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Strategies for production of parts textured by grinding using patterned wheels

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ABSTRACT

The functionalization of surfaces by introducing pre-engineered textures is a new requirement from industry. Surfaces more prone to promote micro-lubrication are being designed by engineers and incorporated into the components specification. The major challenge is to develop manufacturing methods able to produce these textures in a repeatable and economically viable way. The aim of this research work is to develop grinding strategies based on the method proposed in [1] for producing textured surfaces by grinding. The characteristics of the produced textures are measured and evaluated using new proposed parameters. The obtained results show the potential of this process solution for the production of micro pockets for hydrodynamic bearings application.

1. Introduction

With the constant pressure for lower emissions in the automotive industry the world is searching more and more for engineering solutions that could improve the performance of internal combustion engines. One of the approaches is to increase load capacity in the hydrodynamic bearings, so the size of some of the engine components can be reduced, diminishing the energy loss, material consumption and inertia. This can be accomplished by introducing surface engineered textures on the bearing surfaces.

Bruzzone et al. [2] published a CIRP keynote paper in 2008 on the advances in engineered surfaces for functional performance with a comprehensive view of the surfaces functionalities and processes that can be applied for texturing. One of the topics discussed on that publication was the application of textures for the improvement of lubrication showing good perspectives.

Among the CIRP keynote, a considerable number of papers have been published on the influence of micro texturing on the lubrication performance of surfaces. Previous research [3] showed that the use of small cavities uniformly distributed over the sliding surface offers the best tribological results for hydrodynamic bearings. Simulation studies [4] show that short grooves with sinusoidal profile perpendicular to the movement give the most performing lubrication results for traditional automotive applications. One common conclusion of most papers in this area is that a group of pockets can perform as a set of micro-bearings on the surface. Therefore, the challenge is to produce these pockets at low cost and feasible manufacturing cycle times.

Current approaches to produce functional surfaces include, but are not limited to: etching, lithography and laser machining. The last is the most cited process, but with major drawbacks including: fine tuning of process parameters to control metal recast, burr formation, low production rate and high hardware investment as well as more complex operational training and safety requirements. Alternatives for producing functional surfaces using traditional machining processes are presently sought.

Grinding with patterned wheels by dressing arises as a potential alternative by combining its inherent finishing process characteristics, its capacity of cutting hard materials, with relative low process technical requirements, low investment and short cycle times. The proposed scheme developed by [1] in CIRP 2010, in which user defined patterns can be imprint on the wheel surface during dressing and later transferred to the part, promotes a freedom of choices for transferring patterns to the workpiece during regular grinding.

Initial results of the technique were very encouraging, with setup and process times similar to conventional grinding. A deeper evaluation on process control requirements would be a natural next step in the development of this solution and for its application in industry. The research presented here is a partnership with a crankshaft producer aiming at the evaluation of the impact of ground pockets in hydrodynamic bearings for automotive applications. This is the objective of the present research: to develop grinding strategies that would allow a full control of the pocket features. The following sections of this paper will present the main characteristics of the developed strategies and the resulting surface features, a method for grinding control of the texture properties and the main conclusions.

2. Characteristics of the developed process

Details on the developed method can be found in [1]. Basically, the production of textured workpieces is realized by using a patterned grinding wheel and integer angular speed ratio between workpiece and wheel when grinding. In this paper the term pattern is used for the features generated on the wheel surface by dressing and textures or pockets for the features ground on the workpiece.

The synchronization between both part and wheel for accomplishing the grinding process was described in the same 2010 paper and don't require any additional hardware. The

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production of a patterned grinding wheel was done during dressing by adding an extra high-speed axis perpendicular to the wheel surface. The patterns were generated by specific software and controlled using an acoustic emission mapping system according to the presented by [5].

Fig. 1 shows the used setup where some improvements have been implemented: radial feed elastic bearings (A), new magnetic transducer assembly (B) and the monitoring feedback of power, AE and grinding wheel position (C). A new grinding head with direct drive was also installed in order to get a more stable angular speed on the grinding wheel.

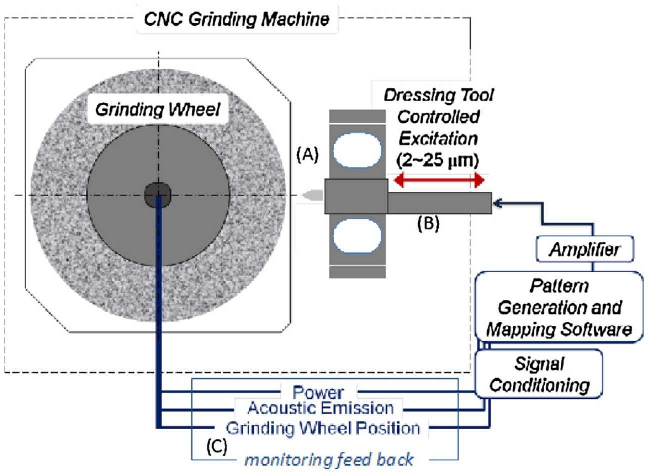

Fig. 1. The grinding wheel patterning setup: elastic bearings (A), magnetic displacement actuator (B) and monitoring system (C).

