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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ
Satbayev University

# Х А Б А Р Л А Р Ы

# ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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OF THE REPUBLIC OF KAZAKHSTAN
Satbayev University

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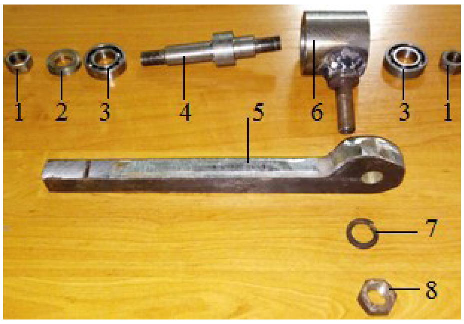
# USING ANSYS WB FOR OPTIMIZING PARAMETERS OF A TOOL FOR ROTARY FRICTION BORING

**Abstract.** The authors developed a special design of a rotary friction tool with a self-rotating cup cutter for rotary friction boring of large holes. This paper presents the results of parametric optimization of stressed components of the rotary friction tool by virtual experiments in ANSYS WB. The authors predicted the cutting force components at the worst position of the cup cutter, which was 20 degrees as contact forces in the process of boring a large diameter hole, and built a design model. Using the Johnson-Cook model as the failure criterion for the elements of the mesh, projections of the cutting forces resulting from the hole processing were obtained. The relation between input and output parameters (stresses) is established, optimization criteria are specified, and optimal parameters of the tool stresses components are chosen. It was also found that the averaged values of the force at the initial moment (cutting into the workpiece) change linearly, then becoming practically constant. The idea of parametric optimization consisted in carrying out several virtual experiments, in which the possible range of variation of the basic dimensions was indicated and the optimization criteria were set, the optimal parameters of the tool design were selected from the presented candidates. The optimization method bypasses the design cycle, which is costly and time-consuming due to prototype testing and subsequent refinement.

**Key words.** Rotary friction tool, large hole machining, cup cutter, parameter optimization, cutting force, bearing fit, design model, stress.

**Introduction.** In modern mechanical engineering, one of the pressing problems is the processing of large holes. Engineering practice sets high requirements to the accuracy of size, shape and location. Most often, large holes are processed with boring tools. The processing of these tools involves a number of difficulties, primarily due to the low rigidity of the tool and difficulty of supplying cutting fluid and removing pulp (a mixture of chips and cutting fluid) to the cutting zone. This leads to a decrease in the accuracy and performance of the machining and durability of the tool. As part of the government-funded research, the authors studied and developed resource-saving combined methods of thermal frictional processing [1,2,3,4], in particular the rotary friction boring of large holes [5,6]. For rotary friction boring of large holes, the authors developed a special design of a rotary friction tool with a self-rotating cup cutter. Figure 1 shows the general view of the rotary friction tool and its parts.

*a)*




*b)*

1 - nut; 2 - sealing washer; 3 - bearing; 4 - shaft; 5 - holder; 6 - head body; 7 - engraved washer; 8 - clamping nut

Figure 1 - The rotary friction tool and its parts

The performed experimental research has shown that correct choice of the tool parameters and dimensions has a direct impact on the quality and accuracy of processing. In this regard, finding optimal parameters and dimensions of the proposed special rotary friction tool with a self-rotating cup cutter is a relevant task.

Techniques to optimize parameters. Designing a tool structure is a long process in which design parameters are constantly changing until they meet the performance criteria, while the mass must be minimal at a low cost [7,8,9]. An initial design undergoes many changes and improvements before reliable geometric parameters are found (Figure 2)

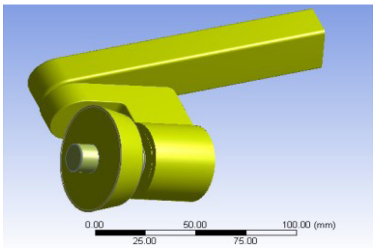



Figure 2 - Initial scheme of the tool design

The designing stages are expensive and time-consuming. Due to time and cost limitations, the decision is made on the basis of the most satisfactory option and experience of designing [10,11,12]. For today's problems, it is proposed to use optimization techniques to save time and consider the largest number of options, taking into account the spread of parameters, thereby ensuring stability of the solution to external factors. The idea of parametric optimization consists in carrying out several virtual experiments which take into account the spread of the input parameters (geometric parameters of the tool), i.e. the possible range of change in basic dimensions. We established the relation between input and output parameters (stress). Then, having set the optimization criteria and based on calculated data, we chose optimal parameters of the tool design from the candidates (variants). The optimization procedure consists of the following steps [8,12,13,14]: building a design model, determining the parameters, planning the experiment, building the response surfaces, building an optimization model, launching an optimization, viewing the results.

