Forming conditions of complex-geometry profiles in corrosion-resistant materials

V V Maksarov, A I Keksin
Saint-Petersburg Mining University, 21 Line, St. Petersburg, Russia, 199106
E-mail: maks78.54@mail.ru; keksin.a@mail.ru

Abstract. This paper describes the results of research in forming the condition of geometrically-complex surfaces during processing blanks of corrosion-resistant material. It has been established that the most efficient solution for this issue is application of finishing in preliminary preparation of a cutting tool that is later used for production of the geometrically-complex surfaces. The preliminary stage in tool preparation allows not only improving the quality of the geometrically-complex surfaces in products manufactured of the corrosion-resistant material, but increasing the cutting tool durability, thus, justifying the engineering solutions of the authors. The article was prepared according to the State task (the project's number № 9.10520.2018/11.12)

1. Introduction
Corrosion-resistant steels find more and more applications in the modern power plant engineering. This is due to the fact that they have increased durability and corrosion resistance compared to other construction materials. However, despite increased resistance to various deformations, corrosion resistant steels have their disadvantage, namely, they are hard-to-machine. High viscosity, low thermal conductivity, propensity for coldhardening during the mechanical processing of this material lead to increased cutting force, intensive wear of cutting tools, resulting in low-quality surface finish of processed blanks.

One of complex processes where attaining necessary surface condition is difficult is inside threading, which in addition to hard-to-machine nature of the material is further complicated by curved spacial form of the thread surface. Inside threading is often performed with a thread tap that allow easy formation of inside thread profile, however, while using this tool it is very problematic to attain one of the most important surface condition indicators, surface roughness at $Ra \leq 1.6$ micron (for hard-to-machine materials).

Due to this, all the test performed by the authors of this research were aimed at attaining surface roughness of $Ra \leq 1.6$ micron in inside threads in corrosion-resistant steel blanks.

2. Materials and methods
One of possible ways to improve the quality of inside thread is preliminary treatment of contact surface of the cutting tool [1, 2, 3]. Usually, this process is performed with finishing operations [7, 9, 10], which have a positive impact on creating various conditions of the tool teeth contact surfaces [1, 2, 5, 6]. Their improved condition enhances performance properties of the cutting tool and facilitates its advantageous operation during the processing of machined goods.
Magnetic-abrasive finishing (MAF) has been selected as a finishing operation for thread tap preparation (Fig 1, a), which is that ferromagnetic abrasive powder compacted by magnetic field energy acts abrasively onto the die being processed (thread tap), at that, the latter is moved in the necessary manner: rotational, oscillatory and translational (if possible) [1-7, 9-10].

Selection of MAF was determined by wide possibilities of this method in the field of forming various conditions of thread tap contact surfaces. In works [2, 5], it is stated that using MAF as a finishing treatment of thread taps allows removing the previous defective layer in a rather short period of time (t = 60 ÷ 210 s) and forming a new strengthened one, all the while rounding the cutting edges to a necessary limits, as well as reducing the roughness of the cutting teeth contact surfaces. As an example, there are photographs of thread tap teeth contact surfaces before and after magnetic-abrasive polishing given in Figure 2 [5]. The noted features of the MAF process show advantages of this method in comparison with traditional finishing operations.

MAF of M16x2 mm threat taps has been performed on a specially developed bench (Fig. 1, b), located in the CNC Lab of the Department of Engineering, Saint Petersburg Mining University. The MAF device was based on a CNC milling machine that provides the processing with all the necessary movements. Conditions of thread tap preparation with MAF are given in the Table 1.

![Figure 1. Magnetic-abrasive finishing of a thread tap (a) and the device (b)](image)

![Figure 2. Thread tap teeth before (top row) and after (bottom row) the magnetic-abrasive finishing: a-b) the 4th tooth of the cutting section; c-d) the 6th tooth of the sizing section](image)

Table 1. Conditions of thread tap preparation with magnetic-abrasive polishing

| Preparation conditions | no.1 | no.2 | no.3 |
|------------------------|------|------|------|
| Δ, micron              | 160  | 250  | 315  |
| B, tesla               | 0.6  | 0.6  | 0.6  |
| t, s                   | 210  | 210  | 210  |
| 250  | 250  | 250  |
| 1.0  | 1.0  | 1.0  |
| 120  | 120  | 120  |
| 60   | 120  | 210  |

where Δ is a size of grain of the powder; B is a magnetic flux density in the operating space of the electromagnetic system, t is a duration of polishing.

