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Reduction of friction in the cylinder running surface of internal combustion engines by the finishing process

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Abstract

Recent investigations on internal combustion engines show a relationship between the energy input due to the finishing process and the development of friction and wear during running-in, as well as of the subsequent operating state. The aim is to describe the correlation of the operational behavior on the mechanical modification of the inner boundary layer and to draw conclusions about the machining process. Honing process parameters are investigated using a special force monitoring setup. An optimized manufacturing process focused on chemical and mechanical boundary layer properties has been developed to reduce frictional forces in the system piston ring/cylinder running surface.

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1. Introduction

The energy input during finish machining in combination with the running-in conditions for tribological loaded components is of particular interest [1, 2]. Especially during honing of the cylinder running surface of internal combustion engines, roughness parameters and boundary layer properties can be modified [3]. The optimal adjustment of the residual stress state, chemical reaction layers and microstructure determines the friction and wear behavior of the piston group and, finally, the efficiency of an internal combustion engine. Previous scientific studies in this context focus primarily either the influence of finish machining [4] or running-in [5, 6] on the tribological behavior. A lack of knowledge exists regarding the dependencies between them, so correlations are rarely considered in detail [7]. In analogous experiments, *Berlet* shows the relationship between the coolant and process forces used in the finish machining and the tribological performance [8]. Irrespective of underlying mechanisms, *Mezghani* links the energy input during honing with the friction behavior [9]. But the element concentration in the boundary layer of cylinder running surfaces is of high importance [10]. A recent thesis in this context is the advantageous finish machining with low process forces.

2. Experimental setup

With different production settings, the influence of the finish honing operation for cylinder running surfaces made of grey cast iron EN GJL 250 with a diameter of d = 81.01 mm ± 0.005 mm is investigated. For this purpose, a honing machine “Nagel Variohone VSM 8-60SV-NC” and honing oil “Castrol Honilo 930” are used. All samples are produced by a conventional 3-stage honing process with a honing angle of 45 °, to ensure comparability of the surface topography for the following tribological tests. The first and second honing step is realized with metallic bonded diamond honing stones (D) and grain sizes of D107 and D56 microns. Therefore, the infeed is performed electro-mechanically. Honing stones made of silicon carbide (C) and metallic bonded diamonds are used in the finish honing step with the hydraulically infeed system. In addition to the third honing step, two brushing operations (Br) with steel wire or Anderlon™ and a conditioning process (Co) with carbide inserts are applied, see Fig. 1. By brushing, burr can be eliminated with minimum process forces and by conditioning with the utilization of honing or engine oil (SAE 5W-30 containing additives), high friction power can be transferred without material removal.

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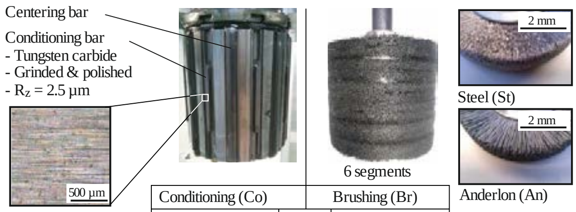

Conditioning (Co)		Brushing (Br)
5 m/min	v_{ca}	20 m/min
47 rpm	n	190 rpm
1 N/mm²	p_n	-

Process fluids
- Engine oil (Eo)
- Honing oil (Ho)

Constants: α = 45°, v_c = 60 m/min	Test series finish machining					
	Cutting material / tool				Additional process	
	Silicon Carbide Sc400Ke20		Diamond D15/118/X33		Brushing (**Br**)	
					Steel (**St**)	Anderlon (**An**)
p_n [N/mm²]	0.21	**C1**	0.15	**D1**	Conditioning (**Co**)	
	1.53	**C2**	1.6	**D2**	Engine oil (**Eo**)	Honing oil (**Ho**)

Fig. 1. Conditioning and brushing tool (top) and parameters of the test series.

The axial and tangential cutting force components are measured in-situ by a developed piezoelectric force measurement platform, see Fig. 2. The design ensures a minimum of disturbances caused by temperature fluctuations or vibrations. On the machine control side all the settings are expressed as a percentage. Therefore, a calibration of the radial expansion forces for each honing tool is necessary and realized by special measurement brackets with strain gauges.

