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Multi-surface topography targeted plateau honing for the processing of cylinder liner surfaces of automotive engines

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ABSTRACT

Cylinder bores of automotive engines are 'engineered' surfaces that are processed using multi-stage honing process to generate multiple layers of micro geometry for meeting the different functional requirements of the piston assembly system. The final processed surfaces should comply with several surface topographic specifications that are relevant for the good tribological performance of the engine. Selection of the process parameters in three stages of honing to obtain multiple surface topographic characteristics simultaneously within the specification tolerance is an important module of the process planning and is often posed as a challenging task for the process engineers. This paper presents a strategy by combining the robust process design and gray-relational analysis to evolve the operating levels of honing process parameters in rough, finish and plateau honing stages targeting to meet multiple surface topographic specifications on the final running surface of the cylinder bores. Honing experiments were conducted in three stages namely rough, finish and plateau honing on cast iron cylinder liners by varying four honing process parameters such as rotational speed, oscillatory speed, pressure and honing time. Abbott–Firestone curve based functional parameters (R_k, R_{pk}, R_{vk}, M_{r1} and M_{r2}) coupled with mean roughness depth (Rz, DIN/ISO) and honing angle were measured and identified as the surface quality performance targets to be achieved. The experimental results have shown that the proposed approach is effective to generate cylinder liner surface that would simultaneously meet the explicit surface topographic specifications currently practiced by the industry.

1. Introduction

Cylinder liner-piston-piston ring system is a major contributor for the mechanical losses in an engine. Surface topography of the cylinder liner is identified as one of the significant factors that influence the performance of engine with regard to friction (fuel efficiency), wear (durability and running performance) and oil consumption (noxious emissions) [1]. For this reason, cylinder liner surfaces are processed by exercising immense attention and are subjected to meet multiple surface quality criteria. Cylinder bores are finished using three stage-honing processes namely rough, finish and plateau honing [2–4]. The first stage is a rough honing process carried out on bored cylinder liners using a coarser honing stone targeted to improve the surface finish and shape. The second process is the finish honing process, which is accomplished using a medium size abrasive grit on honing sticks aiming to improve the surface texture further close to the final product requirements. Finally, plateau honing is carried out with a very fine abrasive grit to alter the roughness peaks to generate a fine surface texture that resemble 'run-in' surfaces. The resulting surface is capable of providing good lubrication retention because of the deep valleys and the proper bearing area for the piston rings travel.

Honing is a slow speed abrasive based finishing operation used to produce components with fine finish and geometric quality suitable for various tribological applications. During the operation, honing machine, not only produces a simultaneous rotational and reciprocating motion, but also a hydraulically driven expansive action on the floating tool attached with several abrasive bonded honing sticks to remove the stock from the work surface. During the course of the honing process, crosshatched groove patterns are generated on the bore surface as a consequence of the simultaneous rotational and the oscillatory movements of honing abrasive stick inside the cylinder bore. The angle formed by these grooves perpendicular to cylinder axis is known as honing angle. Experimental and simulation studies indicate that the honing angle influences the lubrication distribution on the cylinder bore surfaces [5–7]. In addition to the process parameters such as rotational speed, oscillatory

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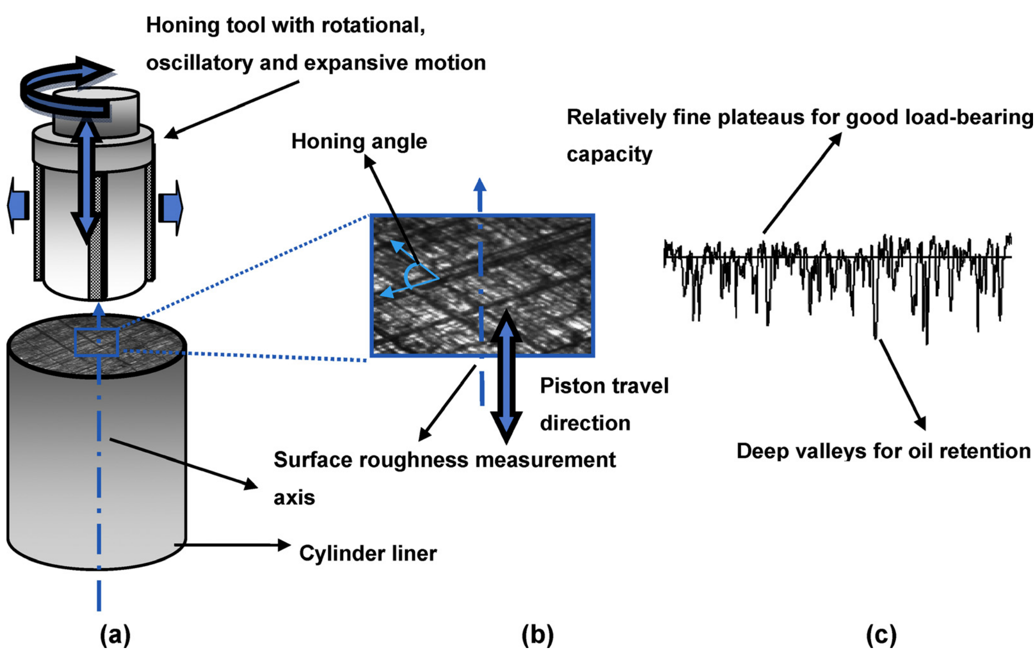

