Machinability metallic materials estimation based on acoustic emission of turning

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Abstract. An experimental study of the possibility of using the acoustic emission signal during turning to assess the machinability of steel by cutting has been carried out. According to the results of previous studies, it has been shown that the use of the total acoustic energy of the cutting process to assess the machinability does not have sufficient resolution. The article presents the results of measurements of the acoustic emission signal in comparison with the results of measuring the tool wear during resistance tests. A group of samples of six steels with a known chemical composition and mechanical properties were used as materials. The group includes steels that differ a priori in machinability and steels whose machinability cannot be predicted in advance. Endurance tests were carried out for face turning with a tool made of high-speed steel with a variable cutting speed. The maximum height of the wear area in the direction perpendicular to the cutting edge was used as a criterion for machinability. The acquisition of the acoustic emission signal was carried out by a broadband sensor built into the tool holder with a preamplifier of 60 dB and a bandwidth of 50...1000 kHz. The integral energy characteristic of the RMS signal is used as a criterion for predicting the processability. As a result of the experiments, it was found that the use of an acoustic emission signal has a good resolution in assessing the machinability by turning steels.

1. Introduction
In modern conditions in machine-building industries, the ability to quickly and efficiently vary production parameters is becoming increasingly important. Production flexibility comes first - the ability to quickly adapt to changing conditions.

One of the variable production factors is the material to be processed. Replacement of material can be caused by both a special order and organizational and economic factors, for example, replacement of a supplier.

The tasks of ensuring the necessary structural characteristics of a part made of a new material can be solved analytically on the basis of the passport characteristics, chemical composition and the results of standard tests. In contrast, the machinability of a new material cannot be determined so easily and requires special methods.

The use of acoustic emission when cutting metals, and, in particular, for evaluating machinability is developing in the areas of diagnostics [1, 2] and process control in real time [3, 4].

One of the examples of the use of acoustic emission for evaluating the machinability of cast iron is shown in table 1 [5].
As a criterion, the author used the value of the relative change in the acoustic energy $E$ released per unit of cutting path. For comparison, we used the relative change $C$ of the consumption of metal-cutting tools during the processing of experimental and serial heats in production conditions. Ultimate tensile strength $\sigma_w$, hardness HB and elongation at break $\delta$ are indicated as mechanical properties.

Table 1. Microstructure and mechanical properties of the investigated cast iron samples.

| Fuse        | Microstructure | Mechanical properties | $E$ | $C$ |
|-------------|----------------|-----------------------|-----|-----|
|             | Perlite        | Ferrite               | Graphite                                                                 |
| Serial      | Lamellar       | 100%                  | Vermicular + globular (45%)     | 280 | 190 | 1   | 1.4 |
| Experienced |                | 70%                   | Vermicular + globular (45%)     | 630 | 207 | 5   | 1.5 |
| 1           |                | 80%                   | Vermicular + globular (40%)     | 630 | 229 | 4   | 2.14| 5   |
| 2           |                | 85%                   | Vermicular + globular (22%)     | 540 | 222 | 2   | 2.77| 7   |

Note that in this case, the ranking of the four investigated cast irons by the energy parameters of acoustic emission did not make it possible to distinguish between experimental melts 1 and 2 - the same relative energy of the acoustic signal was obtained for them. Considering that with an increase in hardness the machinability deteriorates and that vermicular graphite is processed worse than globular, the correct (corresponding to the results of production tests) separation of pairs 1 and 2 of experimental heats can be performed on the basis of the mechanical properties and structure of the material: according to table 1, the first experimental melt it is processed better than the second, since it has a lower hardness and contains less vermicular graphite.

The given example shows the insufficient resolution of the method for evaluating the processability from the signal of the acoustic emission evaluation. This is possibly due to the fact that the total acoustic energy of cutting was used as a criterion, including the low-frequency region noisy with signals from the equipment mechanics.

The use of modern acoustic emission sensors and computer processing of the results make it possible to perform measurements with greater bandwidth selectivity. In this work, a study of the resolving power of the method for evaluating the machinability based on the acoustic emission signal during steel turning has been carried out.

