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Procedia CIRP 46 (2016) 258 – 265

www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Potentials for Improving Efficiency of Combustion Engines due to Cylinder Liner Surface Engineering

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Abstract

Despite new developments like E-mobility or hybrid concepts, the combustion engine will remain of great importance in individual mobility. The article highlights the recent trends, i.e. moving away from monolithic materials in the crankcase towards coated liners with adapted surface structures generated by honing processes. Results of tribological tests are presented for determined surface modifications and different materials to decrease frictional losses. Methods of process monitoring are outlined together with discussion of results from running-in experiments and boundary layer characterisation. Thus, conclusions for the specific finishing of cylinder running surfaces are drawn to improve the honing process.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz

Keywords: Honing; Finishing; Suface integrity; Tribology; Friction

1. Introduction

In the conflict area with legal regulations and the customers' demands for economy, mobility and quality, the continuous improvement of the internal combustion engine is a decisive key point in the development of modern motor vehicles. Especially in the passenger car sector, currently two major development objectives can be identified in terms of reducing fuel consumption and reducing the pollutant emissions (e. g. CO_2, NO_x) [1,2]. Either it can be implemented by improving the power efficiency or reducing the power to weight ratio. So-called downsizing concepts lead to an increase of mechanical and thermal loads of specific engine components. On the other hand, a reduction of power to weight ratio by corresponding lightweight constructions can decrease the fuel consumption. For monolithic, quasi-monolithic and heterogeneous cylinder liner concepts, mainly aluminum alloys and other composite materials are used [3,4]. In addition to cast-in liners made of cast iron, thermally sprayed coatings are focused to ensure a friction-optimized and wear-resistant cylinder running surface [5,6,7]. Even in the context of electric mobility, combustion engines will remain of considerable importance. This shows the current market penetration of electric vehicles with a marginal rate of 0.06 % of the total registered cars at least in Germany [8]. Further new development potentials arise in hybrid vehicle concepts by using range extenders for steady-state operation. Depending on the operating point, nearly 50 % of the frictional losses of the combustion engine are caused in the crank mechanism [9,10]. This includes the tribological pairing piston ring - cylinder running surface as one decisive element. Here, a 5 % reduction of frictional losses can lead to a 1 % improvement in friction efficiency of the entire engine with a profitable cost-benefit ratio, corresponding to lower emissions of 1 g CO_2/km [11]. As the main quality determining process, finishing by honing is the key technology and subject of current research.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
doi:10.1016/j.procir.2016.04.025

2. State of the art

The honing operation of cylinder running surfaces is the last processing step in engine production. Therefore, the friction and wear behavior of the tribological system piston ring - cylinder running surface is determined. The quality of the surface finish directly affects the oil consumption and emissions of the engine. By honing, the micro and macro structure is specifically adjusted. Micro-hardness, residual stresses, lattice structure and chemical boundary layers define the surface integrity and can be seen as a function of honing process parameters and running-in conditions. Honing can be defined as an interaction of mechanical work and physical-chemical processes. The multitude of factors illustrates the complexity, see Fig. 1.

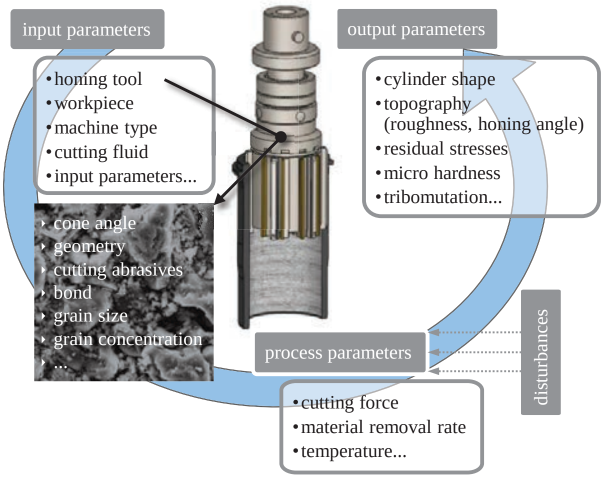

Fig. 1. Parameters of the honing process.