At each stage, additional settings may be required that can significantly affect the calculation results.

**Building a design model.** To build a design model, at first, we determined the predicted components of the cutting force (figure 3) at the worst position of the cup cutter, which was 20 degrees as contact forces in the process of boring a larger diameter hole of 30CrMnSiA. We made the calculation by the finite element method. As the failure criterion for the elements of the mesh, we chose the most widely used Johnson-Cook model. The cutting force projection data were obtained for the following cutting mode: spindle speed - n = 660 rpm, feed - s = 0.42 mm/rev, cutting depth t = 1.0 mm.

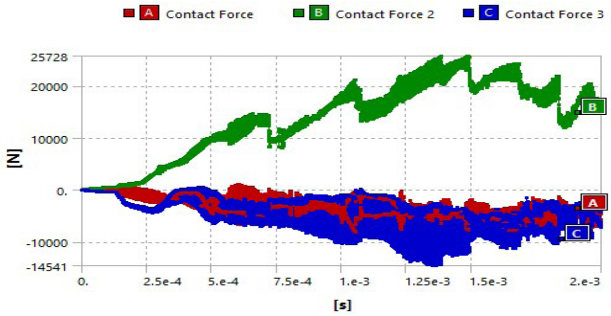



Figure 3 - The predicted change in the projection of the cutting force during rotary frictional boring

It should be noted that actually due to the discrete model the predicted cutting force is not definite, but experiences some fluctuations in the process of rotary friction boring (Figure 3). Therefore, we will determine the value of the cutting force projection by an average value. The average values of the cutting force are presented in the graph (Figure 4).


Figure 4 - Average values of cutting force

Reliability of the model is confirmed by the sensitivity of the cutting force and temperature to the change in the cutting speed in accordance with modern concepts: with increasing cutting speed, the cutting force decreases and the temperature rises.

**Determining the parameters.** planning the experiment. To perform the optimization calculation, the computer applications are used. The main parameters of the shaft geometry are (Figure 5): V10 - projection height (default 4 mm); H11 - projection width (default 10 mm); V13 = V8 - radius of the bearing fit (default 8 mm). The output parameter of the shaft (a parameter obtained after the solution) will be von Mises stress (461.6 MPa). Choose a plan for planning a virtual experiment. In the planning of the experiment, we must specify the range of change for each parameter and select the scheme. In our task, the main composite project is chosen (Figure 6). When choosing design points with a set of parameters, we use this scheme of experiment design which allows improving the efficiency of calculations.

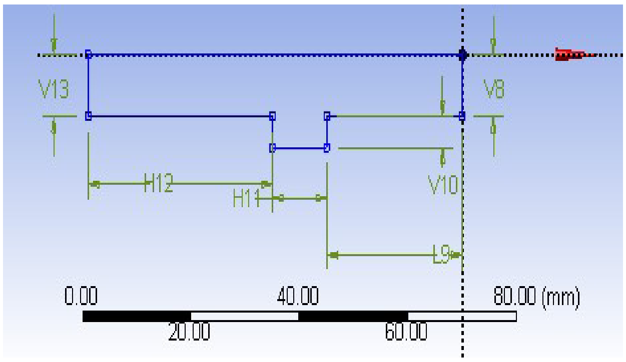



Figure 5 - Basic parameters of the shaft geometry

Properties of Outline A2: Design of Experiment

| | A | B |
|---|---|---|
| 1 | Property | Value |
| 2 | ⊟ Design Points | |
| 3 | Preserve Design Points After DX Run | Central Composite Design<br>Optimal Space-Filling Design<br>Box-Behnken Design<br>Custom<br>Custom + Sampling<br>Sparse Grid Initialization<br>Latin Hypercube Sampling Design |
| 4 | ⊟ Failed Design Points Management | |
| 5 | Number of Retries | |
| 6 | ⊟ Design of Experiments | |
| 7 | Design of Experiments Type | Central Composite Design |
| 8 | Design Type | Rotatable |
| 9 | Template Type | Standard |

