Sensors of vibration and acoustic emission for monitoring of boring with skiving cutters

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Abstract. Diagnosing processing system conditions is a key area in automation of modern machinery production. The article presents the results of a preliminary experimental research of the boring process using conventional and skiving cutters under the conditions of the low stiffness processing system. Acoustic emission and vibration sensors are used for cutting process diagnosis. Surface roughness after machining is determined using a laser scanning microscope. As a result, it is found that the use of skiving cutters provides greater stability of the cutting process and lower surface roughness as compared with conventional cutters.

1. Introduction

Boring is one of the most common process steps in the manufacture of a variety of body parts (engine blocks, gearbox housing, etc.). Boring is carried out with cutters (for small diameter hole) or assembled cutter blocks (for large diameter holes). When boring deep holes, cutter rigidity may be insufficient, which causes strong vibration [1-3]. Vibration may also be formed when boring parts with thin walls (in this case the blank is the system element which causes low rigidity of the system). Strong vibrations lead to an increase in roughness and even reduce processing accuracy. To eliminate vibrations, one can increase the rigidity of system elements and / or to adjust cutting conditions, providing greater stability of the cutting process. In practice, it is not always possible to increase the rigidity of the elements of the technological system. Selection of cutting conditions requires a large number of long-term experiments and complex 3D FEM simulation. A relatively simple way to influence cutting conditions is changing the shape and / or the geometry of cutting blades.

Skiving cutting is characterized by high accuracy of machining and low roughness. As shown in [4, 5], the use of skiving cutters can significantly change the amount and the ratio of cutting force components (Pz, Py, Px), as compared to conventional turning tools. Changing the ratio of the radial (Py) for tangential (Pz) cutting force component has a significant impact on cutting dynamics. At the moment, there are no meaningful research works in oblique skiving boring. There is no information neither on the quality of machining nor on the power dependencies or the dynamics of the cutting process. The in-situ observation of cutting is very hard to implement therefore other indirect approaches are applied to evaluate the dynamics of cutting. One of such approaches is acoustic emission (AE) which possesses high sensitivity for detecting the tribology process stages, for example, such as running-in or steady wear as well as for monitoring a pre-failure stage under condition of choosing the appropriate AE signal processing [6-11].

The aim of this work is preliminary experimental studies aimed at identifying the possibility of using acoustic emission and vibration sensors for monitoring the boring process in the low rigidity technological system using traditional and skiving tools.

2. Materials and methods

Boring was carried out on an OKUMA lathe. Pipes of AISI, 100 mm in diameter with wall thickness 5 mm, were machined. Inserts of the WC-6Co-2TaC material were used. The tests were performed with a radius insert disposed in the holder with an inclination angle of 45° (in the Results and Discussion section is marked as Test 2), and with a traditional triangular plate with an angle of 60° (in the Results and Discussion section is marked as Test 1). Cutting data: t = 0.3 mm, s = 0.1 mm / rev, n = 300 rpm. Figure 1 shows images of the tools, having been used, and a diagram of the boring work, indicating locations of AE and vibration sensors.

Vibrational accelerations have been detected using the NI 9234 device. AE signal recording has been performed using a high sensitivity sensor. In order to reduce the AE low frequency noise from the AE sensor, we used a corresponding low-pass filter 50-1200 kHz without gain. Laser scanning microscope Olympus OLS LEXT 4100 was used for observing the surface roughness.

