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Influence of microstructures on tribological systems - development of process and surface structure

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Abstract

Requirements are constantly rising for friction and wear reduction of moved components in combustion engines. Numerical simulations and investigations have demonstrated the potential of microstructured surfaces at tribological highly stressed sliding contacts, in particular the cam-tappet contact area. Using the innovative cutting process of single-grain scratching, the microstructures shall be implemented. The requirements of this implementation are defined based on simulations for cam-tappet contacts. After determining boundary conditions an empirical process model for the scratching process is created. It forms the basis for fundamental investigations carried out on the technology development. By conducting subsequent experimental investigations, relationships between the influencing parameters are established. Finally the process model and the results of the experiments lead to a device for integrating this process into existing production chains.

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Keywords: Friction; Tribology; Wear; Process development; Abrasive grain; Microstructure

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1. Introduction

In automotive engineering, increasing requirements regarding fuel consumption and the related CO_2 emissions demand for resource-efficient and low-emission drive technologies. Research often focuses on reducing friction and wear of moved components in combustion engines. In addition to piston assembly and crankshaft, the focus especially lies on valve trains. The share of friction loss in the engine caused by the valve train assembly alone amounts to approx. 25% at low rotational speeds [1]. Furthermore, the load requirements of tribologically highly stressed sliding contacts increase, which illustrates the need for optimizations.

In the past numerous investigations were carried out to modify the surfaces of sliding contacts and to detect their influence on friction and wear [2,3,4].

In particular, numerical simulations show the potential influence of micro structures on the tribological conditions in the contact area [5]. Consistent transfer of the results into practice requires the development of efficient manufacturing technologies. This implies an integrative development of process and surface structures using a novel cutting process which is called single-grain scratching in the following. This cutting process is developed based on an empirical process model and integrated into existing production chains. Moreover, this model will allow predictions of accuracy and possibilities of process control.

The objective and content of this paper is the process development with the help of a process model on single-grain scratching.

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2. Cam-tappet contact area

Nomenclature

A_R, A_1, A_2	parameter cutting area [µm²]
$A_{t\text{-ideal}}$	cutting area using ideal tool [µm²]
b	groove width [µm]
f_{ab}	relative cutting area
F_R	radial force [N]
h	groove depth [µm]
K, K_{vc}, K_{FR}, $K_{\Delta r}$	proportionality factors
l	scratching length [m]
v_c	cutting speed [m/s]
Δr	radial wear path [µm]

2.1. State of the art

The cam-tappet-tribosystem (CTT) is an example for tribologically highly stressed sliding contacts. It exhibits very unequal load conditions causing unfavorable hydrodynamic friction conditions in the contact area. This in turn leads to increased wear at the cam and also at the related tappet surface. Both, friction conditions and wear behavior, were determined by simulations and experiments [6]. The input variables included the macro geometry of the contact partners, the applied load forces as well as the operating parameters. The calculated and measured values of friction and wear form the basis for a comparison with the cam and tappet surfaces manufactured by single-grain scratching.

2.2. Requirements deriving from the simulation of the CTT

The requirements on a micro structure result from an extensive numerical model for calculating the complex movement ratios in the contact of cam/tappet base as well as tappet/tappet guide [6]. It demonstrated that under certain preconditions defined micro structures have a positive influence on the flow conditions of the lubricating oil in the contact area. The resulting structural geometry is based on a sine-like wave shape in the circumferential direction of the cam and on radial grooves on the tappet surface. Thus the cam has a structural geometry of parallel grooves in axial direction with defined depth, width and distance. Figure 1(a) shows the wave shape from the numerical model. First results of experimental implementations differ, for example, in the arising plateau between the indentations, as shown in Figure 1(b). Future investigations will include iterative comparisons with the simulation.

The numerical model indicates that structuring of the cam surface is sufficient as a first step for comparison between simulation and experimental implementation. The following values have been found to be ideal for the microstructure:

• Width	b = 2-4 µm
• Depth	h = 2 µm

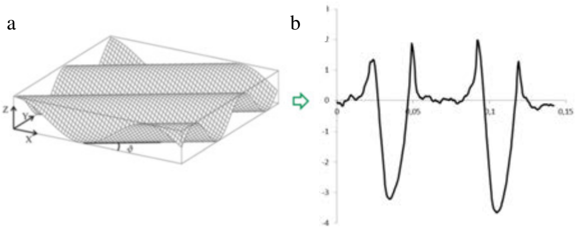

Fig. 1 (a) Sine wave for numerical model [6]; (b) real scratching geometry

3. Empirical model of the scratching process

In order to determine an empirical process model for single-grain scratching, the boundary conditions and influencing parameters need to be established. Furthermore, the target values of section 2.2 were defined as geometrical characteristic variables of the grooves.

These relations can be expressed mathematically in so far that the area of the arising groove cross-section is a function of the influencing factors, Equation (1).

$$A_R = f(A_{t-ideal}, F_R, \Delta r, v_c) \quad (1)$$

The radial force is set up as infeed via the machine axis. Due to the flexible bearing of the tool there is a correlation between infeed and the applied radial force, which can be approximated via spring pre-load and spring characteristics.

The radial wear path Δr of the tool cutting edge depends on the already traveled feed path and the wear behavior and characterizes the current radius at the scratching tool.

Furthermore the cutting speed v_c combined with the wear behavior of the cutting edge has a significant influence on the groove depth.

Thus the following equation can be set up as an approach for a model function that can be interpreted physically:

$$A_R(l) = A_{t-ideal} \cdot K(l) \quad (2)$$

$$A_{t-ideal} = 0.5 \cdot b \cdot h \quad (3)$$

$$K(t) = K_{F_R} \cdot K_{\Delta r}(l) \cdot K_{v_c} \quad (4)$$

This approach assumes that the initially ideal tool geometry is represented in the cross-section of the groove. The influence of cutting speed, radial force and wear path is integrated via the proportionality factors (K_{FR}, $K_{\Delta r}$, K_{vc}). The objective and content of current and subsequent test series lie in determination of interrelationship of the proportionality factors as well as specifying and validating the model Equation (2).

4. Experimental design and implementation

Based on the requirements of the simulation regarding a microstructured surface, boundary conditions result for the innovative single-grain scratching. These boundary conditions apply to the tool, the workpiece and the technological