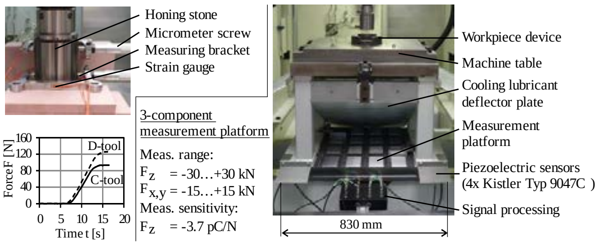

Fig. 2. Normal force measuring brackets and exemplary chart (left), piezoelectric force measurement platform (right).

The tribological behavior of the cylinder running surfaces is investigated with an SRV®3 test rig (Optimol Instruments Prüftechnik) with a friction force resolution of 0.01 N. For the oscillating friction wear (OFW) test, the honed samples are prepared by electrical discharge machining with a size of 10 x 15 mm. As counterpart an original piston ring segment made of spheroidal graphite cast iron with a wear resistant DLC coating is used. An OEM surface serves as reference. The experimental conditions are comparable to the conditions in the top dead center of the real combustion process, where mainly mixed friction conditions occur. Apart from dynamic effects the coefficient of friction (CoF) is measured in the running-in process at a stroke of s = 3 mm and a frequency of f = 20 Hz for a period of t = 3 h. The samples are fixed in an oil bath of SAE 5W-30 at a temperature of T = 130 °C. The cylinder running surface is characterized before the OFW test by a tactile measurement (3D profilometer Form Talysurf PGI 800, Taylor Hobson) with a measurement range of 1.2 x 1.2 mm, a point distance of 1 micron and a resolution of 3.2 nm. In contrast, the workpiece surface integrity is analyzed by X-ray diffraction (XRD), secondary ion mass spectroscopy (SIMS) and focused ion beam (FIB).

3. Results

3.1. Cutting force measurement and surface topography

In preliminary tests, shown in Fig. 3, a suitable process window for honing stones made of silicon carbide could be defined. Only at high honing pressure p_n = 1.53 N/mm², an influence of the cutting speed v_c on the cutting force F_c can be determined. An optimum in terms of small cutting forces is reached at v_c = 60 m/min. The settings are analogous to the conventional process with diamond honing stones. In general, the surface roughness increases at high contact pressure except low cutting speeds. In each case a minimum of the roughness is reached at v_c = 60 m/min. Here the reduced peak height R_{pk} and the reduced valley height R_{vk} are comparable and independent of the honing pressure, only the core roughness R_k differs. Therefore, this cutting speed is kept constant for all further investigations.

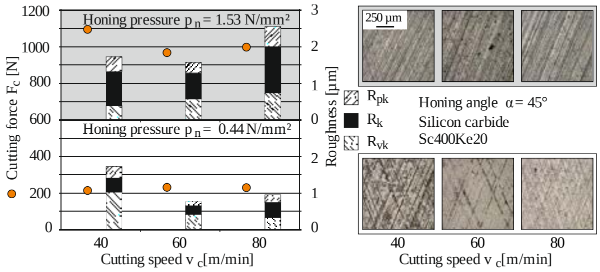

Fig. 3. Influence of the cutting speed on cutting forces and surface characteristics.

The test series in finish machining with all process variations verifies advantages of ceramic honing stones in terms of low process forces (Fig. 4). For similar honing pressure, significantly lower cutting forces appear compared to metal bonded diamond honing stones based on a beneficial cutting ability. The results confirm those mentioned in [10].

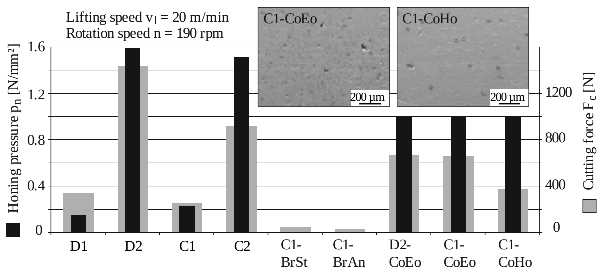

Fig. 4. Correlation of honing pressure and cutting force in finish machining and REM-images with artefacts on the conditioned surfaces (top).

As expected, the lowest cutting forces are generated by brushing processes. The measured cutting force for conditioning represents the friction between the tungsten carbide inserts and the cylinder running surface without chip removal. The different cutting forces for C1-CoEo and C1-CoHo results from the different viscosity of the process fluids. Using raster electron microscopy, round cavities with oxide