Досліджені методи виготовлення профільних отворів в умовах дрібносерійного виробництва. Запропоновано метод ротаційного видавлювання профільних отворів, який має суттєво спрощену конструкцію технологічного оснащення. У якості інструменту використовуються біти для шуруповертів або ручних викруток. Визначено раціональний діапазон параметрів процесу ротаційного видавлювання методом трифакторного планування

Ключові слова: профільні отвори, різьбові з'єднання, прошивка, видавлювання, ротаційна головка, біта, токарний верстат

Исследованы методы изготовления профильных отверстий в условиях мелкосерийного производства. Предложен метод ротационного выдавливания профильных отверстий, который имеет существенно упрощенную конструкцию технологической оснастки. В качестве инструмента используются биты шуруповертов или ручных отверток. Определен рациональный диапазон параметров процесса ротационного выдавливания методом трехфакторного планирования

Ключевые слова: профильные отверстия, резьбовые соединения, прошивка, выдавливание, ротационная головка, бита, токарный станок

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IMPROVING THE METHOD OF ROTATIONAL BROACHING IN THE PRODUCTION OF PROFILE OPENINGS ON THE LATHES OF TURNING GROUP

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1. Introduction

Profile openings in the form of internal hexahedrons or stars have been recently widely used in bolts or screws of threaded connections. It is known that threaded connections are the most common detachable connections when manufacturing machines and their nodes. They are the most technological and represent the bodies of revolution.

To transfer effort while tightening or loosening, a hexagonal shape of nut and bolt head is widely used. In most cases, the desired effect is accomplished by open-end wrenches. But using open-end wrenches in the tightening or loosening of elements in the threaded connections is not always convenient. A required free space for turning the wrench is lacking. That is why they use spanners (ring wrenches) or socket wrenches with 12 or 6 working facets. The specified wrenches are related to the surfaces with external engagement.

A more compact design of the product and better operating conditions are provided by the bolt heads with internal contour engagement by hexagonal wrenches or wrenches-stars of the Torx type. As their smaller variants, the bits (inserts) for screwdrivers or manual screwdrivers are used.

There are many varieties of deepenings on the fastener (screws or bolts). The most common among them are:

– Torx (denoted as T or TX, is a tool in the form of a hexagonal star);

– pentagonal Torx (vandal-proof variant, also called 5-lobe Torx);

– Torx Plus (improved slit from cut ends of the star to provide for maximum torque, denoted as IP (Internal Plus).

Application scope of profile openings is rather wide. They are used in the automobile-, machine-, instrument making, fittings in sanitary wares, robot-controlling elements. A peculiarity of using these particular profiles (hexagon, star) is in the fact that profile products can work as conjugated parts. To provide for the whole range of these types of openings is impossible because each profile requires its own tool. That is why a cost reduction in the manufacturing technology of profile openings and the feasibility of practical implementation is a relevant direction.

2. Literature review and problem statement

Openings in the form of inner hexagons or the Torx type stars are widely used in fastening joints [1]. Bolts are manufactured using mass-production technology as was noted above. To meet the needs of the industry, the range of minimum tensile strength for bolts is assigned from 420 to 1450 MPa. It is defined by the class of the bolt strength. Bolts are made either by cold or hot forming under conditions of mass production. Depending on the class of bolt strength, a required mode of thermal treatment is applied. When manufacturing products in limited batches, it is economically inexpedient to use equipment of the specialized enterprises, the same is true if the shape of profile openings differs from standard and commonly used or is intended for customized parts [2, 3].

Among the main directions to solve a task of independent manufacturing of profile openings under conditions of serial or small-scale production, described in the resources of world scientific periodicals, technologies for stretching or broaching can be highlighted.

Let us consider the fabrication of profile openings using broaching. Unlike the stretching that works on elongation, broaching works on compression. They are mostly used when working out the openings with a diameter of 10...75 mm. They can be made with a diameter from 3 mm [4].

The use of broaching requires both the application of separate specialized metal-cutting equipment and special shape of broaching, which is impossible under conditions of small-scale production. A similar peculiarity was observed in articles [5, 6], where a conclusion is drawn on the necessity of compromise solutions to utilize widely distributed metal-cutting equipment, such as a drill press. Authors of the given papers demonstrated that the use of rotation broaching makes it possible to obtain profile openings, based on tools from the drilling group. This method, however, does not allow properly extending the scope of application. It requires both specialized equipment and specialized tools.

