An Introduction to the Vibration Analysis for the Precision Honing of Bores

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Abstract
Honing is mostly the last step in the production process for precise elements and thus has to comply with high standards for the resulting quality regarding form, measurement and surface quality. Tolerances are currently even further reduced. Crucial for the ability of the honing process to reach the high quality is the process control. A new approach to a further improvement of the honing process could be the use of vibration analysis during the machining process. Vibration analysis for process control is already successfully used, e.g. for grinding. The paper presents an experimental setup for the measurement of vibrations during the honing process and shows first results of conducted experiments.

Keywords: Precision machining, Honing, Vibration analysis, Process monitoring

1 The Honing Process

In future, production engineering will have to face new challenges concerning production accuracy which call for a continuous optimization and advance in the field of production engineering research. An important contribution can be made with abrasive processes, as these fine machining processes help to create the required smooth and exact surfaces. An abrasive process for the fine machining of cylinder bores is the honing process. The surface of a honed part describes a ready functional surface. High-precision, cylindrically honed bores can reach a form- and dimension exactness as well as a very high surface quality with values less than 1 µm. They are applied e.g. in high pressure injection pumps or valve spool bores in hydraulic systems.

The honing process for the final finishing of bores combines three overlaying movement components. These are a rotational movement around the tool axis, an oscillating movement along the tool axis and a feeding movement of the honing stone as shown in Figure 1. The tool in Figure 1 is a single stone honing tool equipped with one honing stone and two guiding stones. Both consist of a steel base with an abrasive layer on top. The guiding stones have finer abrasive stones in a higher
concentration as they are only supposed to guide the tool in the bore and not to contribute to the material removal process. Due to the overlying movement components, the honing stone leaves the characteristic crosshatch pattern on the surface of the work piece. In the later use of the work piece this characteristic pattern helps to keep oil at the surface if parts are moved contrary to each other, e.g. in a cylinder-piston combination. Therefore, one of the most frequently used applications is the honing of cylinder bores. As it is the last machining process the honed parts have to meet high requirements regarding measurement-, form- and surface- quality where the process control plays an important role for that. State of the art is the so-called feed-controlled approach where the honing stone is fed outwards in certain time intervals by certain feeding steps. A newer approach describes the feeding dependent on the force measured at the feeding cone.

Figure 1: The honing process (Bähre, 2010)

To reach even higher tolerances new ideas are needed. As the process control via the use of vibration measurements has been very successful for other machining processes with geometrically undefined cutting edges, namely grinding (Karpuschewski, 2000; Tönshoff, 2000; Tönshoff, 2002), it could also be useful for the honing process. The machining area during the honing process is hardly accessible for further investigations in contrast to processes like turning and milling. Thus, it is
difficult to supply information referring to this area. A scientific approach to improve the manufacturing exactness as well as the process stability may yield in the analysis of vibration signals in order to better characterize the honing process as well as to gain a more elaborate evaluation of the machine behavior as a whole. This paper provides some insights into an experimental setup and the possibilities of the signals’ analysis using the Fast Fourier Transformation (FFT). These are initial investigations. Further research can help to relate the measured signals to the outcome of the process, especially regarding material removal and quality. These results can then help to create new regulation approaches.

2 Process control through acoustic emission analysis

The process control through the use of vibration measurements has proved to be successful for other machining processes in the field of production engineering (Lee, 2006). Vibration analysis is applied amongst others within the field of external cylindrical grinding as well as drilling. Both methods – external cylindrical grinding and drilling – show properties which can be transferred to the honing process. The following paragraph explains the main idea and the transfer mentioned above.

Like the honing process, external cylindrical grinding is a machining process with geometrically undefined cutting edges. The aim is the monitoring of the process dynamics and the compensation of process vibrations in order to control the blunting and the grinding tool’s breaking of grit and bond. This abrasive wear has negative effects on the entire process resulting in excessive friction and process forces, thermal disadvantages for the work piece and can lead to a geometrical inaccuracy. The experimental setup includes the monitoring of the dressing process of the grinding tool via force- and structure-borne emission sensors. Due to the rotary movement, the use of force sensors with an exact positioning is difficult to reach so that the use of structure-borne sensors would be a better approach for the grinding application (Karpuschewski, 2000; Kim, 2001; Jacobsen, 2012). In this context, a further approach describes the model–based AE-monitoring of the grinding process. At this juncture, the fundamental idea is the description of the contact between the single grains and the work-piece (Hundt, 1997).