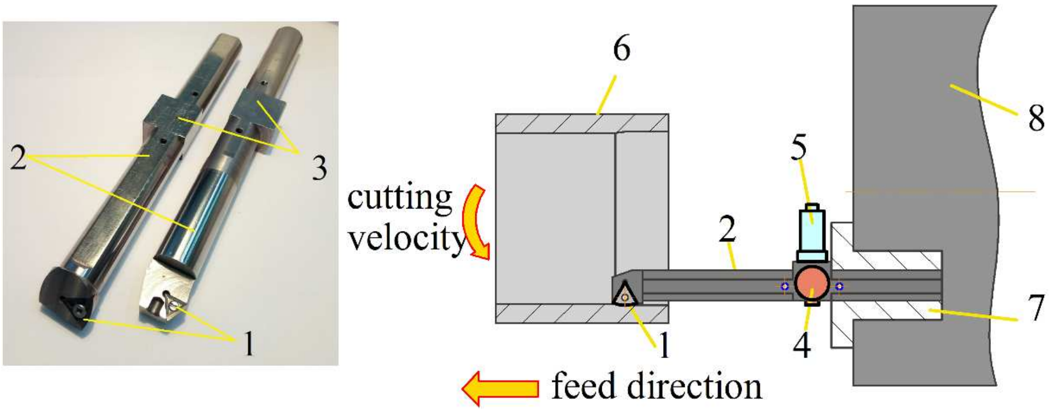

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Figure 1 Images of boring cutters (a) and boring scheme (b):1 - cutting insert, 2 - holder, 3 - sites for sensors, 4 - AE sensor, 5 - vibration sensor, 6 – workpiece, 7 - removable sleeve, 8 - lathe

3. Results and discussions

Graphs in Figure 2a show variations of vibration acceleration signals when working with conventional (test 1) and skiving cutters (test 2). The graphs prove that conventional inserts allow a higher level of vibration levels (acceleration reaches 47 m/s^2) as compared to skiving cutters . A similar level of vibration for the cutters under test is monitored only in the initial period of cutting. When using skiving cutters, vibrations take place only at the beginning of machining work; after that there is a stable period (in the range of 24-44 seconds) followed by a period (44-100 seconds) with unstable changes in vibration acceleration values. After that, the cutting process is stabilized. Dynamics of changes in vibration acceleration signal can be traced based on the runRMS value (Figure 2b). As we can see, the value of runRMS is constantly changing when conventional cutters are used that shows continuous variation of cutting conditions (lack of process stability). Skiving cutters provide runRMS ~2.5, which corresponds to the vibration acceleration ~5 m/s^2.

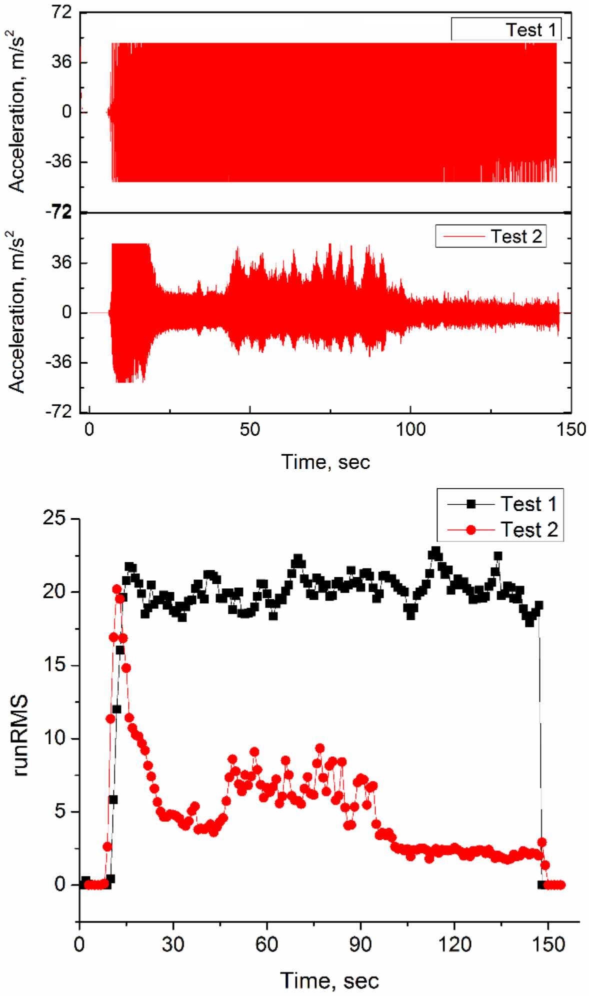

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Figure 2. Measurement of vibration acceleration (a) and runRMS (b) when using conventional cutters (test 1) and skiving cutters (test 2)

Figure 3 shows graphs of changes in AE energy and median frequency when working with the cutters under test. As it can be seen in the graphs, the value of AE energy and median frequency with conventional cutters is significantly higher than that with skivings.

