Surface treatment by combined processes of cutting and magnetodynamic rolling

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Annotation. Technologies for mechanical treatment of the inner cylindrical surface of parts using combination tools have a number of advantages over traditional methods. The combination of two technological processes in one operation (cutting and magnetodynamic rolling) leads to increased production efficiency, reduced cost of parts manufacturing and improved quality characteristics of the machined surface. The developed designs of tools for combined treatment with various magnetic modules (with radial and axial arrangement of the magnetic system) have a number of specific features and advantages, which makes it possible to expand the field of application of the combination tools.

1. Introduction
Methods of surface plastic deformation have been widely used in industry [1–4]. Technologies of surface treatment by combining the cutting operation and the method of surface layer modification by magnetodynamic rolling are used to obtain high performance surfaces and reduce the time required to manufacture parts, which leads to increased productivity and improved competitiveness of products.

The technology of finishing and strengthening treatment of holes using magnetodynamic modules has a number of advantages over classical methods of treatment of internal cylindrical surfaces, e.g. it helps obtain high-level quality characteristics of the surface layer of treated parts by improving durability as well as wear and corrosion resistance of the product in the shortest amount of time [5].

2. Results and discussion
The technology of surface treatment by combined processes of cutting and magnetodynamic rolling is used to perform finishing and strengthening treatment of holes in cylindrical parts such as cylinders, bushings, rings with a diameter of over 60 mm. The treatment is performed using a tool with boring and magnetic-dynamic modular components, which are mounted coaxially on a single mandrel. To carry out this technological operation (the combined treatment), the combination tool is preliminarily adjusted for the proper depth of cut taking into account the amount of allowance for finishing or semi-finishing (0.1 – 0.5 mm). For this purpose, a jig bush can be used. Cylindrical part 8 is fixed in a device preliminarily mounted on the machine table (drilling and milling machines) or in a chuck (lathes). Figure 1 shows a schematic diagram of the combined treatment.
Figure 1. Combined cutting and magnetodynamic rolling treatment technology.

The rotational motion $\omega$ in the range from 350 to 500 m/min is imparted to mandrel 5 fixed in the spindle (drilling and milling machines). In lathes, rotation is imparted to workpiece 8. The feed motion $S$ (0.02-0.16 mm/rev; 22.4-256 mm/min) is transferred either to the part or to the tool depending on the type of machine used for treatment.

Cutting module 1 includes cutting tool 2 for carrying out the cutting operation and ensuring the dimensional accuracy of the workpiece. Adjustment to the required diametrical dimension is performed using a boring head. Besides, cutting module 1 has a source of additional magnetic field 3 that carries out two tasks: it removes the chips formed during the boring operation from the zone deformed by the magnetic module and performs pre-magnetization of the deformation zone.

The magnetodeforming module is designed to perform finishing and strengthening treatment and contains a magnetic system with radially oriented magnetic field sources in the form of permanent cylindrical magnets 6 and a number of deforming balls 4. The deforming balls are freely located in the annular chamber (cavity) formed by two disks 7 and are set in motion by the joint action of centrifugal force and concentrated magnetic flux (energy). The balls perform oscillatory movements striking the surface of the workpiece at regular intervals [6, 7].

In order to intensify the process of the surface layer modification and increase the durability of the boring component of the tool, an additional speed of rotation in the direction coinciding with the rotation of the tool is imparted to the workpiece, which reduces the relative speed of the tool with respect to the workpiece. In this case, the boring speed is equal to the difference between the speed of rotation of the tool and that of the workpiece and can be reduced to 200-250 m/min, and the rotational speed of the rolling module can be increased to 500-1000 m/min. Composite materials modified by cubic boron nitride can be used as tool materials [8].

3. Materials, equipment and methods
The main requirement in critical machine parts manufacturing is to achieve the accuracy specified on the drawing. To determine the accuracy of the surface treatment technique by combined processes of cutting and magnetodynamic rolling, a statistical and computational method and advantages of statistical and probabilistic as well as computational and analytical methods of machining accuracy calculation were used.

A batch of 80 workpieces was used to conduct the experimental studies.
The parameters of the workpieces used in the experiments were as follows:

- dimensions \((D \times d \times l)\), mm – 120 \times 99.6 \times 50 mm;
- workpiece material: steel 20 (180–200 HB);
- hole surface roughness \(Ra\) 10.4–11.7 \(\mu m\).

For subsequent treatment, the batch of workpieces was divided into two parts, forty pieces each. The treatment of both batches of workpieces was performed on a HAAS ST-20Y machine.

The boring operation of the first batch of workpieces was carried out by means of a tool with a cutting module; the magnetodynamic module of the tool had been removed.

The second batch of workpieces was machined with a tool designed for combined treatment by cutting and magnetodynamic rolling (with both cutting and magnetodynamic modules).

Both batches were machined under the same conditions:
- cutting speed 703 m/min (frequency of rotation 2240 min\(^{-1}\));
- axial feed of the tool \(S\) = 20 mm/min;
- depth of cut \(t_c\) = 0.2 mm;
- the number of tool passes: 1;
- metalworking fluid: industrial oil 45.

