Spectral characteristics of noise during hardening of welds of rod structures

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Abstract. The article deals with the task of forming a noise spectrum during the processing of parts by the method of surface plastic deformation using a ball-core hardener. Processing using this method is used to harden both flat and curved surfaces, create compressive residual stresses, smooth out cavities, apply a regular microrelief on friction pairs, and also to process welds. The treatment process is accompanied by a loud noise, which mainly exceeds the standard values in the working area of the operator. The results of experimental studies of the spectra of noise and vibration to ensure acoustic safety are presented. The evaluation of the formation of the sound field in the working area of the sources considered. In the course of experimental studies, hazardous and harmful production factors arising from the implementation of machining welded structures were identified. The results of measuring sound pressure levels at the operator’s workplace during compressor operation and the processing of welds of channels and angles are presented. The obtained data are compared with theoretical conclusions about the laws governing the formation of noise spectra and the contribution of noise sources to the sound field at the operator’s workplace.

1. Introduction

In modern production, one of the important tasks is to increase the product life cycle, which is ensured by improving the performance properties of the most critical parts. When solving these problems, methods of processing parts by surface plastic deformation (SPD) are used, and, from an economic point of view, the methods of local hardening of parts areas on which stress concentrators are located are most beneficial.

The ball-rod strengthen (BRS) is a new method designed for surface treatment of parts surface plastic deformation [1]. The universal device allows processing not only flat surfaces but also surfaces of curved shapes with small elevation differences. Impact processing methods and materials research are widely used in engineering, construction, geo-technology [2-5]. The hardener contains the packaging of indenters, which are steel rods with spherical sharpening on one of the ends 2, installed in the housing 3 using a collet clamp, contains several layers of hardened steel balls 4, on which shock-wave action is performed using the striker 1 (figure 1).
A blockhead driven by a pneumatic hammer transmits shock impulses to the end of the indenter rods through several layers of balls. Indenters, in turn, with spherical tips have a shock effect on the surface of the workpiece.

**Figure 1.** Diagram of the device for ball-rod hardening: 1 - pneumatic hammer impactor, 2 - packing of indenter rods with spherical sharpening, 3 - reinforcer body, 4 - steel balls, 5 - workpiece, 6 - collet clamp, 7 - elastic element

The layers of steel hardened balls provide the flexibility of processing within certain limits by creating the possibility of rounding the shaped surface of a part with a package of rods with spherical tips. Due to this, BRS is used to harden both flat and curved surfaces with a small difference in height, creating a favorable picture of residual stresses in the surface layer of the workpiece. Such processing can be used to strengthen the welded joints to create a correct and partially regular microrelief. Subsequent tests of the degree of hardening are carried out according to the method [6-8].

One of the advantages of this device was the possibility of local hardening of the surface areas of the part containing stress concentrators, as well as the refinement of the attachment points for large-sized parts of the device for SPD. Also, the creation of regular and partially-regular micro-reliefs when fixing the device in the tool holder of lathes, or on the spindle of milling machines, allowing to provide the constant feed rate of the device.

However, it should be noted that in modern production it is important to ensure acoustic safety during percussion machining of machine parts. It is known that the protection of workers from exposure to hazardous and harmful production factors is relevant. Sanitary standards limiting the intensity of noise and vibrations are continually being tightened. This is because noise is an always acting factor of high intensity, affecting both the deterioration of the health of workers (the emergence of occupational diseases) and the decline in labor productivity and in many cases the quality of the parts being processed. Therefore, noise reduction is an urgent task, for the solution of which it is necessary to produce the corresponding material costs. When designing new technological processes and creating equipment for their implementation, the task of reducing noise and vibrations to acceptable values is one of the most important.

As a result of numerous studies, it was established that with ball-rod hardening, noise significantly exceeds the standard values. With this type of processing, noise is the only parameter that does not meet sanitary standards. This leads to the need to conduct a comprehensive study of the formation of noise and vibrations with ball-rod hardening, the purpose of which is to develop technological processes and devices that eliminate the harmful effects on the body of workers.
To reduce noise of process equipment numerous methods of sound insulation are used, as well as vibration absorption [9,10]. For vibration absorption, coatings are used, which consist of several layers of individual plates that can be glued onto the surface of metal parts.

For the application of other coatings, special mastics are used, applied to the surface of parts by various methods. Sound-absorbing and vibration-absorbing polymeric materials must have unique properties, including sufficient rigidity, which makes the use of rubbers and soft polymeric materials ineffective.

Reinforced coatings are also often used, in which the soft vibration-absorbing plates are located between the metal sheets, which give the device sufficient rigidity. Methods for calculating multilayer protective coatings have been developed, which provide reliable convergence with experimental data in a wide frequency range.