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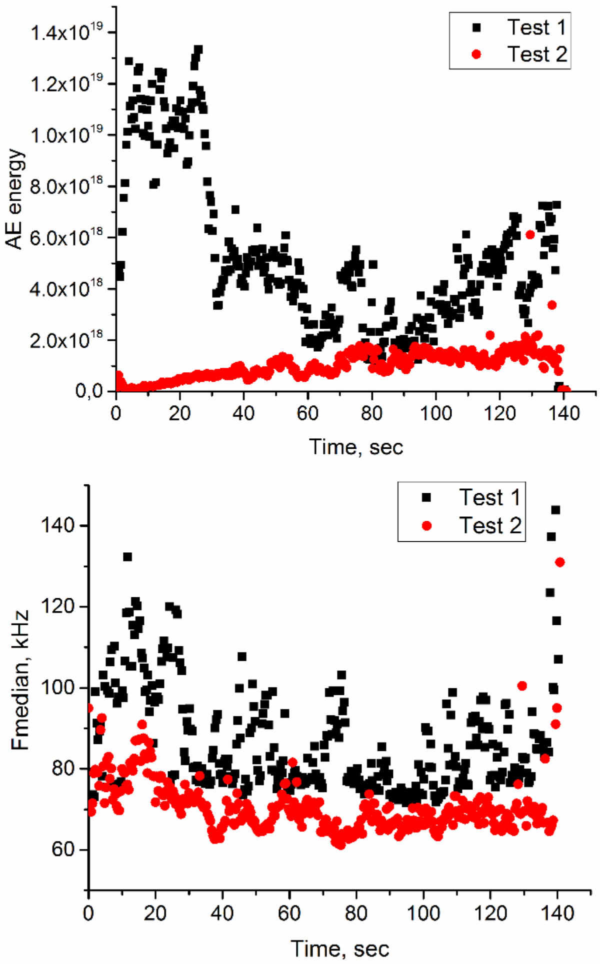

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Figure 3. Changes of AE Energy (a) and F median (b) with conventional (test 1) and skiving (test 2) cutters

Graphs in Fig. 4 show the correlation of median frequency and AE energy. As we can see, when using a conventional instrument two groups of AE signals are recorded. The first group (a large number of signals) has lower energy and the median frequency range of 75-110 kHz. The other group of signals (fewer signals) has great energy and median frequency range of 75-135 kHz. When working with skiving cutters, we observe only one group of signals with low energy and median frequency range of 60-95 kHz.

