ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia CIRP 1 (2012) 377 – 381

www.elsevier.com/locate/procedia

5th CIRP Conference on High Performance Cutting 2012

Analysis of the Differences between Force Control and Feed Control Strategies during the Honing of Bores

Dirk Bähre[a,]*, Christina Schmitt[a], Uwe Moos[a]

[a]Institute of Production Engineering, Saarland University, D-66123 Saarbrücken, Germany

* Corresponding author. Tel.: 0049-681-30257559; fax: 0049-681-3024858. E-mail address: d.baehre@mx.uni-saarland.de.

Abstract

Honing is a machining process that can economically produce very exact bores regarding form, geometry and surface quality. It is mainly used as the final finishing operation for ready made parts and typically conducted on the inner surface of a cylinder. Due to their specific surface structure which has a good ability to keep lubricants and a high wear resistance, honed parts usually serve as functional surfaces to guide moved parts. Today, the main fields for applications of honing technology can be found in most sectors of the metal working industry, e.g. the automotive industries, hydraulic and pneumatic manufacture and aircraft industries. During the long-stroke honing process the tool, equipped with one or several abrasive honing stones, is performing three overlaying movement components. These are a rotational movement, an oscillating stroke movement in axial direction and the radial feed movement of the honing stone. This feed movement is one of the decisive factors for the results of the honing process. It can be realized through feed control or, in a more recent approach, through force control strategies. By feed controlled honing, the position of the honing stone is changed in defined invariable steps in certain time intervals. In contrast, by force controlled honing the force of the honing stone against the wall of the workpiece is measured indirectly by a force sensor, which is located within the feed unit of the honing machine. A required force value is given and, if necessary, the honing stone is fed outwards to reach and maintain a constant cutting force throughout the honing process. This constant force is supposed to produce better results of the honing process in terms of geometric and form accuracy as well as surface structure. The presented research studies aim at improving process know-how to further increase the production accuracy and process repeatability. In a comparison between parts honed with the two different feeding strategies for the honing stone, force components and moments were analyzed and correlated to the phases of the process and several influencing parameters. In addition to the forces and moments measured during the honing process, the quality parameters of the honed parts have also been analyzed and compared.

Keywords: Precision machining; honing; force analysis; finishing.

1. Introduction

Honing is an abrasive manufacturing process that can produce economical part removal together with very exact workpiece results regarding geometric and form accuracy as well as surface quality. Honing is often used as the final finishing operation for ready-made parts, especially where parts are moved against each other, e.g. in piston raceways in engine blocks or – on a smaller scale – in fuel injection pumps. Through honing a wide range of parts, regarding their size and material, can be manufactured. This paper deals with the internal long stroke honing of small bores (up to 10mm in diameter). Despite the increasing importance of the process, the research and further development of honing has been neglected over the last years [1]. While there have been several studies considering the honing tool [e.g. 2, 3], research activity with regard to the control of the honing process is lacking.

The traditional form of honing is an open loop control called feed-controlled honing [4]. A newer appraoch, the so called force-controlled honing, uses a closed loop control. In the case of force-controlled honing the forces occuring during the process are measured and kept constant through a regulation of the feeding movement. This constant process force helps to reach a more stable

 http://dx.doi.org/10.1016/j.procir.2012.04.067

honing process regarding the quality parameters, the material removal and the wear of the honing stone. A force-controlled approach can help to increase the process stability, the quality of the honed workpieces and the tool life. It also helps to reduce the running-in period of the process and makes it possible to hone in small lot sizes. The presented study explains the differences between the two control types and shows the advantages of the force controlled approach.

Nomenclature

F_c	cone force
F_z	axial force
M	Moment
R_a, R_{pk}, R_z	surface quality parameters

2. Experimental Setup

Honing is an abrasive machining process with geometrically undefined cutting edges. The process is mainly characterised by three overlaying movement components: a rotational movement along the tool axis, an axial stroke movement and the feeding movement of the honing stone.

Due to the overlaying rotational and axial movements, the honed surface shows a typical crosshatch pattern. The honing angle of the crosshatch pattern is dependent on the ratio of axial and tangential speed. On the one hand, this characteristic surface is able to hold lubricants better than a perfect even one. On the other hand, the ratio of bearing area to total area is pretty high, so that a honed surface has a remarkably reduced wear caused by running-in.

