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Technical Paper

Use of results from honing test machines to determine roughness in industrial honing machines

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ABSTRACT

In the present work, a new methodology is presented to translate roughness results from a test machine to different industrial machines without the need to stop production for a long time. First, mathematical models were searched for average roughness Ra in finish honing processes, in both a test and an industrial machine. Regression analysis was employed for obtaining quadratic models. Main factor influencing average roughness Ra was grain size, followed by pressure. Afterwards, several experiments were simulated in the common range of variables for the two machines using the models for average roughness Ra. A new variable DifRa corresponding to the difference between roughness values from the test machine and the industrial machine was defined and a quadratic model was obtained. Once DifRa is modeled, it is possible to predict roughness in a different industrial honing machine from results of the test machine by performing a few experiments in the industrial machine and translating the curves. This will reduce the number of tests to be performed in industrial machines. The suggested new methodology has been tested with two more roughness parameters, maximum height of profile Rz and core roughness depth Rk, proving its validity.

1. Introduction

In interior honing processes, a honing head provided with abrasive stones is used for removing material from the internal surface of cylinders. Honing is employed to improve shape, dimensional precision and surface finish of previously machined parts. Usually, the honing head combines a linear alternate movement with rotation, so that abrasive grains provide a crosshatch pattern on the workpieces' surface [1]. Main advantages of interior honing are high material removal rate up to 0.6 mm/min, much higher than that obtained in lapping processes, with typical values of 0.5 μm/min, the fact that a lower pressure is usually employed than in grinding processes, making it possible to control roundness and dimensions of the part, and improved surface texture [1,2]. Main drawbacks are that it is a low-velocity process, it does not allow correction of misalignment and that it has a reduced area of application [1]. Surface finish obtained by means of honing is related to friction between piston and cylinder liners [3] as well as to tool wear [4].

Honing is a multistage process that usually comprises rough, semifinish and finish operations. Each successive operation is performed with finer grain size of abrasive in order to achieve a smoother surface. In industry, both vertical and horizontal configurations are used. In order to improve productivity, three-head vertical machines that allow honing with three cylinders working simultaneously, in three different stages, can be used.

In the literature, few authors have obtained mathematical models for roughness in honing processes. Troglio carried out a full three-level design of experiments, with factors like abrasive grain size, lubricating oil and workpiece material, and responses such as roughness Ra or Rk family (Abbott-Firestone) parameters. In addition, he studied influence of the process on roundness and cylindricity. He also studied influence of tool wear on consumed power, material removal rate and specific energy [5]. Bai and Zhang studied how to increase efficiency in honing, with variables such as pressure, speed and cross-hatch angle. Best material removal rate was observed at a crosshatch angle between 40° and 60°. Pressure was one of the most influential parameters on roughness [6]. Kanthababu et al. employed rotation speed, linear speed, pressure,

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Fig. 1. Test honing machine.

honing time and plateau-honing time as variables in a three-level design of experiments. Responses were roughness parameters of the Abbott-Firestone curve (Rk, Rpk, Rvk, Mr1, Mr2) [7]. Main factors affecting surface roughness were pressure and honing time. In plateau honing processes, Pawlus, Cieslak and Mathia employed diamond abrasive stones for honing cast iron cylinders, with grain size 151 and 76 (FEPA) in rough and semifinishing steps, which correspond to size ranges 150/125 and 75/63 μm respectively, and 15 in plateau honing, which corresponds to size range 15/25 μm [8]. They considered working pressure in honing and in plateau-honing, as well as plateau-honing time. They searched a correlation between roughness parameters related to the Abbott-Firestone curve and roughness parameters related to the probability curve, both in two and three dimensions. They found that probability parameters are independent, while Abbott-Firestone parameters show linear dependence. Buj-Corral et al. obtained models for average roughness Ra as a function of both machine parameters (pressure, linear speed and tangential or rotation speed) and honing stone parameters (grain size, density of abrasive) in rough honing. They found that, in the range studied, grain size of abrasive and pressure were main variables affecting roughness and material removal rate [9]. Lawrence and Ramamoorthy studied rough, finish and plateau honing processes by means of robust process design and gray-relational analysis in order to optimize Rk family parameters, Rz and honing angle [10]. Vrac et al. found models for average roughness in honing processes with diamond abrasive stones. Main factor influencing roughness was cutting speed for grain size 181 (size range 180/150 μm) and specific pressure of finishing honing for grain size 151 (size range 150/125 μm) [11]. It is well known that the higher grain size, the higher surface roughness is [12]. In addition, pressure increases roughness, while tangential speed reduces it [13].

In a previous paper by the authors of the present paper, average roughness Ra obtained in a test machine and in an industrial machine in semifinish honing processes were compared [14]. In the present paper, roughness parameters Ra, Rz and Rk were compared for both a test and an industrial honing machine in finish processes. Mathematical models were obtained for roughness parameters as a function of five process variables. For the three roughness parameters studied it was observed that shapes of models for test machine and for industrial machine are similar, although they are separated by a certain distance. For this reason, the difference between values from the two machines was modeled. Assuming that different industrial honing machines will have a similar behavior regarding roughness, the models for differences will allow predicting roughness values to be obtained in a certain industrial machine by only performing few tests and translating values from the previously obtained models of the test machine, without having to stop production a long time in order to perform time-consuming tests. Once the method had been tested for three different roughness parameters, Ra, Rz and Rk, a general methodology was defined. It will allow determining roughness in industrial machines from roughness in test machines. The results guarantee the validity of the methodology.

2. Materials and methods

2.1. Honing tests

Two different machines were employed: a horizontal test machine (Fig. 1) and a vertical Honingtec industrial machine (Fig. 2). Steel St-52 cylinders of 80 mm internal diameter were machined. Length of cylinders was 100 mm for the test machine and 390 mm for the industrial machine. Finish honing tests were carried out. Characteristics of performed tests are presented in Section 2.2.

A Hommel W5 roughness meter was employed for measuring roughness. For each cylinder, 9 points were measured along a diametric circumference in the internal surface of cylinders [15]. Measurements were performed at the mid-height center of the cylinders in order to avoid ends where honing head decelerates and accelerates. It corresponds to 50 mm from both ends for the test machine and to 195 mm from both ends for the industrial machine.

2.2. Statistical tools

In order to obtain quadratic mathematical models for roughness, experiments according to a central composite design were performed. A central composite design has three kinds of experimental data points: cube, axial and central points. A graphical representation of the structure of this type of experiments is shown