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Tribological performances of elliptic and circular texture patterns produced by innovative honing process

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ABSTRACT

Honing is a manufacturing process which uses friction and abrasion mechanisms at a reduced velocity to print a multiscale and anisotropic texture on the liner surface of automotive engines. It enables to enhance the functional performances of a ring-pack system. However, industrial honing basically generates cross-hatched rectilinear textures. This paper proposes new surface textures, generated by an innovative honing prototype machine, with original patterns (circles and ellipses) at different size and aspect ratio. Then, the friction performances of each generated surface are evaluated using a reciprocating ring–liner tribometer and compared with industrial helical slide honed (HSH) texture. The results show that ellipse patterns oriented at ring sliding direction contribute the most to reduce the friction coefficient.

1. Introduction

In an automotive industry, manufacturing low emission engines with optimized performances is a major objective. The cylinder surface texture has a high contribution towards engine functional performances (friction, oil consumption, wear, etc.). This texture is generated by three superfinishing honing process stages (rough honing, finish honing and plateau honing). Different honing techniques are used in industry such as Plateau Honing (PH), Helical Slide Honing (HSH) and Slide Honing (SH). They generate cross-hatched textures with different surface roughness and anisotropy [1–3].

Two optimal honing cross-hatched angle ranges ([25–55°] and [120–140°]) for friction reduction were identified by ring liner simulation models [4,5] and friction test rig [2,6]. Engine tests [1,7,8] confirmed these two groove orientations. They correspond to that generated by PH/SH and HSH processes, respectively. Nevertheless, HSH honed surface (cross-hatched orientation of about [120–140°]) has shown better functional performances. On the one hand, their friction losses are lower and less sensitive to roughness amplitude than PH surfaces [2,4,9]. An experimental study using a tribometer showed a friction reduction until 20% of HSH texture in comparison to PH surface [2]. On the other hand, HSH contributes to lower oil consumption. Some studies using engine tests showed an oil consumption reduction greater than 40% for HSH surface in comparison to PH one [1,7,10]. Unfortunately, only cross-hatched rectilinear texture patterns can be basically generated with abrasive honing, due to the kinematics industrial honing machine capabilities [11].

Moreover, original surface patterns form and size, like circle and ellipses cavities, generated experimentally by etching, Laser Surface Texturing (LST) process or simulated numerically using virtual texturing approach have shown improved functional performances (friction, lubrication) in comparison to abrasive industrial honed surface texturing (SH or PH)) [6,12–17].

However, abrasive industrial honing has an advantage to be more reliable, with a good repeatability in mass production and reduced manufacturing costs, compared to other surface finishing and texturing processes such as Laser Surface Texturing (LST) or Ultraviolet (UV) laser [1].

In this paper, new texture patterns are generated (circles and ellipses) using abrasive honing process through an innovative honing prototype machine, open for texture programming and with enhanced kinematics [18]. For that, different honing kinematics are used in order to obtain circular and elliptical patterns at different size and aspect ratio (perpendicular ellipse axis/longitudinal ellipse axis ratio).

Then, the friction performance of each generated surface is evaluated at different lubrication conditions with a reciprocating ring–liner tribometer. The obtained results show the contribution of pattern size and orientation (of major ellipse axis) on friction performances. Finally, friction reduction of these original textures is compared to an optimized industrial texture (HSH).

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Nomenclature

S_{pk}	3D roughness parameter for reduced peak height (μm)
S_k	3D roughness parameter for depth of the roughness core profile (μm)
S_{vk}	3D roughness parameter for the reduced valley depth (μm)
SC	small size circular texture patterns
BC	big size circular texture patterns
BLE	big size elliptical texture patterns oriented at the longitudinal direction of the ring sliding direction
SLE	small size elliptical texture patterns oriented at the longitudinal direction of the ring sliding direction
BTE	big size elliptical texture patterns oriented at the transverse direction of sliding direction
STE	small size elliptical texture patterns oriented at the transverse direction of sliding direction
μ_D	lubricant viscosity, Pa.s
v	mean sliding velocity during friction tests
F_N	normal contact force between ring and liner surface
F_T	tangential contact force between ring and liner surface
l_y	contact width between ring and liner surface
HSH	helical Slide Honing or Helical Slide Honed (surface)
COF	coefficient of friction
S	average Sommerfeld number $S=\frac{\mu_D\times v}{F_N/l_y}$
$R1$	radius of first ellipse arc
$R2$	radius of second ellipse arc
X	ellipse width (on the transverse direction of sliding)
Y	ellipse length (on the sliding direction)
Rm	average radius of ellipse or circle

2. Experimental procedure

2.1. Honing experiments

Flexible honing experiments have been carried out on an instrumented vertical prototype honing machine with an expandable tool (Fig. 1) in order to generate innovative circular and elliptical texture patterns. Moreover, an HSH texture pattern is generated for comparison. The considered part is a gray cast iron cylinder liner for combustion engines with a diameter of 72.2 mm and a height of 127 mm.

