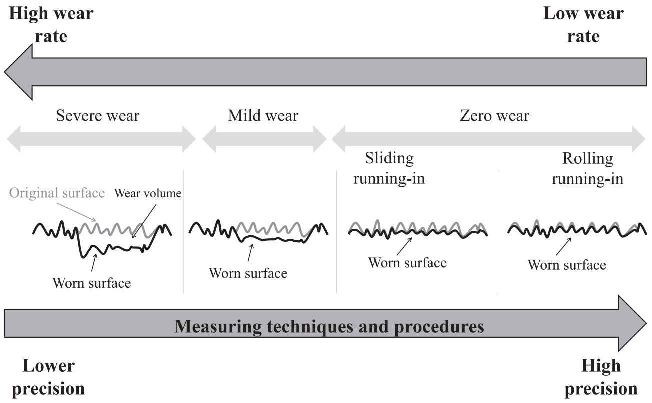

Fig. 2. Different types of wear.

- *Sliding running-in*: By measuring with a stylus the very same place before and after wear (relocation) it is possible to observe smaller amounts of wear [15,17,18]. Atomic Force Microscopy (AFM) can also be used for more details [19,20].
- *Rolling running-in*: In the case of rolling contacts Jamari [2] showed that the changes observed are mainly due to plastic deformations of asperities. As a consequence changes are extremely mild and only a few studies are made for observing such wear: Jamari and Schipper made observations and models by using a dry contact tribometer [21,22]. Since the aim was to confirm models, the deformation of asperities could be amplified by using specimens in Aluminum alloy with rough surfaces. Lindholm explained that for a cam roller contact running-in could be seen (see Fig. 3) by the naked eye (polished surface) but could not be measured by a stylus [18].

1.3. Wear and running-in characterization

Surfaces being measured, it is necessary to quantify wear. Once again, several characterization methods can be used depending on

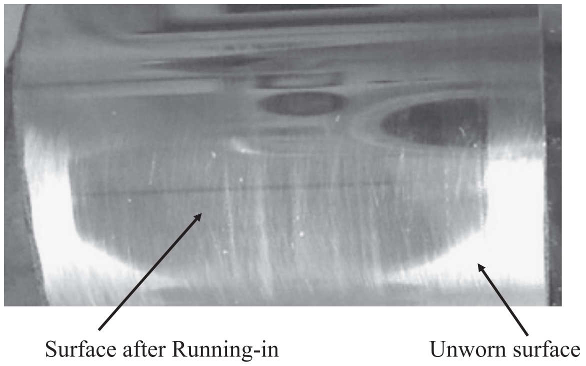

Fig. 3. Photography of a cam lobe after running-in.