2. Materials, tools and methods

During the experiments, a system for recording acoustic emission during cutting was used [6]. The system consists of a subsystem for converting acoustic vibrations (acoustic emission sensor), a transmission subsystem (preamplifier, analog-to-digital converter), and a control subsystem (software that provides control of the ADC, viewing and saving information). The conversion subsystem is characterized by the frequency range and amplitude-frequency characteristic of the sensor, the location of the sensor relative to the cutting zone, and the level of uninformative acoustic component from the equipment operation. The transmission subsystem is characterized by the effective frequency range of the preamplifier (analog filter), ADC settings, and the length of the wire from the sensor to the preamplifier. The characteristics of the control subsystem are selected in such a way as to provide the best information content for the given technological setup schemes and cutting conditions, the characteristics of the conversion and transmission subsystems. Therefore, the method of relative testing is used - with the processing of all compared samples in one series of experiments on the same settings.

For experimental studies, we used samples of steels 18Kh1G1FR, 20Kh1G1F, 20Kh1G1R, 30KhGSA, 40KhGNM, 20Kh1G1FR in the form of round bars $\varnothing$ 50. The nomenclature of samples was chosen so that there would be steels that a priori differ in machinability (30KhGSA and 40KhGNM) and a group of four experimental low-carbon carburized low-alloyed nickel-free steels, the machinability of which is approximately at the same level and is unknown in advance.

The chemical composition and hardness HB 5/750/20 of the studied samples are shown in Table 2.
Table 2. Chemical composition and hardness of the investigated samples.

| Parameter | Brand | 18Kh1G1FR | 20Kh1G1F | 20Kh1G1R | 30KhGSA | 40KhGNM | 20Kh1G1FR |
|-----------|-------|-----------|-----------|-----------|---------|---------|-----------|
| Hardness  |       | 173       | 178       | 160       | 233     | 194     | 168       |
| C (%)     |       | 0.18      | 0.19      | 0.21      | 0.33    | 0.4     | 0.19      |
| Si (%)    |       | 0.3       | 0.33      | 0.34      | 1.11    | 0.32    | 0.27      |
| S (%)     |       | 0.018     | 0.022     | 0.028     | 0.004   | 0.026   | 0.029     |
| P (%)     |       | 0.012     | 0.013     | 0.014     | 0.022   | 0.013   | 0.019     |
| Cr (%)    |       | 1.25      | 1.27      | 1.2       | 0.91    | 0.7     | 1.19      |
| Ni (%)    |       | 0.13      | 0.14      | 0.14      | 0.14    | 0.77    | 0.09      |

To obtain reference values of machinability, endurance tests were carried out in face turning at variable speed. As a cutting tool, plates were made of high-speed steel R6M5F3. When turning, a straight through holder is used to set the insert. Geometrical parameters - rake angle 0°, clearance angle 12°, main and auxiliary angles in the plan 45°.

The estimated parameter is the amount of wear h (the maximum height of the wear chamfer in the direction perpendicular to the cutting edge). During face turning on a reverse rapid traverse, the cutter is not retracted from the machined surface, as a result of which increased wear along the top hv is excluded from measurements (figure 1).

Figure 1. Schematic for measuring wear.

To control the amount of wear, an MBS-10 microscope with an MU500 eyepiece camera was used.

Cutting mode during turning - processing diameter D = 50...22mm, spindle speed n = 400 rpm, cutting speed V = 63...28 m/min, cutting depth t = 1mm, feed per revolution S = 0.085 mm/rev.

The placement of the acoustic emission sensor during turning is performed on the holder with the preservation of the same setup as in the resistance tests. A broadband sensor with a preamplifier of 60 dB and a bandwidth of 50...1000 KHz was used.

For data collection, the Advantech PCI-1714UL board and specialized National Instrument software were used. Removal mode - sampling frequency 5MHz, recording interval length 1s, pause between intervals 0, number of intervals 10...50, depending on the duration of the tool's working stroke.