Fig. 1. Honing of cylinder liners: (a) Schematic of honing process, (b) a typical surface texture image and (c) a typical roughness profile generated after plateau honing process.

speed, contact pressure and honing time, the surface roughness generated after honing is also influenced by abrasive parameters such as type and grain size of the abrasive, density and bond material used in the abrasive stone, etc. [8]. An average grit sizes between 7 and 250 μm (FEPA standard) could be used for honing process. In general, bigger the grit sizes, higher the roughness profile height. Studies are reported about the influence of abrasive material, grit size and binder material on the various surface roughness parameters generated during honing process [8–10]. A schematic sketch of the honing process, a typical plateau honed surface image and the resulting roughness profile are shown in Fig. 1.

Currently, five surface profile parameters based on material ratio curve (ISO 13565-2) namely reduced peak height (R_{pk}), core roughness depth (R_k), reduced valley depth (R_{vk}), material ratio 1 at the peak zone (M_{r1}) and material ratio 2 at the valley zone (M_{r2}), coupled with mean roughness depth (Rz (DIN/ISO) and honing angle are used as the surface topography specification for the cylinder liner surface [2–4,11]. Rz (DIN) or Rz5 ISO is defined by ISO 4287, 1997 as the sum of the distance between highest peak and deepest valley per sampling length and is usually expressed as average of such values for five successive sampling lengths. Based on the inputs from the industrial practitioners and the reported literature [2,11–14], it has been identified that the following are the range of surface topographic characteristics recommended by the engine manufacturers in the final plateau honed cast iron cylinder liners: R_{pk} value that is less than 0.3 μm, R_k in the range of 0.8–1.2 μm, R_{vk} of 1.2–2 μm, M_{r1} of 2–10%, M_{r2} of 70–85%, Rz (DIN) in the range of 3–4 μm and honing angle in the range of 40°–55° (see Table 1).

Selecting the honing process parameters at three stages to obtain these seven surface topographic characteristics concomitantly within the specification tolerance is a challenging task for the process/manufacturing engineer. This is usually carried out based on experience, trial runs and/or based on the broad guidelines given in machining data handbooks/application note provided by the honing machine manufactures. Nevertheless, this does not always guarantee an optimal and economic generation of cylinder liner surface that is complying with all the required surface quality characteristics within the tolerance range. Taguchi's design of experiment is an established method for analyzing and optimizing

Table 1
Surface topographic parameters used for the quality control of plateau honed cylinder liner surfaces.

Surface topographic parameters	Range of acceptable values[a]	Average value set as 'target'
R_{pk}	0.1–0.3 μm	0.2 μm
R_k	0.8–1.2 μm	1 μm
R_{vk}	1.2–2 μm	1.6 μm
M_{r1}	2–10%	6%
M_{r2}	70–85%	77.5%
Rz (DIN)	3–4 μm	3.5 μm
Honing angle	40°–55°	48°

[a] Range selected based on inputs from industrial practitioners and literature [2,11–14] information.

production processes [15,16]. This method can analyze and provide optimal operating conditions for several independent variables and a single response variable. However, if there are multiple responses for the same set of independent variables, the methodology provides a contradicting set of operating conditions for each of the responses. For example, the optimal honing process parameters for achieving the targeted R_{vk} value may not be the same as for getting the required M_{r2} value, as observed in a study reported by Kanthababu et al. [14]. They have conducted three stage honing experiments on cylinder liners by systematically varying rotational speed (34–40 m/min), reciprocating speed (10–14 m/min), pressure (0.5–0.7 MPa), rough/finish honing time (140–300 s) and plateau honing time (8–16 s) and described the honing process parameters effect on average roughness and material ratio parameters. Another work reported using data mining approach [17] for the cylinder liner surface production targeted only two surface quality parameters (Mr_2 and R_k) for the optimum parameter selection at plateau honing stage alone. Pawlus et al. [3] conducted slide honing experiments and suggested that coarser honing pressure and plateau honing time are the two process parameters that have significant influence on cylinder liner surface topography defined by ISO 13565-2 (R_k family) and ISO 13565-3 (R_q family). Feng et al. [18] reported a neural network model for the prediction of four material ratio parameters (R_k, R_{pk}, R_{vk}, M_{r2}) generated in two stage