Figure 6 - Virtual experiment design Plan

In this task, the following spreads of parameters were set: radius of the bearing fit from 15 to 25, projection width from 5 to 20, projection height, also discrete, from 3 to 8.

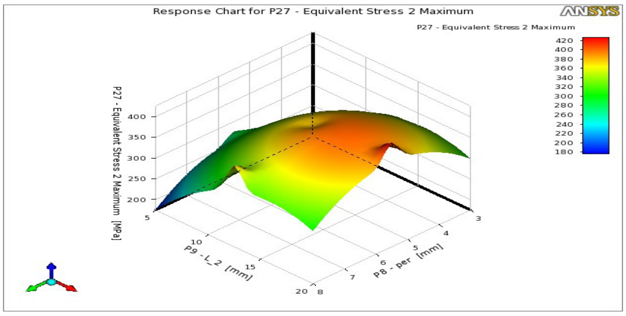
For calculation, using the main composite project, we have got 75 design points which will be determined by the finite element method. This point is very important and should be considered when optimizing. The experiment with the design points is presented in Figure 7.

Table of Schematic C2: Design of Experiments (Central Composite Design : Rotatable : Standard)

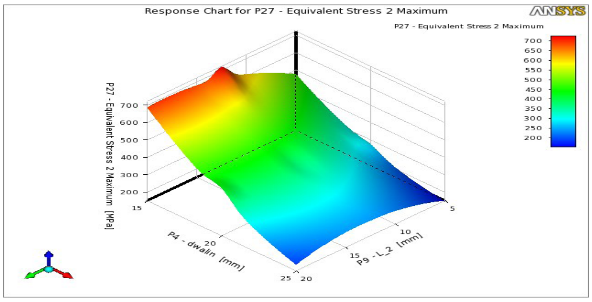
| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Name | Update Order | P4 - dwalin (mm) | P8 - per (mm) | P9 - L_2 (mm) | P27 - Equivalent Stress 2 Maximum (MPa) |
| 2 | 1 | 8 | 20 | 5.5 | 12.5 | 376.52 |
| 3 | 2 | 1 | 15 | 5.5 | 12.5 | 723.28 |
| 4 | 3 | 15 | 25 | 5.5 | 12.5 | 238.25 |
| 5 | 4 | 6 | 20 | 3 | 12.5 | 315.07 |
| 6 | 5 | 10 | 20 | 8 | 12.5 | 371.48 |
| 7 | 6 | 7 | 20 | 5.5 | 5 | 276.3 |
| 8 | 7 | 9 | 20 | 5.5 | 20 | 426.01 |
| 9 | 8 | 2 | 17.027 | 4.0135 | 8.0405 | 416.22 |
| 10 | 9 | 11 | 22.973 | 4.0135 | 8.0405 | 209.96 |
| 11 | 10 | 4 | 17.027 | 6.9865 | 8.0405 | 369.46 |
| 12 | 11 | 13 | 22.973 | 6.9865 | 8.0405 | 207.52 |
| 13 | 12 | 3 | 17.027 | 4.0135 | 16.96 | 510.1 |
| 14 | 13 | 12 | 22.973 | 4.0135 | 16.96 | 238.92 |
| 15 | 14 | 5 | 17.027 | 6.9865 | 16.96 | 463.26 |
| 16 | 15 | 14 | 22.973 | 6.9865 | 16.96 | 240.72 |

Figure 7 - Plan of the experiment with the design points

**Building the response surfaces.** Response surfaces are functions of a different nature which describe output parameters as a function of the input parameters. The response surfaces represent the approximated values of the output parameters in the entire analyzed space without the need for a complete calculation at all points. There are several types of response surfaces: a second-order polynomial, Kriging, nonparametric regression, a neuron network, a sparse grid [15,16,17,18,19]. Figure 8 shows the response surfaces.