The diameter of the machined parts was measured using a dial bore gauge with a graduation of 0.001 mm GOST 9244-75.

First, the tool was adjusted to achieve the desired geometry of the workpieces (tolerance range). The batches of workpieces were sequentially machined. After that, they were grouped according to the diametrical dimensions obtained, and the average value \(X_a\) of each corresponding interval and the frequency of repeated dimensions were calculated.

Based on the research results, a distribution plot of diametrical dimensions \(X\) versus the frequency of repeats \(\omega\) was created (figure 2).

To test the hypothesis of normal distribution, the Pearson Chi-Square and Kolmogorov goodness-of-fit tests were performed and the following values were obtained \(\chi^2_o=1.27; \lambda_o = 0.317\). The goodness of fit criteria for the second batch of parts were as follows: \(\chi^2_o= 0.7; \lambda_o = 0.17\). Since the observed criteria \(\chi^2_o\) and \(\lambda_o\) are less than the critical values, there is no reason to reject the hypothesis of a normal distribution [9].

The experimental studies have demonstrated that the diametrical dimensions of the workpieces obtained after machining follow the Gaussian distribution. After the parts are machined with the combination tool, they are still within the tolerance range.
1 – diametrical dimension distribution plots after boring; 2 – diametrical dimension distribution plots after combined cutting and magnetodynamic rolling treatment

- theoretical curves;
- empirical curves

**Figure 2.** Study of accuracy after boring and after combined cutting and magnetodynamic rolling treatment.

After performing experimental studies, graphs of the dependence of the change in the original size of the part on the rotational speed of the tool was created after the operations of boring and combined cutting and magnetodynamic rolling performed with a tool with radially oriented magnetic field sources (figure 3).

Frame 2

1 – boring of steel 20 (180-200 HB) performed by means of cutting module; 2 – treatment performed by means of combination tool designed for cutting and magnetodynamic rolling with radially oriented magnetic system of steel 20 (180-200 HB)

**Figure 3.** Dependence of change in original dimension of part on rotational speed of tool.
4. Conclusions
Summing up the results, it can be concluded that the change in the original dimension of the part occurring as a result of mechanical treatment by combined processes of cutting and magnetodynamic rolling is equal to the sum of two values, the amount of the allowance to be removed by the cutting module and the amount of the allowance to be modified by magnetodynamic rolling, and lies within the range 18-20 μm, which can be used to provide recommendations on calculation of the allowance for the combined treatment.

The developed technology of surface treatment by combined processes of cutting and magnetodynamic rolling provides the following advantages:

- surface roughness $Ra$ decreases significantly (from 10.4-10.7 μm to 0.2-1.7 μm);
- the surface layer is strengthened to a depth of 0.05-1 mm;
- the original diametrical dimension of the part is changed during combined cutting and magnetodynamic rolling treatment;
- treatment of parts with hardness up to 50 ... 55 HRC can be performed;
- machining efficiency is increased by a factor of 2-5.

References

[1] Nagorkin M N, Fedorov V P and Kovalyova E V 2019 Process control of forming the surface quality parameters of parts according to a desired law by methods of surface plastic deformation Int. Conf. on Aviamechanical Engineering and Transport AviaENT 2019 188 258–263
[2] Dovgalev A M, Sviurepa D M and Ryzhankov D M 2008 Classification of tools for magnetodynamic strengthening Belarusian-Russian University Bulletin 2 30–38
[3] Pilipenko O V, Golenkov V A, Radchenko S Y and Dorohov D O 2018 Numerical mathematical Simulation of Penetration of Indenters of Different Shapes During Strengthening Machine Parts via Local Loading of Deformation Zone Int. Symp. on Engineering and Earth Sciences ISEES 2018 177 pp 568–573
[4] Gryadunov I M, Golenkov V A, Pilipenko O V and Radchenko S J 2017 Hardening treatment by plastic deformation under conditions of the integrated local loading of a deformation zone Int. Journal of Applied Engineering Research 2017 12 pp. 11094-11100
[5] Dovgalev A M and Sviurepa D M 2014 Technology of magnetodynamic rolling and its implementation in mechanical engineering Proc. Materials, Equipment and Resource-Saving Technologies (Mogilev, Belarus, 24–25 April 2014) (Mogilev: BRU) pp 10–15
[6] Sviurepa D M and Semionova A S 2019 Optimization of the number of magnetic field sources in tools used for combined processes of cutting and magnetodynamic rolling Proc. New materials, equipment and technologies in industry (Mogilev, Belarus, 24-25 October 2019) (Mogilev: BRU) p 40
[7] Sviurepa D M and Semionova A S 2019 Influence of methods of combined treatment by cutting and magnetodynamic rolling on surface roughness Belarusian-Russian University Bulletin 2 34–43
[8] Kudryashov E A, Smirnov I V and Khizhnyak N A 2018 Selection and evaluation of the efficiency of cutting inserts made of various cutting tool materials Int. Conf. on Aviamechanical Engineering and Transport AviaENT 2018 158 226–229
[9] Vadzinskij R N 2001 Probability Distributions Handbook (St.Petersburg: Science)