Note.
The rotational speed of the blank (thread tap) in the operating space of the electromagnetic system \( n = 475 \) rpm; movement of the blank (thread tap) along the pole faces \( S = 120 \) mm/min; operating gap between the pole faces and the blank (thread tap) \( \delta = 1 \) mm. These parameters are constant.
After preparing the cutting tools with various MAF process factors, the threading of inside thread has been studied; the threading has been performed on a turning lathe, model Trens SN 32/750 under factory conditions. The processing was performed on blanks of corrosion-resistant material (metal thickness of 40 mm) grade 08X18H10T.

Roughness monitoring of inside thread profile sides of the blanks was performed with Hommel Tester T8000 profilograph and profilometer (an example of monitoring is shown in Fig. 3). The experimental data obtained on roughness of inside thread surfaces underwent statistical processing in Statistica 10 software.

3. Results and Discussion

As a result of the testing and statistical treatment of the experimental data, graphs were plotted reflecting dependency of the inside thread roughness value on condition of thread tap teeth contact surfaces (Fig. 4). Due to the fact that the condition is understood as the total of microgeometric parameters of the thread tap teeth contact surfaces, i.e., rounding radius of cutting edges and roughness of front, side and back surfaces of the teeth, and separating individual influence of each on these parameters onto roughness of inside threads appears impossible as they are simultaneously formed by the MAF, a decision was made to plot the graphic dependencies in the following way: values of thread roughness are plotted along the vertical axis, while the MAF process parameters that were changed when attaining various condition of teeth contact surface of the thread tap are plotted along the horizontal axis.

Analysis of the graphic dependencies allows for the following conclusions. Increase in powder grain size from 160 to 315 micron, magnetic flux density from 0.6 to 1.0 tesla and polishing time from 60 to 210 s when treating the taps with MAF corresponds to increased roughness of the inside thread profile when working on blanks of corrosion-resistant material grade 08X18H10T, from 0.73 to 1.42 micron as measured with the $Ra$ parameter. It should be noted, that the inside thread roughness for threads produced with thread taps untreated with MAF is $Ra = 1.77$ micron (Fig. 5). When using a MAF-treated thread tap, independent of variations in process factors in the studied range, that is, powder grain size $\Delta = 160 \div 315$ micron, magnetic flux density $B = 0.6 \div 1.0$ tesla and polishing time $t = 60 \div 210$ s, the thread roughness is reduced minimum by a factor of 1.25, thus, supporting the efficiency of application of this finishing method.

It is known [1, 2, 5-6], that after magnetic-abrasive polishing, item's performance characteristics are improved. However, despite improved performance, in particular durability of the cutting tool (thread tap) which was exhaustively studied by Yu. M. Baron [1, 2], it is good to know indirect influence of MAF onto thread roughness by varied formation of contact surface condition of thread tap's teeth. In this case, the result may be opposite, which is supported by the authors' research.
In [5] it was found, that over the studied range of the MAF process factors, i.e., $\Delta = 160 \div 315$ micron, $B = 0.6 \div 1.0$ tesla, $t = 60 \div 210$ s, not only roughness of the thread tap teeth contact surface decreases as $Ra = 0.09 \div 0.061$ micron and its microhardness increases $Hv = 766 \div 1505$ kgf/mm$^2$, but the cutting edges are blunted as well, which manifests as increased rounding radius $\rho = 26 \div 64$ micron. Despite positive influence of thread tap teeth contact surfaces formed by MAF onto the tool's durability [1, 2], there is a negative factor as well, manifesting as deteriorating surface roughness in threads produced with such thread taps in cases where the rounding radius of the tool's cutting edges is larger than the thickness of cut layer of a blank, $a < \rho$. It is caused by elastic deformation arising in the surface layer of the blank during cutting that has a deteriorating effect on formation of surface microrelief [8].

