Identification of the relationship of the magnitude of the rise tool tooth and the physical and mechanical properties of the material and the tool broaching

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Abstract. The article considers the existing methods of designing a broaching tool. The analysis revealed that they do not take into account the change in the physicomechanical measurements of the workpiece and tool occurring with the material at various temperatures in the cutting zone. The article offers a technique for taking this circumstance into account to increase the productivity of the pulling process. The method will allow to design a broaching tool for processing internal surfaces and it will increase the productivity of machining of internal surfaces.

1. Introduction
Broaching is a type of machining using a multipoint tool with translational primary cutting motion distributed over the entire surface being processed without feed motion. In addition to high performance, one of the most important advantages of a broaching tool is high durability due to the design in which shaping elements duplicate each other, partially or completely [1-13]. Drawing as a process depends on the choice of the amount of climb on the cutting tooth of the broach. The place has a large amount of lifting per tooth, so the place has a short cutting part of the broach, the cost becomes less, and productivity increases. We cannot increase the tooth lift excessively, as this will lead to an increase in the axial force per mm of the length of the cutting edge [8, 13-22].

2. Methods
Opinion prevailed in the publications of past years and the practices of the recent past about increasing wear and decreasing durability of a broaching tool with increasing feed per tooth. But the broaching tool is widespread in the automotive industry. Use broaches with large rises on the tooth. Practice has shown the possibility of not decreasing, but increasing resistance with increasing feed in some cases. The authors came to the opinion of the dependence and high temperature in the zone of a significant change in the physico-mechanical properties of the processed material from pulling with large feed rates. Figure 1 shows the change in hardness of tool material, carbon steel and alloy steel with increasing temperature.
The graph indicates a sharp decrease in hardness as a physicomechanical property of carbon steels and alloy steels upon heating at 400-500 °C. Tool steels do not lose their characteristics in this temperature range. Of interest is the study and consideration of this phenomenon when designing a broaching tool from the point of view of the possibility of increasing the productivity of the pulling process.

3. Research and discussion

The work [8] considers the general temperature dependence for the pulling process:

\[ t^\circ = \frac{9.6\Omega^0.39S^0.2HB^0.62T^0.11}{\gamma^{0.08}\alpha^{0.05}} \]  

where \( \Omega \) – pulling speed, m/min.; \( t^\circ \) – cutting zone temperature, HB – hardness of the material of the stretched surface; T – resistance or mean time between failures in meters of the stretched surface with the working part of the broach; \( \gamma \) – the value of the rake angle, deg.; \( \alpha \) – value of a back corner, deg.

The value of HB is included in dependence (1); it is proposed to be independent of temperature in the cutting zone, but we consider this trouble to be unjustified. We performed a study of changes in the hardness of steel 40X from temperature. Steel 40X was not chosen by chance, it is used for the manufacture of a wide range of parts: axles, shafts, plungers, rods, crankshafts, cam shafts, axle rings, bushings and other high-strength parts. The samples were heated as a result of an experimental study in a muffle furnace from 20 to 400 °C in increments of 50 °C. We took three samples for each temperature point and we calculated the average value. The results are presented in the table 1.

| Temperature (°C) | 20   | 50   | 100  | 150  | 200  | 250  | 300  | 350  | 400  |
|------------------|------|------|------|------|------|------|------|------|------|
| Hardness (HB)    | 226  | 217  | 214  | 200  | 205  | 203  | 198  | 196  | 192  |

We obtained an empirical dependence according to the results of the study:

\[ HB=225.7-0.126t^\circ +0.00011t^\circ^2 \]  

Based on the calculation results, we proved its adequacy and we plotted the hardness versus temperature; we presented it in figure 2.
Figure 2. The place has a dependence of hardness on the temperature of steel 40X.

The graph shows a decrease in hardness of steel 40X by 15% with an increase in temperature to 400 °C. We select the modes of drawing (we select in particular the magnitude of the rise per tooth> 0.2 mm/tooth), the researchers adhered to the temperature in the cutting zone at the level of 300-400°C. The range is not chosen randomly. Hardness is not reduced for most tool steels and we can increase the productivity of machining.

The authors propose to determine the amount of tooth lift from a condition of exceeding the temperature in the cutting zone of the heat resistance limit of the material being processed and not exceeding the heat resistance limit of the broaching material intended for machining the internal surfaces when designing a drawing tool for processing internal surfaces.

We transform formula 1 to assign parameters taking into account changes in hardness versus cutting temperature using the dependence [8]:

\[
S_z = \frac{0,2 \cdot \gamma^{0,08} \cdot t_k^{0,08} \cdot 0,8 \cdot t_\alpha}{\sqrt{9,6 \cdot 0,39 \cdot HB(t_k)^{0,8} \cdot T^{0,11}}}
\]

where \( \Omega \) – pulling speed, m/min.; \( t_k \) – temperature resistance of the processed material, \( HB(t_k) \) – function of changing the hardness of the material of the stretching surface from the temperature in the cutting zone; \( T \) – resistance or time to failure in meters of the stretched surface of the working part of the broach; \( \gamma \) – the value of the rake angle, deg.; \( \alpha \) – value of a back corner, degrees.