However, in the field of mechanical assembly production, a significantly smaller number of studies on noise and vibration reduction were carried out than in construction and transport. The most significant development received questions "machine acoustics." They consider the processes of noise generation of machine tools for various types of processing, as well as their main components. A methodology has been developed for engineering calculations to predict the noise and vibrations of equipment at the design stage, which makes it possible to evaluate the contribution of individual nodes to the noise generation processes and find ways to reduce noise levels to sanitary standards. Various devices and methods for noise reduction have been developed for various lathe assemblies, as well as for the workpiece-cutter zone. Due to the particular selection of bearings, taking into account the permissible vibration level and an increase in the dissipative characteristics of the housing parts. The research results received widespread adoption for lathes.

2. Materials and methods

When conducting experimental studies, the BRS device was attached to the spindle of the milling machine (Figure 2).

![Figure 2](image)

**Figure 2.** Fastening the BRS on a milling machine: 1 - milling machine, 2 - BRS, 3 - reinforced part, 4 - compressed air supply

In the present work, for the experimental studies, the pneumatic hammer KPM-14M was used as a drive. The acoustic system of the equipment for the study objects includes the following sources of noise: a hardener; products on which the hardening of welds; carrier system of the equipment itself.

Taking into account the peculiarities of the force effect at BRS, it can be assumed that the dominant noise sources that create excess over the limiting spectra are a hardener and, in particular, a product with hardened welds. This assumption is confirmed by the existing studies of vibroacoustic characteristics in rods and compound structures [11,12].

Considering the overall dimensions of the hardener and the product, the models of noise sources are investigated. Taking into account the methods of their installation based on these works, the following dependencies were obtained for calculating sound pressure levels.
\[ L = 20 \log v_K + 40 \log D^{2k-1}_{l_y} - 20 \log z + 14.2 \]

where \( v_K \) is the oscillation velocity of the body of the hardener on its own vibration modes, m/s; \( D \) - case diameter, m; \( l_y \) - length of the body of the hardener, m; \( z \) is the distance from the noise source to the calculated point, m; \( k \) - coefficient characterizing the natural frequencies of the noise source.

At \( k_0 h < 1 \)

\[ L = 20 \log B \left( \frac{2k-1}{l} \right)^4 + 20 \log \frac{E J}{\rho} 20 \log z + 20 \]

(2)

At \( k_0 h \geq 1 \)

\[ L = 20 \log B \frac{k-1}{l} + 5 \log \frac{E J}{\rho} 20 \log z + 11.5 \]

(3)

where \( h \) is the length of the weld, m; \( l \) - product length, m; \( E \) is the modulus of elasticity of the material, Pa; \( J \) - moment of inertia of the product, m\(^4\); \( \rho \) is the density of the material of the product, kg/m\(^3\); \( k_0 \) is the wave number, 1/m; \( B \) is a function that takes into account the amplitude-phase distribution of the oscillation velocity over the surface of the source, can be determined

\[ B = \int_0^1 v_K(z) \exp - ik_0 z \, dz . \]

Thus, for the theoretical determination of sound pressure levels, it is necessary to obtain the dependences of the oscillation velocities of sources at their own frequencies as a function of time and coordinates.

Elements of the bearing frames of cranes, electric locomotives, diesel locomotives, etc. represent a channel, the I-beam profile, angles.

According to the well-known relation \( \delta \frac{l}{l} \leq 0.1 \), where \( \delta \) is the wall thickness of the cross-sectional profile, m; \( l \) - the characteristic size of the cross-section (width or height of the profile), m.

To measure the octave sound pressure and vibration levels, we use a standard method of workplaces assessment for working conditions, which has an accreditation certificate.

This paper solves the problem of performing sanitary norms of noise in the operator's working area; therefore, octave sound pressure and vibration levels were measured in the normalized sound frequency range of 31.5-8000 Hz.

The overall speaker system includes the following sources: a compressor, a machine carrier system, a hardener, and the part itself on which the hardening of welds is performed.

To assess the contribution of the above sources to the formation of the sound field in the working area of the operator, the measurement of the octave sound pressure levels was carried out in the following sequence: 1) only the compressor works; 2) working mode when hardening welds.

It should be noted that the noise of the machine itself in the idle mode was not measured, because actually drive systems do not work. Indeed, the supply of products is carried out on the roller conveyor, and the ball-rod hardener receives the drive from the compressor. Therefore, on the carrier system of the machine, the levels of vibration excited from the most hardened part were measured, as well as the
vibration on the body of the hardener. Experimental studies were conducted by the Assistant Total noise and vibration analyzer (serial number 3049410, accuracy class 1, with a pre-amplifier PU-01 (049010) using a microphone capsule Mk233 (serial No. 719) with a frequency range of measurements from 2 to 40000 Hz. Measurements of vibrations in the seventh, eighth and ninth octaves were measured at VSHV-003-M3 (at geometric average frequencies of 2000, 4000, 8000 Hz).

3. Results and discussion
The measurement results (Figure 3) showed that the sound pressure levels of the compressor itself exceed the maximum permissible values in the fifth octave (with a geometric mean frequency of 500 Hz) by 5 dB, and in the sixth (with a geometric mean frequency of 1000 Hz) by 4 dB. Also, in the fourth and seventh octaves (with geometric average frequencies of 250 and 2000 Hz, respectively), the sound pressure levels below sanitary standards are only 2 dB.