3. Results and discussion

The results of resistance tests during turning (table 3) indicate that the highest specific wear (the lowest machinability) occurs when processing steel 30KhGSA, the lowest when processing steel 20Kh1G1FR.
Table 3. Results of resistance tests.

| Brand          | Number of machined ends | Wear, \(h\) (mm) | Specific wear, \(h_c\) (\(\mu m/\end{end}) |
|----------------|-------------------------|-------------------|---------------------------------------------|
| 18Kh1G1FR     | 80                      | 0.31              | 3.875                                       |
| 20Kh1G1F      | 80                      | 0.26              | 3.25                                        |
| 20Kh1G1R      | 80                      | 0.12              | 1.5                                         |
| 30KhGSA       | 60                      | 0.30              | 5.00                                        |
| 40KhGNM       | 80                      | 0.15              | 1.875                                       |
| 20Kh1G1FR     | 80                      | 0.10              | 1.25                                        |

The integral energy characteristic of acoustic emission signals RMS is calculated by the formula:

\[
RMS = \frac{1}{n} \sum_{j=1}^{n} \sqrt{\frac{1}{F_s \cdot \tau} \sum_{k=1}^{F_s \cdot \tau} (x_k - \bar{x})^2},
\]  \hspace{1cm} (1)

Where: \(n\) – number of signals; \(F_s\) – sampling frequency, Hz; \(x\) – instantaneous amplitude value of the signal, \(V\); \(\tau\) – signal duration, \(s\).

The relative machinability \(M_r\) of the investigated materials was calculated in the range from 0 to 1 as the reciprocal of the tool wear rate \(h_c\) when processing the corresponding material.

\[
M_r = \frac{h_c^{\text{min}}}{h_c},
\]  \hspace{1cm} (2)

Where: \(h_c^{\text{min}}\) – minimum specific wear among the investigated materials.

Obviously, just like the amount of tool wear, the integral energy characteristic of acoustic emission signals RMS and hardness HB are inversely related to machinability, therefore their relative values \((RMS)_r\) and \((HB)_r\) are calculated using formulas similar to formula 2.

The strength and direction of the influence of alloying elements on machinability were estimated using the correlation coefficient. The results of pairwise comparison of the content of alloying elements (table 2) of the relative workability calculated by formula 2 are shown in figure 2. It can be seen that for the materials under study, the sulfur content has a significant direct relationship with the workability, the silicon content has a less pronounced, but also significant, inverse effect on workability.

Figure 2. Coefficient of correlation between the content of alloying elements and machinability.

Thus, the relative content of silicon \(Si_r\) is calculated by analogy with formula (2), the relative content of sulfur \(S_r\) – inverse proportion:
$$S_r = \frac{S}{S_{\text{max}}}$$

Where: $S_{\text{max}}$ – maximum sulfur content in the studied samples.

The relative parameters of the investigated materials are presented in table 4.

| Brand       | $M_r$ | $HB_r$ | $Si_r$ | $S_r$ | $RMS_r$ |
|-------------|-------|--------|--------|-------|---------|
| 18Kh1G1FR   | 0.32  | 0.92   | 0.90   | 0.62  | 0.27    |
| 20Kh1G1F    | 0.38  | 0.90   | 0.82   | 0.76  | 0.53    |
| 20Kh1G1R    | 0.83  | 1.00   | 0.79   | 0.97  | 0.65    |
| 30KhGSA     | 0.25  | 0.69   | 0.24   | 0.14  | 0.13    |
| 40KhG1NM    | 0.67  | 0.82   | 0.84   | 0.90  | 0.60    |
| 20Kh1G1FR   | 1.00  | 0.95   | 1.00   | 1.00  | 1.00    |
| Correlation coefficient | 0.62 | 0.59 | 0.83 | 0.93 |

The experimental results show that the correlation with the machinability determined from the tool wear $M_r$ for the relative integral energy characteristic of the acoustic emission signal $RMS_r$ is significantly higher than for other investigated relative parameters.

4. Conclusions
As a result of the studies carried out, it has been experimentally shown that using the integral energy characteristic of the acoustic emission signal RMS, the relative machinability of steels can be determined much more accurately than by strength characteristics or chemical composition.

The use of acoustic emission for evaluating machinability has a resolution close to the determination of machinability by tool wear with much lower labor intensity and material consumption.

References
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