a - the width and height of the projection;

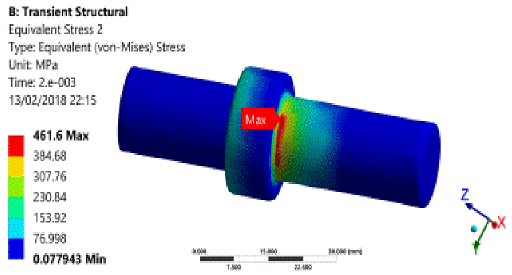



b - radius of the bearing fit and the projection width

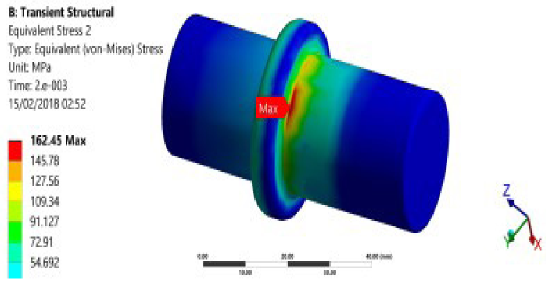
Figure 8 - Surface response:

Different approximation for the same set of data is given below. In order to make sure the choice of approximating the design data is correct, we use the method of estimating the distribution of design points on the response surface, as well as the coefficients: the determination coefficient (R-squared, it shows how well the response surface reflects the variability of the output parameter), the root-mean-square error, relative root-mean-square error, relative error of the absolute maximum. In our case, the Kriging approximation was the most suitable technique [20,21,22].

**Building an optimization model.** Viewing results. The optimization approach is an approach in which the search for the "best" possible design takes into account limitations on a set of parameters. We establish a series of target design conditions that will be used to form the optimal version: desired values of input values and response parameters are set, parameters are given the ranks of importance, a set of design options is generated, the most promising candidates are selected [23,24,25]. There are four methods for optimizing the response surface in DX: Shifted Hammersley, MOGA (Multi-objective Genetic Algorithm), NLPQL (Nonlinear Programming by Quadratic Lagrangian), MISQP (Mixed-Integer Sequential Quadratic Programming). In our case, the stresses should be in the range from 152 to 160 MPa. As a result of the calculation, 5 variants were obtained among which we choose the appropriate one. Similarly, the remaining tool components are optimized, becoming robust and effective. As a result, for the selected shaft parameters and taking into account the bearing dimensions, we perform a dynamic strength analysis and hence obtain the following picture of the change in the maximum stress (Figure 9).



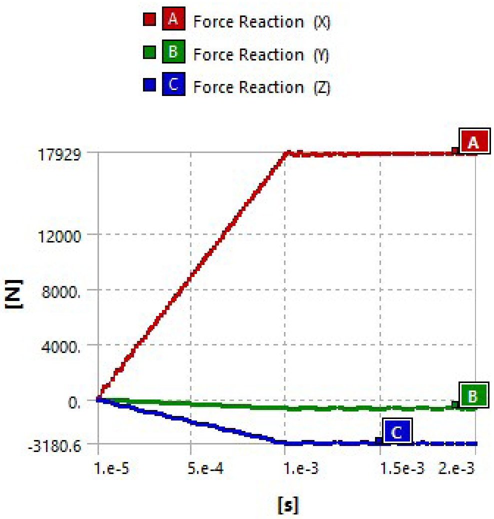

*(a)*



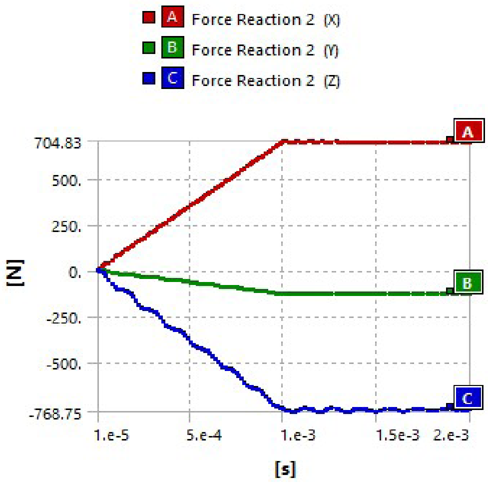

*(b)*

Figure 9 - Stress state of the shaft before (a) and after (b) optimization

This completes the shaft optimization and then we proceed to build a design model of the tool body (bearing), changing the parameters obtained after optimizing the shaft design. Using the components of the reference reactions from the strength calculation, we obtain the design scheme of the bearing assembly (Figure 10).