An improved variant to solve the problem on making profile openings is described in article [7]. It enables processing operations using the existing nomenclature of drill presses. This technical solution, according to authors of the given paper, makes it possible to apply a rotational head as a completing part of components for machines of the turning group, including CNC machine tools (Fig. 1).

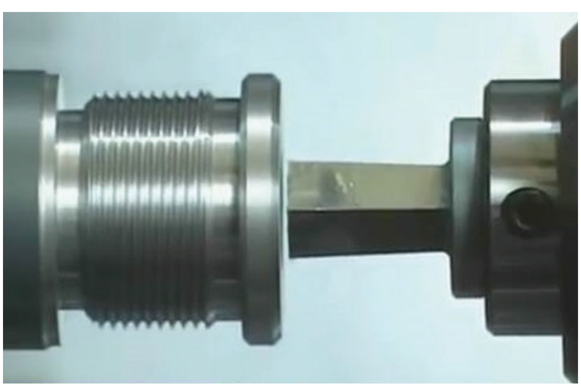


Fig. 1. Broaching of profile opening on the lathe

Authors [8, 9] actually realize a weak point in this approach because the rotational head requires preliminary adjustment when changing a cutting tool. Adjustment is applied to align the head rotation axis with the top of the tool. The latter requires sharpened edges. In the opposite case, quality of profile opening worsens considerably. In addition, the design of rotational head does not provide for a change in the entrance angle for a workpiece. This does not allow fabricating profile openings with an input cone of working facets.

Therefore, results of an analysis allow us to conclude that there are no possibilities to simplify the method of manufacturing profile openings on machine tools of the turning group. A choice of acceptable technical solution for the method of shaping profile openings is likely to be based on the design, which would allow the simplification of handling process under conditions of small-scale production.

3. The aim and tasks of the study

The aim of present research is to improve the method of manufacturing profile openings on machine tools of the turning group. This would simplify the manufacturing process without compromising on quality, and would lead to a substantial reduction in the cost of handling profile openings.

To achieve the set aim, the following tasks were to be solved:

– to propose a technological method for making profile openings, which would provide for the maximal simplification in the design of equipment;

– to propose and substantiate the tools, which would make it possible to manage the entire range of variations in the configuration of fastening profiles that are used as deepenings in bolts (screws);

– to define rational range of operating parameters of the proposed technological method.

4. Materials and methods for research into improving the rotational broaching of profile openings

In order to make a technical decision as for creating the design, which would make it possible to simplify the process of handling the profile openings, we analyzed design of rotational head for machine tools of the turning group (Fig. 1). The indicated set-up is suitable for the work on universal lathe machines. It implies that errors in the parameters of lathe machine precision must be within the norm. Exceeding the errors considerably degrades the quality of profile opening, or makes the production impossible at all.

Let us consider a kinematic schematic of the specified head (Fig. 2). Holder 3 with a shank of Morse cone is mounted with hub 5. In its body, the buffers are fixed in such a way that the axis of rotation is located at angle α to the axis of holder rotation 3. The corresponding inclination angle α accepts spindle 4, which is set in these buffers. At the end of the spindle, there is a working tool. To enable the process of working out a profile opening, the tool has relieving angle γ, which is provided by the tool sharpening angle β. The tool, mounted in spindle 4, can rotate freely relative to the axis of tailstock, which holds Morse cone of the head at angle β.

In chuck 1 of the lathe, treated workpiece 2 is fixed; it has an opening, drilled in advance. During rotation of the workpiece, rotational head, which is mounted in the rear center of the machine, moves in the direction of workpiece, the tool touches the workpiece and rotation from the workpiece is passed on to it. Each of the edges of the cutting tool has rotational synchronous motion relative to the workpiece and, under the action from supply S, the rotational broaching of profile opening takes place.

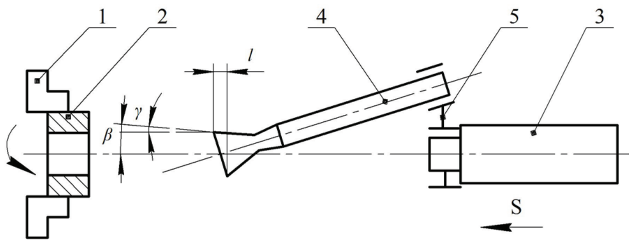
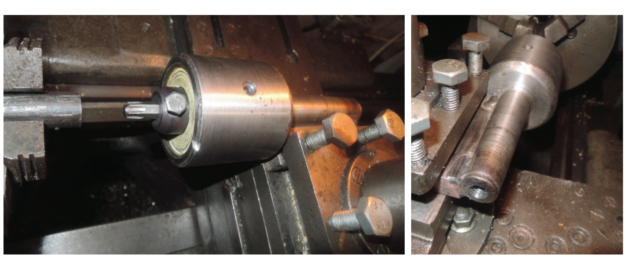