For long-stroke honing with a single stone tool, as used in the conducted experiments, the feeding movement of the honing stone is realized by an axial movement of the feeding cone as shown in Fig. 1. The axial movement of the feeding cone results in a radial feed movement of the honing stone.

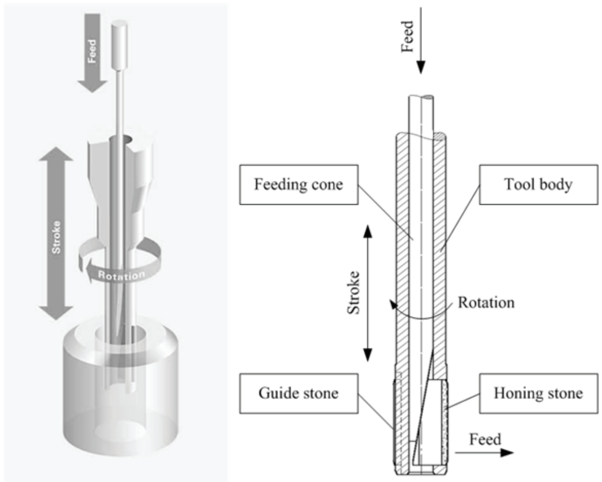

Fig. 1. Single-stone honing tool for the internal honing of bores [5].

This feeding movement can either be realized by fixed steps in a given time interval (feed controlled honing), or in dependence of the occurring process forces (force controlled honing). In addition to the honing stone the single-stone tool also has two guide stones which are not supposed to contribute to the abrasion, but shall guide the tool in the bore.

3. Experimental Setup

The described honing experiments are conducted on a vertical single-spindle honing machine with a single-stone hone as shown in Fig. 2.

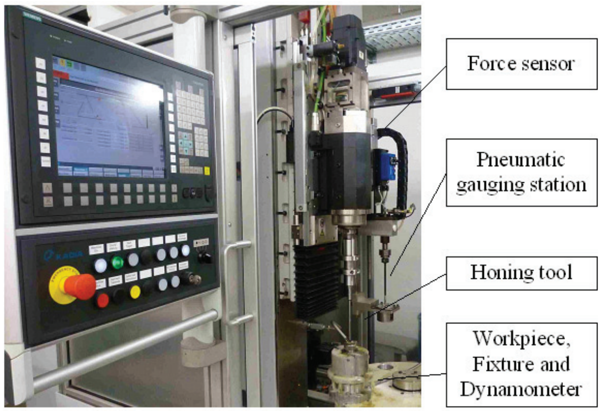

Fig. 2. Vertical honing machine used in the experiments.

The machine is equipped with a honing station, a pneumatic gauging station to measure the honed diameters and a deburring station. A four-component dynamometer is installed beneath the gimbal-mounted workpiece fixture. This dynamometer measures the axial force F_z and the moment M. The honing machine also has an internal force sensor that measures the cone force

F_c on the feeding cone during the honing process and enables the force-controlled honing. The cutting grains of the single-stone honing tool were made from Cubic Boron Nitride (CBN).

The oscillation of the vertical stroke axis of the machine is given in figure 3(a).

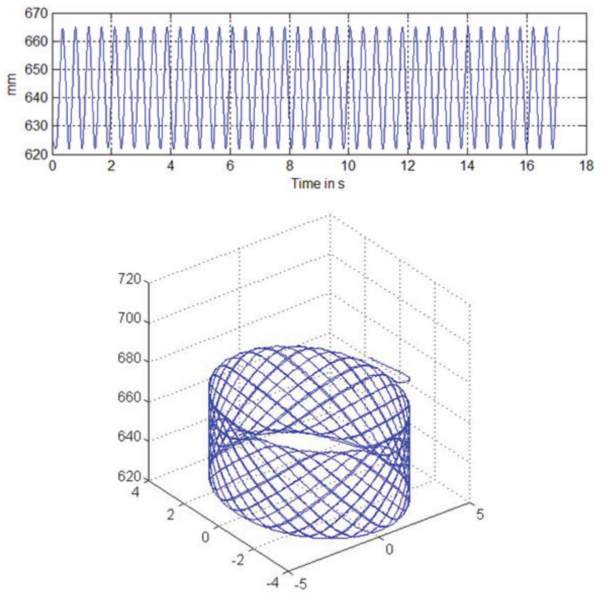

Fig. 3. (a) Stroke position, (b) superposition of rotation and oscillation.