Another application for vibration analysis is the drilling process. Unlike honing, it is a machining process with geometrically defined cutting edges, but there are still elements of the vibration analysis which can be useful for the honing process in order to find new approaches. During drilling and honing, the machining area is hard to access for further examinations. Therefore, only indirect conclusions about the processes involved can be drawn. For example, vibrations during the drilling process impact the shape accuracy and the surface quality of the boring as well as the tool life. Hence, the use of vibration measurements can contribute to a better understanding of the factors influencing the boring quality (Tschanerl, 2007).

3 Experimental setup

Figure 2 shows the setup during the conducted experiments. The honing machine used is a vertical single spindle machine from the German manufacturer Kadia Produktion GmbH + Co, Nürtingen. It is equipped with one honing spindle, a pneumatic measuring device to determine the diameters of the honed parts and a deburring station. The honing tool used is equipped with one honing- and two guiding stones. The abrasive grains of the honing stone are made from diamond and held in a metallic bonding. For the measurements a Piezotron acoustic emission sensor type 8152 A together with a Piezotron coupler type 5125 A1 from Kistler Instrumente AG, Switzerland, has been used. The advantages of this sensor are its high sensitivity and wide frequency range together with its small size and robustness. These properties describe a fundamental requirement for obtaining measurements in
The coupler is used for the power supply of the sensor and for signal processing. The measured signals have been recorded by a Genesis 2i high speed data recorder. The measurement has been conducted on four different positions close to the honing process to determine the most liable ones. The different positions include the honing spindle (compare Figure 2 – position 1), the top of the work-piece fixture (position 2), the side of the work-piece fixture (position 3) and the machine table (position 4). In each case, the sensor has been fixed onto its position with a screw.

![Figure 2: Experimental setup with four different positions of AE sensor](image)

### 3.1 The honing process

The honing process has been conducted with the parameters shown in Table 1. The work pieces used were made from unhardened steel 16MnCr5. The diameter at the beginning was 7.98 mm and honed to reach 8.00 mm. During the experiments Kadiol 180 was used as a cooling lubricant. Some parts were honed both feed- and force-controlled, the respective parameters are shown below. The time of relaxation describes a phase at the end of the process when rotation and oscillation go on but without further feeding of the honing stone.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Kadia LH 30/300R</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feed-controlled honing</strong></td>
<td></td>
</tr>
<tr>
<td>Rotation Speed</td>
<td>1600 min⁻¹</td>
</tr>
<tr>
<td>Oscillation velocity</td>
<td>0.26 m/s</td>
</tr>
<tr>
<td>Radial feed per step</td>
<td>0.0005 mm</td>
</tr>
<tr>
<td>Time between feed steps</td>
<td>0.5 s</td>
</tr>
</tbody>
</table>
3.2 Analysis of acoustic emission signals

Typical applications for the Fast Fourier Transformation (FFT) are found in the areas of acoustics, electronics and optic. This paper focuses on the Fourier Transformation for production engineering. The Fast Fourier Transformation (FFT) is an optimized variant of the Discrete Fourier Transformation (DFT). It is an algorithm that uses the calculated intermediate data in order to minimize any arithmetic operations. By using the DFT, respectively FFT, the honing process should be researched more from the point of signal processing. Therefore, the motivation is to identify the important frequencies of the sampled signal. The next step is to identify the amplitude to these frequencies by applying a spectrogram. The implementation is carried out with MATLAB from MathWorks. The basis for the Fast Fourier Transformation is a sampled signal with a high sampling rate. This requirement is existent at a sampling rate of 200 Mb/s. The memory exists in the form of an ASCII-File. The evaluation results show the representation of the measuring signal of the accelerometer, the oscillating stroke, the spectrogram and the FFT.