Fig. 2. Kinematic schematic of the work of rotational head for broaching the profile openings: 1 – chuck of lathe; 2 – treated workpiece; 3 – holder; 4 – spindle; 5 – hub

To simplify the process of working out profile openings is possible by replacing the existing process with the process of rotational broaching. In this case, as the tool we propose to use conventional, commonly widely used, bits that are used in sets of tools for car repair or any equipment. Steel S2 is used in their manufacturing, which is characterized by good resistance in contact with any metals. Processing method in their fabrication: cold forming followed by thermal treatment. It provides for a homogeneous structure at the largest strength. The surface is polished and protected from corrosion. Hardness of most bits is HRC 58...60. This allows their use as a working tool. Replacement to steel S2 is the Ukrainian analog – 5HV2S, which is used for making knives for cold cutting of metal, punches and compacting tools for cold metal, which operate under elevated impact loads.

A bit for screwdrivers is used as working tool without additional treatment, the edges are beveled. On one hand, transition to the process of broaching increases the pressing force, on the other hand, it makes it possible to reduce precision of the preliminary adjustment of tool – it is sufficient to drive conditional bit axis to the axis of workpiece rotation.

As a simplified variant of rotational head, it is possible to consider using the rear-rotating center, which has the following revisions (Fig. 3).



a *b*

Fig. 3. Rotational head from rotating center: *a* – view of rotational head; *b* – method of fixing in the tool carrier

In the cone of rotating center, we make an opening along the cone axis and threaded opening for the stopping bolt (Fig. 3). It is necessary to take into account two peculiarities: the cone of rotating center is thermally treated and thus requires special measures for drilling, and to remove the cone from the center, we make additional opening for knocking out the cone with extension from the center.

For fastening, an additional plate is welded onto the rotating center, which is clamped in the tool carrier. The required tool entrance angle for workpiece is ensured by turning the tool carrier to the desired angle.

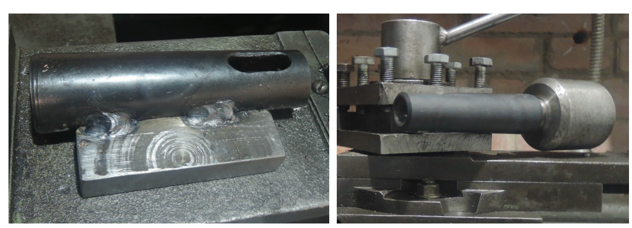
An experience of using the simplified variant of rotational head has confirmed effectiveness of the specified method. But, in case of inaccurate preliminary positioning of bit's axis relative to the axis of opening, one observes significant deformation and, as a result, break-up of the opening and clamping bolt.

To simplify the design of rotational head is possible when tool self-centering is provided. Without changing the course of the rotational broaching process, we place the bit between a workpiece and the rotating center (Fig. 4).

a *b*

Fig. 4. Fabrication of profile openings with tool self-centering: *a* – making profile openings; *b* – bit-centering technique

It is possible to obtain clamping of the bit by rotating center, which, to ensure the scrapping of rotation axes that provides for the process of rotational broaching, is fixed in a tool carrier with a welded plate. The bit has to be prepared in advance by making a centering opening (Fig. 4). In view of the lack of hard alloy drills, it is expedient to make a transition hub, in which, without any problems, a centering opening is made. By changing the angle of tool carrier's location, we ensure tool entrance angle for the workpiece. It is more promising to weld the plate onto the transition Morse cone (Fig. 5).



a *b*

Fig. 5. Fixing a rotating cone in the tool carrier through the transitional Morse cone: *a* – transitional Morse cone with welded plate; *b* – fixing the cone in a tool carrier

In order to find rational parameters for the rotational broaching of profile openings, which is carried out by the scheme, we shall conduct a series of studies. As an indicator of efficiency in the process of shaping profile openings in small parts, we considered the pressing force, F, N, or the strength of bit when entering the opening. Small parts are suitable for fixing in the lathe chuck. The axis of a would-be profile opening coincides with the axis of rotation after clamping. Conducting a comprehensive study of the process of shaping profile openings is sufficiently complicated process, including, if we take into account all the factors: shape of the profile opening, dimension of the opening, length of the opening profile in the normal cross-section, mechanical properties of material for a part and a bit. We considered such basic input parameters as tool supply S, mm/rev, tool entrance angle α, degrees, rotation frequency of part n (rpm). Other parameters are taken to be constant or insignificantly variable. We use a Torx 50 bit for the study. It is a hexagonal star whose outer diameter is 8.83 mm.