The superposition of rotation and oscillation brings the characteristic crosshatch pattern at the surface of the bore. To make this visible, Figure 3(b) shows exemplary the path of a honing stone over the machining of a workpiece. For this, the rotation in the x,y-plane is given and the stroke position is plotted at the z-direction. For better visuabililty other parameters than those used in the experiments have been chosen for the rotation speed.

Table 1. Parameters for the honing experiments

Honing parameter	
Rotation speed [1/min]	1600
Lifting speed [m/s]	0.26
Lifting acceleration [m/s^2]	5
Feed per step [mm]	0.0005
Time between feed steps [s]	0.25
Time of relaxation [s]	2
Force range [N]	80-90
Diametral material removal [mm]	0.002-0.003

The honed workpieces were made of hardened steel 16MnCr5 (HRC 60+2) and were honed with the parameters according to Table 1. The honed diameter was 8mm.

4. Feed-controlled Honing

The feeding movement can be realized as an open loop control by giving constant, user-defined feeding steps at fixed time intervals. Fig. 4 shows the constant steps and the occurring force at the honing stone. The axial oscillation causes longitudinal deformations in the honing tool and so the axial position of the feeding cone to the tool body is not totally fixed between the feeding steps. This movement between feeding cone and honing stone makes the force between tool and workpiece oscillating as visible at the right part of the figure.

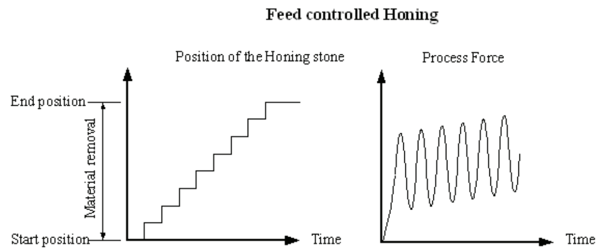

Fig. 4. Feed position and process force for feed controlled honing.

At the beginning of the process, the surface roughness of the bore is slightly higher due to former process steps. With the decreasing roughness over the process, the material removal rate also decreases. The feeding rate in contrast stays constant, because the height of the feeding steps and the times between them are constant. This causes an increase in the axial cone force over the honing of each workpiece as visible at the right part of Fig. 4.

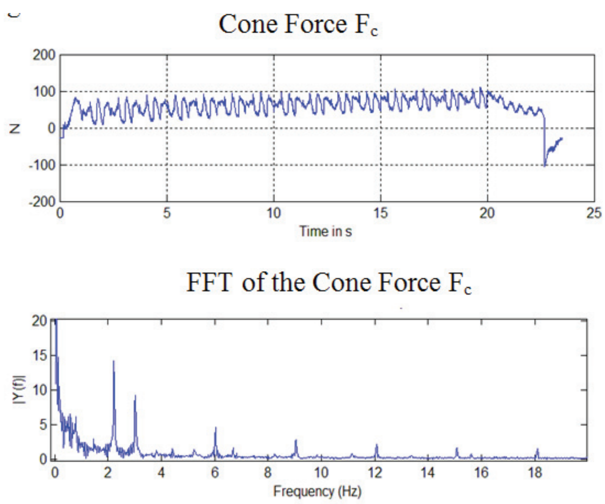

Fig. 5: Cone force with Fast Fourier Transformation (FFT) of the signal for a workpiece honed feed-controlled.

The graph of the measured cone force F_c for a workpiece honed feed-controlled is shown in Fig. 5. The increase of the force by the feeding steps, can be seen superposed with the oscillation of the force caused by the axial movement of the tool, and the rising of the mean value of the force over the machining. The decrease of the force at the end of the process is caused by holding the feeding position constant while oscillation and rotation continue. During this "Sparking out time" the system can relax itself, which leads to a better surface quality.

