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Flexible right sized honing technology for fast engine finishing

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ABSTRACT

The paper discusses a flexible honing technology by describing the new prototype machine with its specificity. Three original methods produced by the flexible honing prototype have been studied. A path combines the two contemporary methods of industrial honing: the helical slide honing at 135° at the bottom of the cylinder and the conventional honing at 45° on the upper part. This method of honing shows the effectiveness of specific motion tracking to remove traces of inversions. Circular trajectories with large radii can be traveled quickly without consuming too much energy. The high cutting speed promotes the removal of material thus saving time. Finally, the multi-circle paths can get original textures thus proving the feasibility of all patterns.

The conventional honing process which produces a textured liner surface with a honing angle close to 45° pertains in automotive industry for over 40 years. The evolving of pollution standards in the last ten years has changed the process with the application of a plateau honing technology. This technology removes the running-in of the engine after assembly [1]. Some manufacturers are engaged in helical slide honing (HSH, with a honing angle of 135°) to increase engine performances by reducing friction [2]. However, this process requires over-sized honing machines and a long cycle time. The latest engine developments tend toward crankcase made entirely of aluminum of which only functional cylinder surfaces are coated with shirts deposit extremely hard. This deposit ensures the retention of oil by its porosity; the surface must, however, be honed to be as smooth as possible before an assembly with the piston and rings.

To reduce the manufacturing cycle and get a right-sized honing machine for development, a new prototype of vertical honing machine was designed with high dynamic performances. A digital controller allows the synchronized control of the rotation and stroke axis and allows interpolation of trajectories. The radial expansion can be hence controlled in position or in force. We sought new paths with the aim to increase productivity of the process and to generate new textures.

This paper compares the performance of the prototype with those of conventional machines before presenting some original new methods.

1. The honing machine

The honing operation of cylinder block liners consists of removing material by abrasion inside the cylinders bored to obtain a good quality of the cylindrical surface. This quality is defined at three levels: at the macroscopic level the cylindrical shape must satisfy the dimensional criteria, roughness at the microscopic level is specified by the designers of the engine, at the mesoscopic level, the surface appearance of a texture must be defined in the specification of the surface. To achieve these objectives, the honing operation must implement abrasive stones that are mounted on an expansion honing tool. The honing tool has the feature to push the stones for contacting with the cylindrical surface. The material removed by abrasion requires cutting speed [3]. The cutting speed defined by the relative speed between the abrasive grains and the machined surface is given by the combination of a movement of rotation and translation of the honing tool about its axis. Fig. 1 shows the kinematics of a honing machine with one pin. The *Z*-axis of the pin is the axis of the honing tool and of the cylinder.

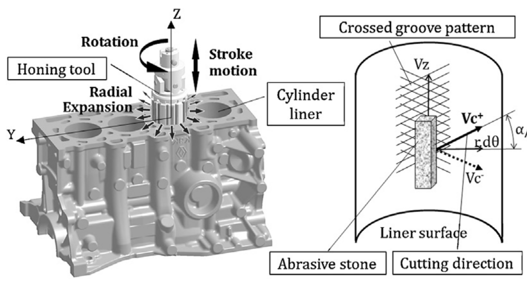

Fig. 1. Honing machine kinematic.

In conventional honing strokes along the *Z*-axis are linear and the rotational speed is constant. Following the trajectory of these movements form helices crossed at the angle $\alpha/2$. The pattern left by the abrasive traces therefore has streaks that cross each other at the angle α, the angle of grinding. To satisfy different levels of quality of honed surface, the honing operation is often divided into several stages. In general one first step, the roughing, is performed with large grains to obtain effective material removal and correcting the shape. Then the finishing steps can combine several

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abrasives to achieve low roughness. The configuration of these conventional operations is optimized empirically to achieve high production rates. The optimization of the parameters can be done with the aid of a simulation [4].

1.1. Characteristics of classical honing

Honing process, like drilling, requires only two axes to fulfill the motion of the tool: rotation and axial translation. Like any machine tool and according to the convention [5], the rotation axis of the tool is designated as the *Z*-axis. On most machines, the workpiece is fixed and the tool performs the movement. Traditionally, the linear actuator is a hydraulic cylinder controlled in position. The stock removal is obtained by generating a contact pressure between the stones and the cylindrical surface of the cylinder bore. There are two different kind of actuator to perform this movement: hydraulic and electromechanical systems, as shown in Fig. 2. For hydraulic system, the cutting force is given by the hydraulic pressure supply of the actuator.

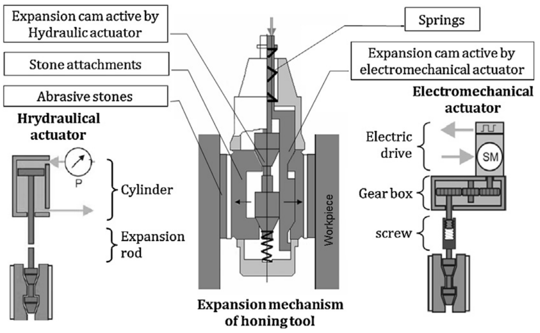

Fig. 2. Two technologies for expansion axis.