We use experiment planning to find the degree of influence of initial parameters on the value of pressing force F, N. Let us also find rational range of parameters in the rotational broaching. We set a goal to find a functional dependence in the form

$$F = f(\alpha, S, V), \tag{1}$$

where α is the tool entrance angle, degrees; S is the tool supply, mm/rev; V is the rate of the process, m/min.

5. Results of the study

Parameters that exert a significant influence on efficiency of the process of rotational broaching are proposed by authors of articles [9, 10]. According to this, they were accepted as the base. Ranges of change in the parameters, the so-called variation intervals, within which there is the largest effectiveness of the rotational broaching process, are listed in Table 1.

The impact of action of the specified parameters on the function value differs from the linear one; we shall use plans of second order. When recording the plan for conducting experiment, number 1 is not specified and the coded record of factors' levels takes the form, respectively: «+», «0» and «–».

To simplify the records and subsequent calculations, the top level of variation in factors is indicated by symbol (+1), medium level – (0), low – (–1).

Results of the studies are processed using the methods of mathematical statistics, thus obtaining a regression equation that reflects a relationship between a function and starting factors.

Table 1

Variation intervals of parameters that influence efficiency of the rotational broaching process

No.	Name	Denoted as	Dimensionality	Level			Variation interval
				top (+)	zero (0)	low (–)	
X_1	Tool entrance angle	α	degree	2.5	2.0	1.5	0.5
X_2	Tool supply	S	mm/rev.	0.3	0.2	0.1	0.1
X_3	Process rate	V	m/min.	25	20	15	5

In a general form, for the three-factor experiment [11]:

$$y_u = b_0 + \sum_1^k b_i x_i + \sum_1^k b_{ii} x_i^2 + \sum_1^k b_{ij} x_i x_j, \tag{2}$$

where i, j = 1, 2, ..., k are the ordinal numbers of factors (i ≠ j); y_u is the function; x_1, x_2, ..., x_k are the starting factors; b_0, b_1, b_2, ..., b_{12}, b_{13}, ..., b_{ij}, b_{ii} are the coefficients of equation, which are calculated by the following formulas:

$$b_0 = 0.1831[0y] - 0.0704\sum_1^k [iiy]; \tag{3}$$

$$b_i = 0.1[iy]; \tag{4}$$

$$b_{ii} = -0.0704[0y] + 0.5[iiy] - 0.1268\sum_1^k [iiy]; \tag{5}$$

$$b_{ij} = 0.125[ijy]. \tag{6}$$

Functional dependence of the aforementioned parameters on the rotational broaching process takes the form:

$$\begin{aligned} y_u &= b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + \\ &+ b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 = \\ &= 1.237 - 0.340x_1 + 0.256x_2 - 0.169x_3 - \\ &- 0.077x_1^2 - 0.057x_2^2 - 0.052x_3^2 - 0.04x_1x_2 + 0.032x_1x_3. \end{aligned} \tag{7}$$

Graphical representation of results of applying a regression equation is in Fig. 6, *a–c*.

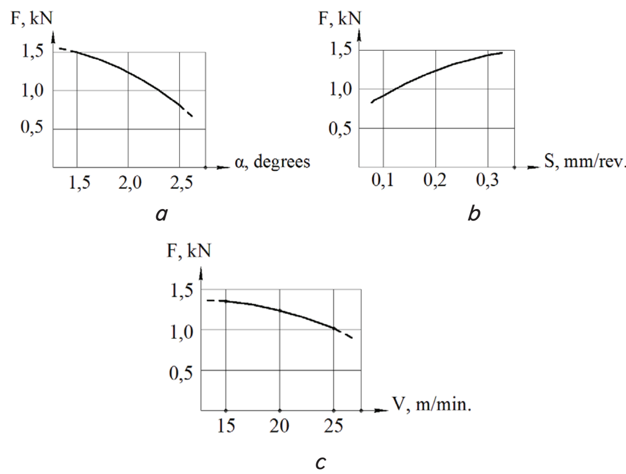


Fig. 6. Dependence of pressing force F, kN: *a* — on the tool entrance angle α, degrees (S=0.2 mm/rev; V=20 m/min); *b* — on the tool supply S, mm/rev (α=2 degrees; V=20 m/min); *c* — on the process rate V, m/min (α=2 degrees; S=0.2 m/min)

Based on the subsequently performed research into stationary region by the method, and verified in papers [12–15] for the optimization of industrial technological processes, we determined suboptimal values of input variables that are accepted as rational in the examined technological process.