The spectrum of the measured force is calculated by a Fast Fourier Transformation using a rectangular window and shown in Fig. 5. Beside the peak at the frequency of zero Hz, the largest peak is nearly at 2 Hz, the frequency of the axial oscillation. At circa 3 Hz, another peak has almost the same magnitude. This frequency is stimulated by the steps in the feeding movement. One step takes 0.33s, which is the time for the feeding movement together with the time between steps. The diametral material removal for the part was 30µm in this case, which determines the time as 20s for the process (without spark out time). The spectrum of the measured forces is pretty diffuse. There is a range of frequencies, especially between zero and 5 Hz, which disturbs the process force, the tool and hence the honing process.

5. Force-controlled Honing

At force controlled honing, the feed is regulated by a closed-loop-controller. In a first step, the feeding is directly correlated to the measured force value. If this measured force is outside a given range, the axis starts moving until the force comes back to the desired range. As at the feed-controlled process, the oscillation of the tool is the main influence on the force sensor. But in difference to the behavior of the former process, the amplitude of the deviation is smaller.

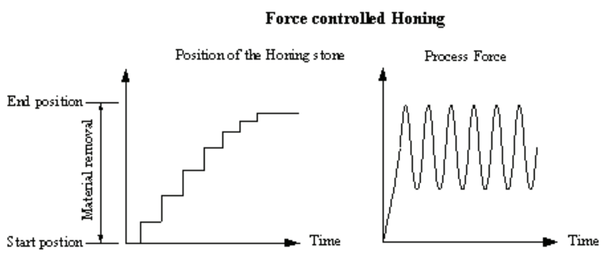

Fig. 6. Feed position and process force for force controlled honing.

Fig. 6 shows the feeding movement and the process force for force controlled honing.

The feeding steps as well as the time intervals between the steps are no longer constant because the feeding movement begins whenever the force goes out of the given range. Through this regulation, the course of the process force is more constant than for feed controlled honing.

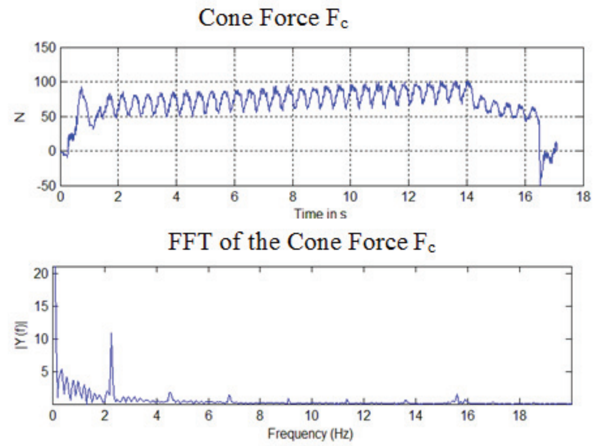

Fig. 7: Cone force with Fast Fourier Transformation (FFT) of the signal for a workpiece honed force-controlled.

The measured cone force F_c shown in Fig. 7 is more regular, while the force in Fig. 5 includes more perturbations besides the oscillation movement. The strong periodical character of the force signal is also visible in the Fast Fourier Transformation of the measured force shown in Fig. 7 which has the main frequency at 2 Hz. As before, this is the frequency of the oscillation axis. But in contrast to the former transform of the signal measured with the open-loop-controller, there is just one main frequency in the signal. This one is the frequency of the oscillation, which is directly mechanically coupled to the system. Between zero Hz and 5 Hz, there are disturbance frequencies in the spectrum, as before for feed controlled honing. But, in comparison they are less noisy and also from smaller magnitude.

6. Comparison between Feed- and Force-control Strategies

The following figures show the surface parameters R_a, R_{pk} and R_z for the parts honed with the two strategies described. R_a is the arithmetic average roughness. To calculate R_z, the measured part is divided into 5 equidistant parts. The average of the distance between the highest peaks and deepest valleys in each section determines the value of the parameter. The reduced height of peaks R_{pk} finally contains information about how susceptible the surface is for breaking-in. R_{pk} is defined on the basis of the Abbot curve [6].