Electromechanical systems are naturally driven in position. The position setpoint is often expressed in microns and corresponds to a diameter that is absolute or relative to advance abrasive stones. Some techniques for detecting the radial position of contacted stones have been patented [6]. The observed diameter of the advance of the expansion is not necessarily identical to the real diameter of the cylinder, because the wear of the abrasive is not taken into account. On the other hand, in-process measurement gives a true measure of the diameter. The control calculates the abrasive wear by comparing the evolution of the actual diameter and the radial feed of the abrasive stones.

The principle of double expansion honing tool was patented in 1986 by industrial company Nagel [7]. A double expansion honing tool has two sets of stones that are separately operable. The superposition of two concentric cams, depicted in Fig. 2, can activate both sets of stones independently. This double expansion allows two successive steps without changing tools in order to save cycle time. On conventional machines, the spindles are frequently equipped with one electromechanical expansion and one hydraulical expansion.

1.2. Characteristics and performance of the prototype

The prototype machine that we designed operates the same type of honing tool as conventional machines.

In order to meet the needs to exceed the dynamic performance of existing machines, we chose an inverted architecture illustrated in Fig. 3.

The liner is clamped in a workpiece holder and is driven in a translation motion. While the rotating tool remains at a fixed height. This solution minimizes the moving masses, prevents vibrations and the jolts in the tool, and can pass on processes requiring high cutting speed and strong momentum. The motion law governing the beat is very dynamic. The reversal of the speed at the end of the stroke involves high acceleration. The integration of a high performance linear motor of 7 kW on the prototype allows

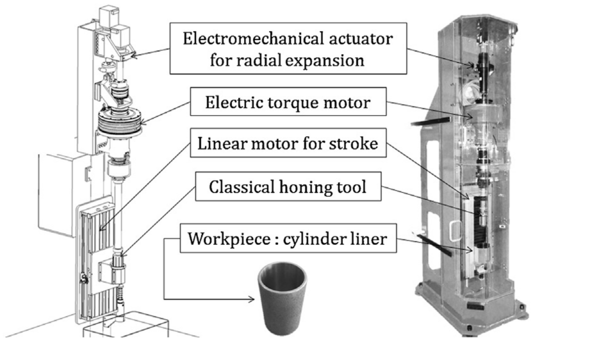

Fig. 3. Machine with inverted structure/photography.

achieving high travel speeds (60 m/min) with high acceleration (50 m/s^2). With the integrated incremental rule in the electric motor, the autopilot provides positioning at 5 μm that is much more accurate than hydraulic systems (1 mm).

In general, on conventional machines, the rotation is provided by asynchronous electric motors controlled in speed (50–2500 rpm). The prototype machine is equipped with an electric motor with permanent magnet mounted directly on the spindle axis. This technology controlled in position or in speed ensures a torque greater than 50 N m at a standstill and at very low speed, up to 450 rpm.

Table 1 shows the main characteristics of the prototype machine compared to current machines.

Table 1
Comparison between the prototype and conventional machines.

	Nagel	Gehring	Prototype
Maximal stroke speed	30 m/min	25 m/min	60 m/min
Acceleration of stroke	30 m/s^2	30 m/s^2	50 m/s^2
Rotation speed with torque >50 N m	50–2500 rpm	50–2500 rpm	0–450 rpm
Rotation acceleration	Constant speed	Constant speed	350 rad/s^2

Coupling the linear motor for the stroke and motor torque for rotation enables a synchronized piloting in position of the two axes to track optimal trajectory. As a numerically controlled machine tool, it is possible to interpolate the linear or circular paths described in ISO language G-Code [8].

The axis expansion requires a special performance to meet the specifications of the prototype machine. It must perform both functions of the two current systems. The selected hardware solution is to combine an electromechanical actuator and a force sensor at the end of the rod. The force control is performed by controlling the command on the force sensor. The machine includes a system for acquisition of all the physical data of the axes and the sensors.

2. Honing path with variable angle

In conventional honing, the constant rotation speed during the inversion of translation at the ends of stroke generates a parabolic trajectory of abrasive stones in the cylinder. Paper [9] shows that the acceleration of inversion plays a role in the amount of horizontal traces. The prototype machine is programmed to interpolate rotation – and stroke axes in order to respect a path defined by the user. Through the high dynamic performance of the actuators, this operating mode allows for precise monitoring of the triangular setpoint path to remove inversions traces.

2.1. Definition of the honing path

The path shown below includes a grooves angle change between the upper part of the cylindrical surface and the bottom. This multi-honing angle provides so-called mixed liners which have a pattern typical of HSH at the bottom to facilitate the