A general view of the obtained profile opening and the bit, which was used as a tool, is shown in Fig. 7.

Fig. 7. General view of the obtained profile opening and the bit, which was used as a tool in the rotational broaching

An analysis of the results allows us to draw a conclusion about adequacy of the resulting mathematical description that was tested by a standard procedure through the verification of statistical hypotheses on the equality of error variances in the experiment and inadequacy of the model. The studies conducted confirmed the correctness of defined rational range of parameters in the rotational broaching.

6. Discussion of results of examining a change in the solution feed pressure

Among the strong points of present research, it is necessary to note the feasibility of manufacturing profile openings without using specialized rotational heads at the universal machine tools of the turning group. Using the proposed methodology allows, without considerable financial cost, the implementation into machine engineering production of the application of modern fastening profiles with a wide scope of their purposes.

Obtained data on the use of nominal range of parameters in the rotational broaching process makes it possible to optimize the manufacturing process of profile openings.

A weak point of present study is due to the fact that the resulting rational parameters in the manufacturing mode of profile openings are valid for nominal values of input parameters that were not involved in the optimization of parameters. It is related to the mechanical properties of the material of both the workpiece and the tool. At the same time, for a stronger material of the workpiece, one should choose super strong material for the tool.

A promising way to improve the method proposed is the development of possibility to profile cylindrical surfaces of rotation, for example, when obtaining a hexagonal profile for the fabrication of nuts.

7. Conclusions

1. We proposed a method for the rotational broaching of profile openings, which is based on the self-centering of the tool relative to the workpiece opening. It simplified design of the equipment for conducting rotational broaching.

2. As a tool for rotational broaching, conventional bits without any revision are used. This makes it possible to cover the entire range of variations in the configuration of fastening profiles, used as deepenings in bolts, screws. Due to excess hardness of bits, transition bushings are used for their centering, which are forcefully mounted onto bits.

3. We determined suboptimal values of input variables that are accepted as rational in the examined technological process of rotational broaching, namely: tool entrance angle $\alpha = 1.5...2.5$ degrees; tool supply $S = 0.1...0.3$ mm/rev; processing speed $V = 15...25$ m/min. In this case, pressing force F does not exceed 1.5 kN.

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DEVELOPMENT OF THE EVALUATION MODEL OF TECHNOLOGICAL PARAMETERS OF SHAPING WORKPIECES FROM POWDER MATERIALS

Розглянуто системний підхід до технологічного процесу формоутворення (процес, машина, заготовка), що дозволило розробити математичну модель оцінки. На основі математичної моделі нечітких множин була виконана оцінка ефективності функціонування технологічного комплексу. Визначені зв'язки між параметрами підсистем на базі вібропресового обладнання з гідроімпульсним приводом для формоутворення заготовок з порошкових матеріалів

Ключові слова: нечіткі множини, формоутворення, рівнощільність, гідроімпульсний привод, вібропресове обладнання, порошковий матеріал

Рассмотрен системный подход к технологическому процессу формообразования (процесс, машина, заготовка), что позволило разработать математическую модель оценки. На основе модели нечетких множеств была выполнена оценка эффективности функционирования технологического комплекса. Определены связи между параметрами подсистем на базе вибропрессового оборудования с гидроимпульсным приводом для формообразования заготовок из порошковых материалов

Ключевые слова: нечеткие множества, формооброзование, равноуплотненность, гидроимпульсный привод, вибропрессовое оборудование, порошковый материал

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1. Introduction

Technologies that are characterized by processes of shaping workpieces, in which fluidity of materials with complex reology is implemented under conditions of complex loading, need new developments, learning and improvement. Vibrational and vibroimpact technological processes, as well as equipment for their implementation are becoming increasingly common [1–3]. It was found that the application of useful vibrations or impact pulses to the objects of treatment makes it possible to significantly intensify the course of a number of technological processes, provide optimum loading parameters and obtain a product with high quality parameters. In particular, when pressing workpieces of products made of powder materials (carbides, borides etc.), average density and equal density by the volume of workpieces increases by 60–70 % under conditions of waste-free production. That is why vibration equipment for shaping workpieces from powder materials should meet more serious requirements. It must have a relatively simple structure, high reliability,