*(a)*

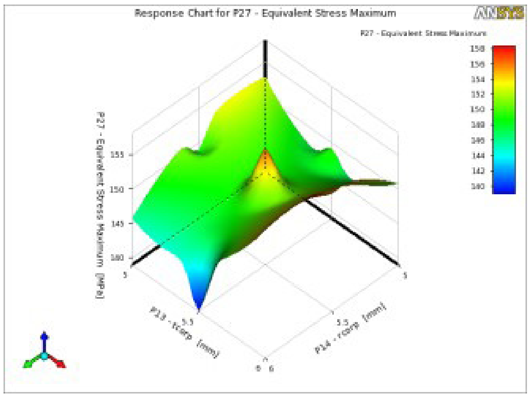



*(b)*

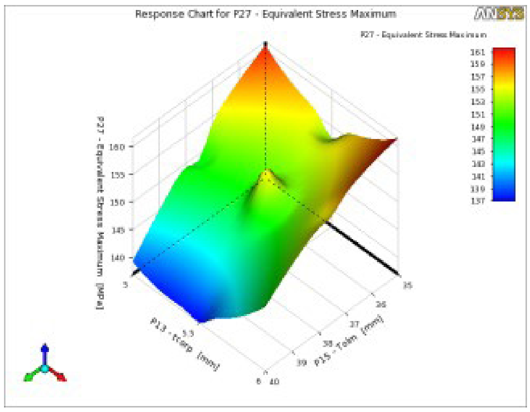
a) the first bearing; b) the second bearing

Figure 10 - Diagram of reaction forces

By the same algorithm, we determine the response surfaces (the maximum Mises stresses) from the main parameters (Figure 11).




*(a)*




*(b)*

a - from the bottom thickness and neck thickness;
b - from the bottom thickness and wall thickness

Figure 11 - Response surfaces

On the figure below, the first option is the most optimal from the presented candidate points since the input parameters in it, namely the dimensions of the tool body, are minimized and the resultant stress is in the specified limit of allowed values (Figure 12).

Table of Schematic D4: Optimization , Candidate Points

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Reference | Name | P13 - tcorp (mm) | P14 - rcorp (mm) | P15 - Tolm (mm) | | P27 - Equivalent Stress Maximum (MPa) | |
| 2 | | | | | Parameter Value | Variation from Reference | Parameter Value | Variation from Reference |
| 3 | ○ | Candidate Point 1 | 6 | 5.8618 | 35 | -0.01% | 163 | 1.49% |
| 4 | ◉ | Candidate Point 2 | 5.0005 | 5.0005 | 35.003 | 0.00% | 160.61 | 0.00% |
| 5 | ○ | Candidate Point 3 | 5.2435 | 5.8091 | 35.009 | 0.02% | 155.19 | -3.37% |
| 6 | ○ | Candidate Point 4 | 5.9725 | 5.2026 | 35.012 | 0.03% | 157.57 | -1.89% |
| 7 | ○ | Candidate Point 5 | 5.4865 | 5.4048 | 35.016 | 0.04% | 154.81 | -3.61% |

Figure 12 - Candidate points of the body parameters

Figure 13 shows the Mises stress in the body after optimization.

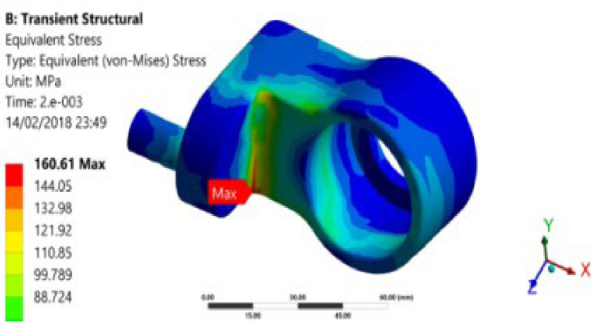



Figure 13 - The Mises stress in the body after optimization

In this regard, a part of the tool parameters for hole boring (which significantly affects the stress state) has been optimized, meeting the strength requirement.