Further statistical processing of experimental data obtained in studying the formation of inside thread surface roughness as a result of action from thread taps processed with MAF allowed to reveal the influence of the cutting edge rounding radius as formed by various variants of MAF onto roughness of the thread profile side surfaces (the graphical dependencies are shown in Fig. 6). It has been found that increasing the rounding radius $\rho$ of the threading tap cutting edges from 26 to 64 micron corresponds to deterioration of thread surface roughness in blanks of corrosion-resistant material grade 08X18H10T as measured with $Ra$ from 0.73 to 1.42 micron, independent of MAF process factors ($\Delta = 160 \div 315$ micron, $B = 0.6 \div 1.0$ tesla, $t = 60 \div 210$ s).

It should be also noted, that the general trend of the inside thread roughness change depending on the cutting edge rounding radius is largely influenced by the process factors of MAF that formed various condition of the thread tap teeth contact surfaces. It is known from [5], that the same values of the rounding radius may be obtained by MAF with different treatment conditions. Despite that, the graphical dependencies shown in Fig. 6 show that the side surface roughness values of inside thread profile resulting from threading are different.

So, e.g., the rounding radius of the thread tap cutting edges $\rho = 40$ micron may be obtained by MAF with powder grain size $\Delta = 160$ micron, magnetic flux density $B = 1.0$ tesla and polishing time $t = 120$ s, or with MAF at $\Delta = 250$ micron, $B = 0.6$ tesla, $t = 120$ s. However, while the rounding radius of the thread tap cutting edges is the same, the roughness of the inside threads in the corrosion-resistant blanks grade 08X18H10T is 3-5% worse in the first case than in the second one.
In addition, there may be a case, when, e.g., the threading tap with the cutting edge rounding radius $\rho = 47$ micron formed by MAF at a powder grain size $\Delta = 250$ micron, magnetic flux density $B = 0.8$ tesla and a polishing time $t = 120$ s, will reduce the inside thread profile roughness in blanks of the corrosive-resistant material grade 08X18H10T by 4-8% compared to the thread surface roughness provided by the thread tap with the cutting edge rounding radii of $\rho = 44$ micron and $\rho = 46$ micron, but formed by MAF at $\Delta = 250$ micron, $B = 0.6$ tesla, $t = 210$ s and $\Delta = 160$ micron, $B = 1.0$ tesla, $t = 210$ s, respectively.

This is caused by various influence of the MAF process factors onto condition of the tool teeth contact surfaces and further process of threading with MAF-treated thread taps. This line of reasoning provides foundation for an assertion that it is possible to select the MAF process parameters within the studied range to provide the most efficient thread tap preparation for formation of inside threads with the surface roughness $Ra \leq 1.6$ micron.

Analysis of the experimental data has led to a conclusion, that in the studied range of the MAF process factors ($\Delta = 160 \div 315$ micron, $B = 0.6 \div 1.0$ tesla, $t = 60 \div 210$ s) the most efficient for thread tap preparation will be using the powder grain size of $\Delta = 160$ micron, magnetic flux density $B = 1.0$ tesla as a constant, while forming of various condition of the thread tap teeth contact surfaces shall be controlled by varying the polishing time in the range of $t = 60 \ldots 210$ s.

4. Conclusion
As a result of research in forming the surface roughness of $Ra \leq 1.6$ micron in inside threads in blanks of corrosion-resistant steel, it may be concluded that the inside thread surface roughness resulting from threading with a thread tap untreated with MAF is $Ra = 1.77$ micron, while when using the MAF-pretreated thread taps, the value of $Ra = 0.73 \ldots 1.42$ micron is attained (depending on various MAF process factors). Thus, the authors deem practical to apply magnetic-abrasive polishing as a preliminary finishing operation in preparation of cutting tools for threading inside threads.

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