4 Experimental results

The following figures show some of the results obtained. As expected, there is no useful information in the signals if the sensor is applied to either the honing spindle or the machining table, as those positions seem to be too far away from the honing process. Therefore, a deeper look is only taken at the results for the other two sensor positions, namely on top and on the side of the work-piece fixture. Figure 3 shows the results of the two positions for the force-controlled honing process. Every figure contains the measured acoustic emission signal, the oscillation movement as an indicator for the honing process, the spectrogram and the FFT of the acoustic emission signal. The sensor supplies two different levels of the output signal depending on the position. The signals measured on top of the fixture show approximately ten-times higher values for the FFT amplitude than those measured on the side. In this regard, the y-axis for the acoustic emission signal and for the FFT of the acoustic emission signal have been adjusted to obtain a better overview. As the acoustic emission and the oscillation movement show, each figure correlates to one honing process. The FFT shows in both cases a clear peak at approximately 5 Hz. As the oscillation movement of the honed parts has been conducted with an oscillation velocity of 2.0 m/s and an oscillation length of 40 mm, a peak at 2.5 Hz would have been expected. However, there is only a very small peak at that position; the peak for the double frequency is much bigger. This could be due to deviations in the cylinder form of the honed parts. The honing stone would meet those deviations twice during an oscillation movement and thus lead to the higher frequency. The deviations of the cylinder form were measured and showed values of up to 13µm. This could be a possible explanation for this effect. The further peaks seem to be the harmonic waves belonging to the original peak. The signals do not, however, show a significant peak at 10 Hz which would be the correlating frequency to the rotation speed. The work pieces in both cases have a good roundness being lower than 3µm before the honing process. This explains why this frequency cannot be detected due to the continuous movement of the tool. The honing improves the roundness slightly to values below 2.5µm. The spectrogram shows lighter areas in the vicinity of the dead centers.
of the oscillation movements. This seems to indicate less material removal due to the smaller cutting velocities which even come to zero at the dead ends for the oscillation portion. The same is true for the beginning of the honing process when the honing stone is not yet in the phase of high removal rates or did not yet even reach the bore wall during the first steps. While the results seem to be similar for both sensor positions, there is one significant difference. If the amplitudes of the FFT are compared, it can be seen that the amplitude for the sensor position on top of the work piece fixture is approximately ten times higher than for the position on the side of the fixture. This could be expected, as on top of the fixture the sensor is much closer to the process.

The results for the feed-controlled process are similar; they are shown in Figure 4. Again, only the positions on top and on the side of the work-piece fixture have been taken into account. As in this case the oscillation velocity was set at 2.6 m/s, the expected responding frequency would be 2.9 Hz. Also in this case, as for the force-controlled experiments, the highest peak is shown at 5.8 Hz, i.e. again with the double frequency. At 2.9 Hz there is only a smaller peak. In this case the rotational movement should correspond to a frequency of 17 Hz which is not detectable. In the case of the feed-controlled process there is a feeding movement of the honing stone every 0.5 s, corresponding to a frequency of 2 Hz. This frequency, however, cannot be seen in the FFT; this could be due to the resolution of the sensor. Again, the position on top of the work-piece fixture shows amplitudes that are ten times higher than those for the other sensor position.
5 Conclusion and outlook

The paper describes a new idea towards the entire monitoring of honing processes. This involves acoustic emission analysis, a successful basis for process monitoring in other fields, e.g. grinding, turning, milling or boring. An experimental setup is described to measure acoustic emission signals during the honing process. The signals are recorded at different positions and analyzed with FFT. The results suggest that a sensor position which is as close to the process as possible is best. Further research should concentrate on the sensor on top of the fixture position. During the experiments bores with a diameter of 8mm have been used, they are representative for smaller bores with a high precision. Some characteristics of the recorded signal can be explained concerning their causes, other topics have to be further investigated. A first approach to measure and analyze acoustic emission signals during the honing process has been made, but further investigations are definitely needed. In this context, an approach is the development of a model which analyzes the material removal process in more detail. The question for further research is if a characterization or monitoring and later even a regulation of the process using acoustic emission analysis are possible. Therefore, further research should concentrate on relating the measured signals to the quality characteristics of the honed work pieces. This would be the precondition for a regulation method.

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References