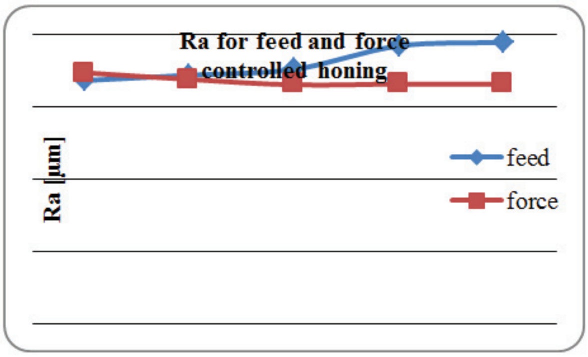

Fig. 8: Surface parameters Ra and Rpk for feed controlled honing.

Fig. 8 shows the roughness parameter R_a for feed and force controlled honing in comparison, Fig. 9 shows the results for the parameter R_{pk} for parts honed under the same conditions also with both strategies. As can be seen the results for the parts honed force controlled are slightly better and more constant than for those honed feed controlled, especially regarding R_{pk}.

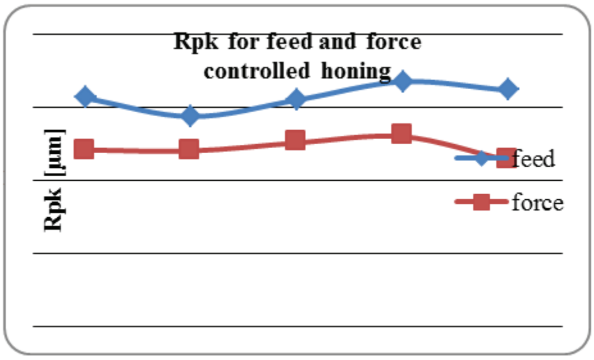

Fig. 9: Surface parameter Rpk for feed and force controlled honing

Fig. 10 shows the surface quality parameter R_z for parts honed with the two respective strategies. While the values and also the variation are rather similar, the parameter is slightly less for the parts honed force controlled.

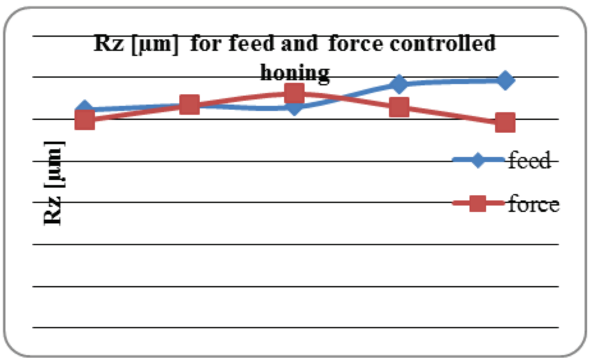

Fig. 10: Surface parameter Rz for feed and force controlled honing in comparison.

7. Conclusion and Outlook

Force controlled honing as a newer approach to the regulation of the honing process can help to improve the process stability as the conducted experiments show. The course of the process force is more constant and the results for the surface quality show less variation.

The further development of force controlled honing has the potential to increase the productivity and to decrease the running-in time for small charges.

Further investigations should take more parts into account to get a higher statistic background and further improve the control strategy.

Acknowledgements

The authors would like to thank the Kadia Produktion GmbH + Co. Nürtingen (Germany) for the provision of their honing machine and for supporting and funding the investigations.

References

[1] Tolinski M. High-Performance Honing. Manufacturing Engineering 2008; Vol. 140 No. 6.
[2] Burkhard G, Rehsteiner F. High Efficiency Abrasive Tool for Honing. CIRP Annals – Manufacturing Technology 2002, Vol. 51, Issue 1, 271-274.
[3] Sabri L, Mezghani S, El Mansori M. A study on the influence of bond material on honing engine cylinder bores with coated diamond stones. Surface and Coatings Technology 205; 2010.
[4] Bähre D, Schmitt C. Analysis of Forces and Process Behaviour during the Honing of Bores. Proceedings of the 4th CIRP International Conference on High Performance Cutting, Japan; 2010.
[5] Schmitt C, Bähre D, Forsch K, Klein H. Feinstbearbeiten hochgenauer Bohrungen durch Honen. Jahrbuch Schleifen, Honen, Läppen und Polieren/65. Ausgabe; 2011.
[6] EN ISO 13565-1 and EN ISO 13565-2. Geometrical Product Specifications (GPS); 1998.