![Figure 3. Noise spectra: 1) compressor (L1), 2) limiting spectrum (L2)](image)

In the operating mode, the hardening of welds is performed for parts such as channels and angles of various lengths and flanges width. The microphone is installed in the workplace. Magnetic mount piezo sensors were mounted on the part, the body of the reinforcer, the table and the frame of the machine. It should be noted that the vibration levels at the operator’s workplace are much lower than the sanitary norms and therefore are not carried out in this work. Vibrations on the parts, the hardener, and the carrier system of the machine were measured in the normalized sound frequency range, i.e., in the range of 31.5-8000 Hz.

The measurement results showed that for parts of the same type, the patterns of formation of noise spectra in the working area and the vibration spectra of all elements of the overall acoustic system (parts of the hardener and the carrier system of the machine itself) are almost identical, and only the levels of the spectral components are different. Therefore, the results of experimental studies are given for the most noise-vibro-active situations of the process of SHS hardening of welds [13] and allow you to use the principles of vibration absorption given in [14,15].

The results of measuring the noise spectra during the hardening of welds of channels and angles are shown in figure 4-6. Since the channels of various geometrical dimensions and, accordingly, of different moments of inertia, are subjected to hardening, in figure 4 shows the dispersion field for hardening channels, fastened according to the schemes. The analysis of the spectral composition is shown for the noisiest octopus situations. It should be noted that the difference in sound pressure levels during the hardening of channels of various sizes is 3-7 dB in the region of middle and high frequencies (0.25-8 kHz).

In all cases of the SHS process, the noise spectra have a pronounced high-frequency character [16]. Although the excess of sound pressure levels over the maximum permissible values begins with the fourth octave (geometric mean frequency of 250 Hz), which refers to the mid-frequency range, the maximum sound pressure levels are fixed in the sixth to ninth octaves (geometric mean frequencies of
1000-8000 Hz). Maximum Sound pressure levels in the above range occur when machining iron bar along channel a and the maximum value also when machining bar b.

![Figure 4](image1.png)

**Figure 4.** The noise spectra for the BRS welded joints of channels: 1) hardening according to scheme a, 2) hardening according to scheme b, 3) limit spectrum.

Similar results were obtained when hardening the angles of various geometrical dimensions and the difference in sound pressure conditions is 3-6 dB. The sound pressure levels during hardening of the angle bar are shown in figure 5

![Figure 5](image2.png)

**Figure 5.** Noise spectra during hardening of welds at the corners: 1) noise spectra during angle processing, 2) limiting spectrum.

As well as in the analysis of the spectra with the hardening of channels, in this case, the patterns were analyzed for the noisiest conditions.

The sound pressure levels during the hardening of welds occupy an intermediate position between the levels of sound pressure during the hardening of welds on channels. This is explained by the fact that for the options considered, the stiffnesses of the technological system differ. Indeed, the most rigid is the technological system when installing the channel according to the scheme "a". The rigidity of the system when installing the angle is higher than when processing the channel according to the “b” scheme. Measurements of vibration spectra are shown in figure 6.
Figure 6. Vibration spectra when machining with BRS: 1) channel when installed according to the scheme “a”; 2) channel when installed according to the scheme “b”; 3) angle; 4) reinforcer; 5) on the machine table; 6) on the frame.

Thus, the research results confirm the validity of the theoretical approach to the description of the laws of the process of noise formation. The dominant sources of noise, which create an excess of sound pressure levels in the working area of the operator over the maximum permissible values, are the workpiece and the reinforcer. The magnitude of the excess sound pressure levels in the working area of the operator is shown in Figure 7.

Figure 7. Exceeding sound pressure levels: 1) when operating one unit, 2) in the area of hardening of welds.

In the workplace of the operator when operating one installation, the excess sound pressure levels range from 8 to 28 dB. Attention is drawn to the regularity of the “unevenness” of increasing the excess of sound pressure levels over the frequency range. For example, when moving from 4 to 5 octaves, the sound pressure level increases by 18 dB.

In the transition from 5 to 6 octaves and from 6 to 7, the increase in sound pressure levels is 5 and 3 dB (respectively). In the eighth octave, the increase in sound pressure level is 12 dB, and the ninth octave is 5 dB.

With the simultaneous operation of several hardening installations of welds, the excess of sound pressure levels above sanitary standards should be further increased by 4-5 dB, which will be from 15 to 33 dB.
4. Conclusions
The obtained data are confirmed by the correctness of theoretical conclusions about the laws governing the formation of noise spectra and the contribution of noise sources to the sound field at the operator’s workplace. The maximum value of vibration levels is observed directly on the workpieces. The vibration levels of the hardener are 10–12 dB lower in the low and medium frequency range 31.5–500 Hz and 7–10 dB in the high frequency range 1000–8000 Hz. It should be noted that the nature of the vibration spectrum on the workpieces and the hardener corresponds to the noise spectra.

It should be noted that measurements of vibration levels at the operator’s workplace are significantly lower than the maximum permissible values and therefore are not given in this work.

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