Key parameters of the process are the cutting and bond material, the feed or expansion system [12], the workpiece clamping and input parameters. Depending on the machining task, cutting materials such as diamond, cubic boron nitride, silicon carbide and corundum are used [13].

The prevailing conditions between cutting material and workpiece are significantly influenced by the cutting fluid. The viscosity and the additives of the lubricant determine the flushing and lubricating effect in the contact area. The influence of different cutting fluids for honing is evaluated in [14] and [15] with respect to the achieved material removal rate and surface topography. Benefits were observed when using ecologically advantageous polymer-based cutting fluids.

The cylindrical shape with a tolerance of less than 6 µm is also finally defined by the honing process and contributes a significant part to the engines performance [16,17]. A further approach for reducing mechanical losses relates to the so-called form honing [18], whereby a non-circular machining with actuatoric elements is performed. For this purpose, the finishing process is designed in consideration of pre-calculated dynamic cylinder form deviations occurring during engine operation. Recent developments illustrate ways to series production [19,20,21].

A significant aspect during honing is basically the topography of the cylinder running surface, which is adapted to each cylinder liner concept. For crankcases made of cast iron, a multi-stage plateau honing technique is state of the art. The honing plateaus form a large real contact area to reduce the surface pressure and friction, whereas the honing grooves serve as an oil reservoir. In contrast, the pores of thermally sprayed iron layers adopt this function and are exposed during honing, so the surface can be finished very smoothly [22,23]. A variety of studies aims at improving the surface topography by adjusting the honing parameters [24,25,26] or at the extension of the finishing process by new strategies [27,28,29,30,31,32,33]. Fig. 2 shows examples of different topographies for cylinder running surfaces.

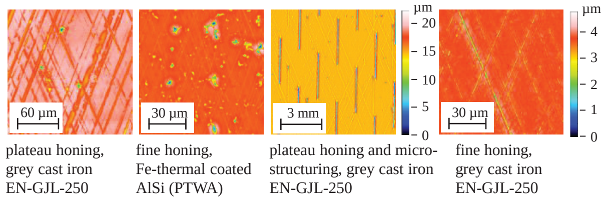

Fig. 2. Exemplary surface topography of various honed cylinder running surfaces.

The process parameters and the cooling fluids additionally influence the surface integrity. Depending on additives used during honing and engine operation, chemical reactions play a significant role for the outer boundary layer characteristics [34,35]. In the field of scientific studies relating to surface integrity issues, tribological models have to be considered and applied in production technologies [36]. Because of relatively low cutting speeds during honing resulting in low contact zone temperatures, the formation of chemical reaction layers tend to be insignificant [37]. However, the formation of these reaction layers depends on the concentration of chemical elements in the lubricant and the machining conditions [38,39]. Investigations related to the formation of reaction layers were previously realized in processes with defined cutting edges [40,41] and in grinding [42]. Due to the modified process kinematics during honing, depicted in Fig. 3, these studies can be transferred only conditionally. The characteristic cross-hatched structure of honed surfaces is a result of the superposition of the oscillating axial movement and the rotation of the honing tool with simultaneous radial infeed of the honing stones.

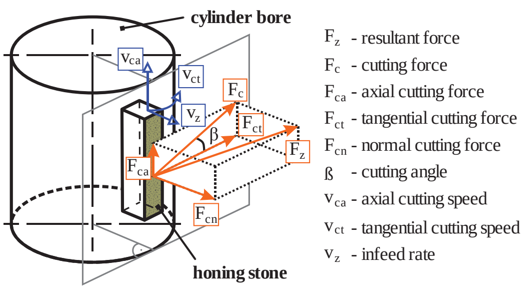

Fig. 3. Schematic image of input and process parameters in honing operation.