3. Surface characterization of ground pockets

Ensuring a proper way to inspect and to qualify the produced textured surfaces for the industrial implementation is mandatory. Basic surface roughness parameters, such as R_a, R_q, R_t and R_z, are not suitable for the evaluation of engineered textures, since they would not allow a proper separation between the surface roughness and the depth of the textures. Thus, the use of surface parameters having stratified functional properties is needed.

The group of parameters R_k, defined in DIN4776 and adopted in ISO 13565-2, are graphically extracted from the Bearing Area Curve (BAC) of the measured surface, aiming at identifying three main curve regions: core roughness depth (R_k); reduced peak height (R_{pk}) and reduced valley height (R_{vk}). Additionally, the bearing percentages M_{r1} and M_{r2} are, respectively, the transition points separating the protruding peaks and deep valleys from the roughness core profile. As indicated by [6], small R_{pk} (the so called 'running surface roughness') and large R_{vk} (lubricant capacity indicator) are good characteristics for tribological surfaces.

Plateau-honed surfaces machined in cylinders liners can be quantified using the R_k set of parameters, according to the engine application. For example, different R_{vk}/R_k ratio can lead to different engine performance [7].

For quality inspection, the particularities of the machined pockets in the proposed textured surface require the introduction of the following additional parameters, derived from the graphical analysis of the BAC curve, as depicted in Fig. 2.

Three new parameters are proposed in this research for the evaluation of pocket-shaped textures. The core roughness depth parameter (R_k) is now replaced by R_{k0} and R_{k1} representing, respectively, the core roughness on the top and at the bottom of the pocket geometry. R_{k0} and R_{k1} values are graphically defined based on limits of the transition line that separates the two core roughness limits.

The third new parameter is the pocket depth (H_k) and is calculated by taking the distance between half of the depth of the two core roughness ranges ($R_{k0}/2$) and ($R_{k1}/2$) as shown in Fig. 2. This way, with a small modification in the meter data processing, it is possible to measure the main surface properties in parts with pocket textures in just one single measurement and using a conventional profilometer.

4. Proposed application and grinding strategy

The industrial application of textured bearings should require parts with pockets around its circumference. The surface roughness of the pockets and its depth and width should be well controlled. Top roughness R_{k0} values should be lower than bottom roughness R_{k1}. Rougher R_{k1} are even better for oil retention inside the pocket while finer R_{k0} should allow low friction when the oil film is broken. These features make the process design much more complex. A grinding strategy for the production of these characteristics will be described and tested in the following sections.

For this research it was assumed parts with 30–90 pockets per rotation in order to test the first samples of textured bearings. Since feasible grinding tangential speed ratios can range from 50 to 200, usual grinding wheels are 500 mm in diameter and automotive bearings diameter are in the order of magnitude of 50 mm, the RPM ratio between wheel and workpiece will range from 5 to 20. Assuming a RPM ratio of 10, and for a part with 30 pockets, the number of patterns to be produced on the wheel surface should be around 3 per rotation. Since the wheel angular speed is about 20 rotations per second (for conventional wheels at $v_s = 30$ m/s) and assuming 3 patterns per rotation, this will lead to the need of a displacement actuator that could feed and return the diamond dresser against the wheel at a frequency of about 60 Hz. Only magnetic or piezo actuators can respond to such frequencies.

Other aspect that has to be considered is the machine dynamics. The frequency range of the dresser movement can be close to natural frequencies of typical cylindrical grinding machines.

So, the response of the system to the transducer (B in Fig. 1) movement is affected by the machine dynamic response. Also, the response of the wave shape transferred to the transducer can be modulated, depending on how close the excitation frequency is to

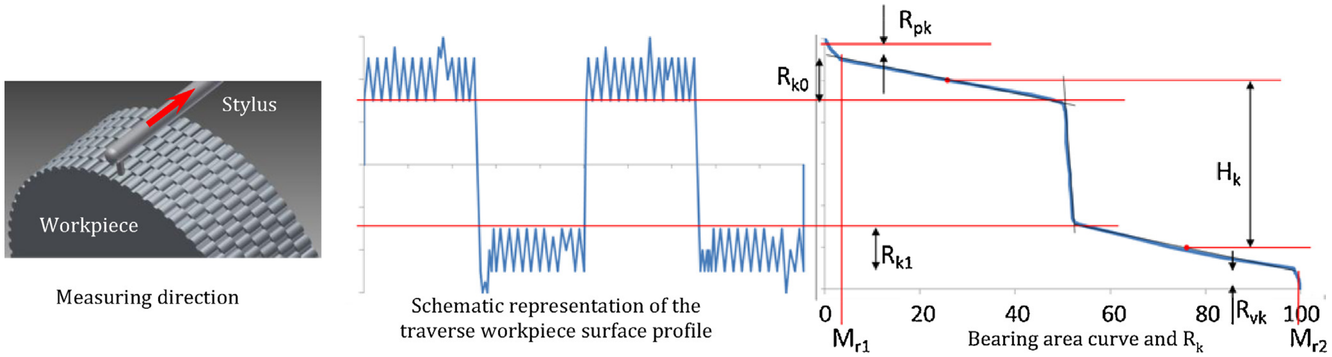

Fig. 2. Characterization of the ground pockets using the Abbot–Firestone curve.

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