Figure 3. The place has a dependence of the tooth lift on temperature when determining the parameters of the broaching teeth for machining the internal surfaces, taking into account the characteristics of materials and workpieces with increasing temperature in the cutting zone.

Figure 3 presents a graph of the change in the magnitude of the tooth lift versus the cutting temperature, taking into account the change in the hardness of the processed material with increasing...
temperature. The graph shows a sharp jump in the amount of tooth lift when the temperature rises in the cutting zone of the heat resistance temperature of the processed material and there is the possibility of increasing the feed to the tooth and increasing the productivity of the broaching tool when processing internal surfaces.

4. Conclusion
The method will allow to design a broaching tool for processing internal surfaces and it will increase the productivity of machining of internal surfaces.

Acknowledgments
The study was carried out within the framework of funding scholarship of the President of the Russian Federation to postdoctoral researchers and postgraduate students performing advanced research-and-development activities in the priority fields for the modernization of the Russian economy for 2018-2020 SP-591.2018.1.

References
[1] Brown M P and Austin K 2004 Appl. Phys. Letters 85 2503–4
[2] 1990 GOST 28442-90 Broaches for cylindrical, splined and polygonal holes Specifications (Moscow: Standards Publishing House)
[3] Emelyanov S G, Seleznev Y N, Gubanov V S, Kochergin V S and Khomutov R N 2017 Study of the working area temperature during broaching of shaped holes Assembling in mechanical engineering, instrument making 12 550–3
[4] Emelyanov S G, Seleznev Y N, et al. 2018 Study of the effect of broaching parameters on the working area temperature when machining shaped holes Assembling in mechanical engineering, instrument making 4 175–81
[5] Seleznev Y N and Gubanov V S 2008 Study of the dependency of the broaching process energy intensity. Materials and reinforcing technologies Proceedings of the XV Russian Scientific and Technical Conference with international participation (Kursk State Technical University, Kursk) pp 260–3
[6] Seleznev Y N, Gubanov V S and Lymanyuk A Y 2011 Study of the dependency of the broaching process energy intensity on the rake angle and depth of cut per tooth Modern tooling systems 13–20
[7] Seleznev Y N, Yatsun E I and Gubanov V S 2008 Setting the problem of studying the thermal phenomena of the broaching process Modern tooling systems, information technologies and innovations 51–6
[8] Margulis D K, Tverskoy M M, Ashikhmin V N et al 1986 Broaches for machining holes (Moscow: Mechanical Engineering)
[9] Shchegolev A V 1960 Designing of broaches (Moscow: Mashgiz)
[10] Emelyanov S G, Seleznev Y N, Gubanov V S, Kochergin V S and Evseev E Y 2017 Study of the influence of design and geometrical parameters of broaching tools on the output characteristics of the broaching process (Kursk: University Book)
[11] Kosilova A G 1956 Reference guide of mechanical engineer (Moscow: Mashgiz)
[12] Evseev E Y and Kochergin V S 2016 Analysis of methods for determining cutting forces for internal broaching Product quality: Monitoring, management, improvement, planning. Proceedings of the third International Youth Scientific and Practical Conference 1 252–4
[13] Chen Z, Peng R L et al. 2014 Effect of thermal exposure on microstructure and nano-hardness of broached inconel MATEC Web of Conferences 718 08002
[14] Evseev E Y and Kochergin V S 2016 Analyzing the assessment of the broaching tool durability. Prospective development of science, equipment and technology *Proceedings of the sixth International Scientific and Practical Conference* pp 45–8

[15] Kochergin V S and Evseev E Y 2017 Analysis of restrictions on the main design parameters when refining the broaching tool *Modern materials, equipment and technology* 2(10) 35–9

[16] Seleznev Y N and Pavlov E V 2004 Analyzing the accuracy of approximating the profile of involute splined broach teeth along a circular arc, two circular arcs and the length of an involute *Modern tooling systems, information technologies and innovations* pp 129–34

[17] Shchegolkov N N 2001 Automated approximation of the profile of cutting tools *STIN* 11 17–22

[18] Seleznev Y N, Gubanov V S and Lymanyuk A Y 2010 Developing and studying mathematical models of the dependency of axial force on the depth of cut per tooth and values of rake angles when broaching *Materials and sealing technologies* pp 184–91

[19] Mo S P, Axinte D A, Hyde T H and Gindy N N Z 2005 *Journal of Materials Processing Technology* 160(3) 382-9

[20] Seleznev Y N, Gubanov V S and Lymanyuk A Y 2010 Developing and studying mathematical models of the dependency of specific force on the depth of cut per tooth and values of rake angles when broaching *Modern tooling systems, information technologies and innovations* pp 177–84

[21] Seleznev Y N, Gubanov V S and Sergeev S A 2005 Automated calculation of the minimum depth of cut per tooth for broaching *Modern tooling systems, information technologies and innovations* pp 118–23

[22] Seleznev Y N and Rukhlin A S 2003 Determination of the dependency of specific cutting forces on the feed per tooth when broaching holes in steel products *Physical and computer technologies in the national economy The eighth International Scientific and Technical Conference (Kharkov)* pp 104–6