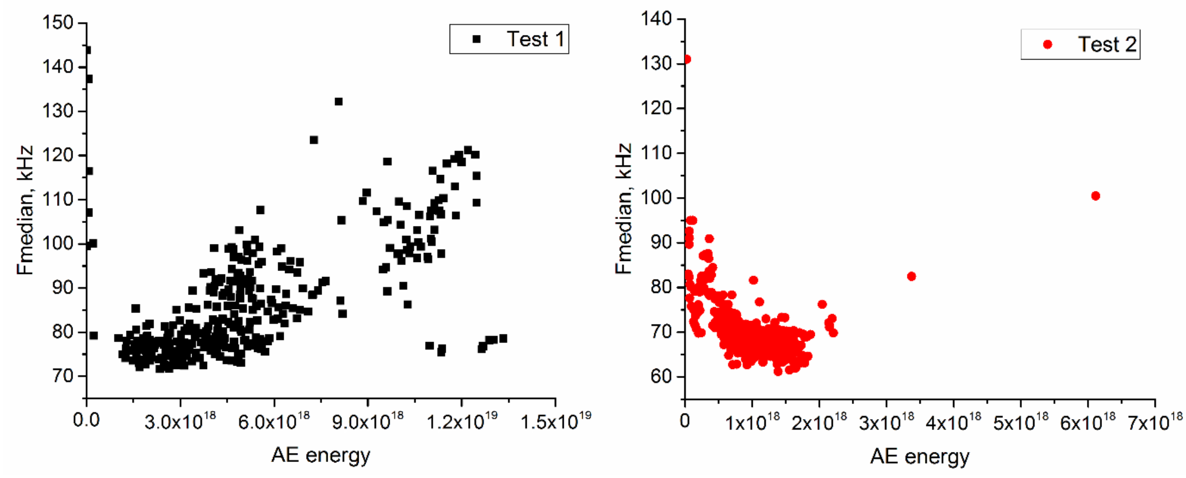

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Figure 4. Correlation of Fmedian and AE Energy for conventional cutters (a) and skiving cutters (b)

Figure 5 shows pictures of the workpiece surface after machining with conventional (Figure 5a) and skiving cutters (see. Figure 5b), as well as their 3D profile. As a result, surface roughness analysis found that after conventional machining a Sa value was 14.7 µm, and after machining with skiving cutters Sa was 1.32 µm. A much lower roughness obtained after machining with skiving cutters is due to the lower vibration level. Also the lower roughness can be the result of a fundamentally different nature of the contact interaction of the workpiece with the skiving cutter. We believe that alongside with cutting skiving cutters inserts perform smoothing action on the surface of the workpiece, thereby smoothing irregularities and reducing roughness.

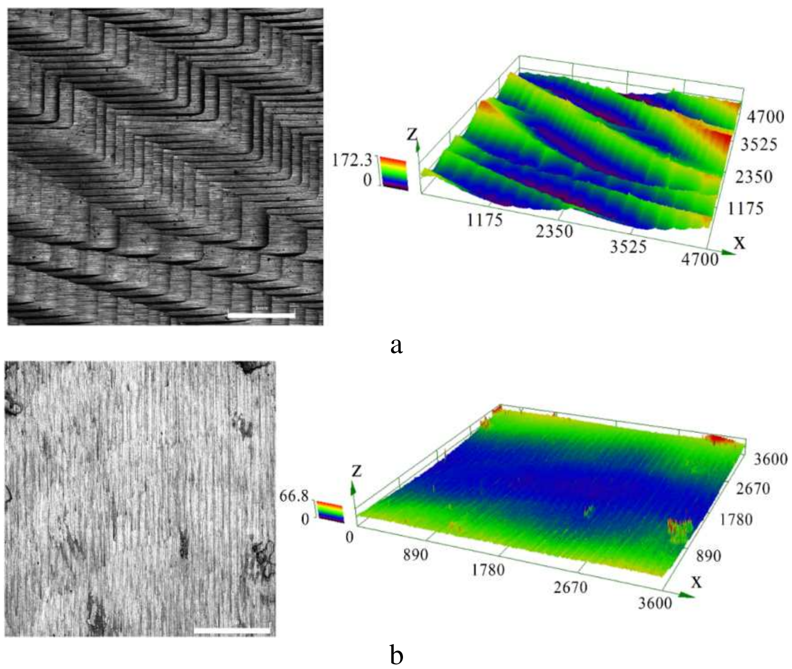

Figure 5. Workpiece surface after conventional (a) and skiving machining (b)

4. Conclusion

On the basis of the carried out experimental studies it may be concluded that the use of acoustic emission and vibration sensors makes it possible to assess the dynamics of a boring process under conditions of low stiffness of the processing system using conventional and skiving cutters. The results prove that a higher level of vibration corresponds to greater energy and median frequency of the acoustic emission. These findings are confirmed not only by the analysis of the dependencies of AE and vibration signals, but also by the analysis of surface relief topography.

Having compared products machined with conventional and skiving cutters, we found that the use of skiving cutters reduced the overall level of vibration when boring under the conditions of low stiffness processing system. Furthermore, the workpiece machined with a skiving cutter has the surface roughness 11 times lower than that of the workpiece machined with a straight-turning cutter with cutting-edge angle of 60°. Consequently, we can recommend the use of skiving cutters for boring operations.

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