Table 1 describes the general honing operating conditions. First, during the rough honing stage, enough material is removed to reach the desired cylindricity. At this stage, all of the process parameters are kept constant for all the honed bores. Then, for the finish stage, which enables to obtain the desired texture patterns, different kinematics are used in order to obtain circular and elliptical grooves pattern at different sizes and orientations. Finally, the third stage (plateau stage) is used to obtain plateaued surface textures [2,19]. Each texture was generated at least three times.

Three different texture anisotropies with two size levels ($Rm\sim7.5$ mm and $Rm\sim14$ mm for the small and big size respectively) were generated and considered in this study and compared to an HSH surface

1. Small size circular patterns (SC).
2. Big size circular patterns (BC).
3. Big size elliptical texture patterns oriented at the longitudinal direction of the ring sliding direction (BLE).
4. Small size elliptical texture patterns oriented at the longitudinal direction of the sliding direction (SLE).
5. Big size elliptical texture patterns oriented at the transverse direction of sliding direction (BTE).
6. Small size elliptical texture patterns oriented at the transverse direction of sliding direction (STE).

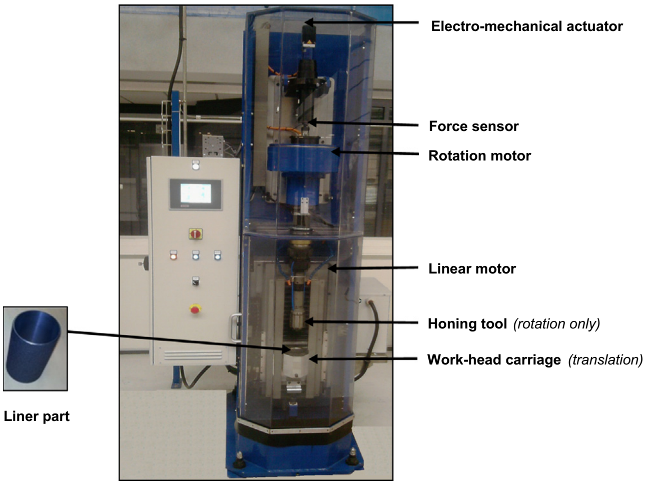

Fig. 1. Vertical honing prototype machine with an expansible tool.

To generate circular and elliptical trajectory, the prototype machine use an ISO programming mode which has the advantage to synchronize rotation motion to stroke motion using a circular interpolation [11,18]. For circular pattern a series of circular arc at the same radius is generated (Fig. 2(a)). For elliptical patterns a series of two tangent circular arcs at different radius ($R1$ and $R2$) is made (Fig. 2(b) and (c)). The orientation of ellipses (longitudinal or transverse) depends on the radius and length of each circular arc.

The size is evaluated using the mean radius Rm expressed by:

$$Rm=\frac{X/2+Y/2}{2} \tag{1}$$

Where X and Y are the width (transverse to the sliding direction) and the length (on the sliding direction) respectively, as shown in Fig. 2. Furthermore, surface patterns orientation can be evaluated by the X/Y ratio ($X/Y=1$ for circles, $X/Y>1$ for transverse ellipses and $X/Y<1$ for longitudinal ellipses).

Table 2 resumes the kinematics honing operating conditions for the different circular and elliptical textures.

For the HSH texture, the classic honing mode is used, like industrial honing machines [2,9,19], with a rotation speed of 70 rpm and an axial velocity of 38 m/min.

Table 1
General honing operating conditions.

Honing parameters	Rough honing	Finish honing	Plateau step
Cutting speed (m/min)	49	22	22
Contact force (N)	800	700	250
Honing duration (s)	120	60	10
Number of stones	8	8	8
Abrasive grit type	Diamond	Silicon carbide	Silicon carbide
Grit size (μm)	149	107	30
Bond type	Metallic	Vitrified	Vitrified
Size of honing stones (mm × mm × mm)	3 × 5 × 80	6 × 6 × 35	6 × 6 × 35

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