**Conclusions**

1. Using the Johnson-Cook model as the failure criterion for the elements of the mesh, projections of the cutting forces resulting from hole processing were obtained.

2. The predicted changes in the projection of the cutting force and the cutting temperature are sensitive to changes in the cutting speed in accordance with modern concepts: with increasing cutting speed, the cutting force decreases and the temperature rises.

3. It is found that the averaged values of the force at the initial moment (penetration into a workpiece) vary linearly, then becoming practically constant.

4. The idea of parametric optimization consisted in carrying out several virtual experiments in which the possible range of variation of the basic dimensions and optimization criteria are specified, and optimal parameters of the tool design from the candidates are chosen.

5. The optimization method outstrips the design cycle, which is costly and time-consuming due to prototype tests and subsequent adjustments.

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## РОТАЦИЯЛЫҚ-ФРИКЦИЯЛЫҚ БҰРҒЫЛАУҒА АРНАЛҒАН ҚҰРАЛ КОНСТРУКЦИЯСЫН ANSYS WB КӨМЕГІМЕН ПАРАМЕТРЛІК ОҢТАЙЛАНДЫРУ

**Аннотация.** Авторлар үлкен тесіктерді айналмалы үйкеліс үшін өздігінен айналатын шыныаяқ кескіші бар айналмалы үйкеліс құралының арнайы дизайнын жасады. Мақалада ANSYS WB-де виртуалды эксперименттер арқылы айналмалы үйкеліс құралының кернеулі компоненттерін параметрлік оңтайландыру нәтижелері келтірілген.

Авторлар кесу күшінің құрамдас бөліктерін үлкен диаметрлі тесікті бұрғылау процесінде байланыс күші ретінде 20 градус болатын шыныаяқ кескіштің ең нашар күйінде болжап, есептелген модель жасады. Джонсон-Кук моделін тор элементтерін бұзу критерийі ретінде қолдана отырып, тесікті өңдеу нәтижесінде пайда болатын кесу күштерінің проекциясы алынды. Кіріс және шығыс параметрлері (кернеулер) арасындағы қатынас орнатылады, оңтайландыру критерийлері белгіленеді және құралдың кернеуінің оңтайлы параметрлері таңдалады. Сондай-ақ, бастапқы сәтте күштің орташа мәні (дайындамаға кесу) сызықтық түрде өзгеріп, содан кейін тұрақты болып қалатыны анықталды.

Параметрлік оңтайландыру идеясы бірнеше виртуалды зерттеулер жүргізу болды, онда негізгі өлшемдердің өзгеруінің мүмкін диапазоны көрсетілген және оңтайландыру өлшемдері берілген,

кандидаттардан құрал дизайнының оңтайлы параметрлері таңдалған.

Оңтайландыру әдісі прототиптерді сынақтан өткізуге және оларды кейіннен жетілдіруге байланысты қымбат және ұзақ болатын жобалау циклын айналып өтеді.

**Түйін сөздер:** айналушы үйкеліс құрал, үлкен тесіктерді өңдеу, табақшалы кескіш, параметрлерді оңтайландыру, кесу күші, мойынтірек қондырғысы, есептеу үлгісі, кернеу.

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## ПАРАМЕТРИЧЕСКАЯ ОПТИМИЗАЦИЯ СРЕДСТВАМИ ANSYS WB КОНСТРУКЦИИ-ИНСТРУМЕНТА ДЛЯ РОТАЦИОННО-ФРИКЦИОННОГО РАСТАЧИВАНИЯ

**Аннотация.** В современном машиностроении одной из актуальных проблем является обработка больших отверстий, к которым предъявляются высокие требования по точности размера, формы и расположения. Чаще всего на производстве обработка больших отверстий осуществляется расточными инструментами. Обработка этими инструментами сопряжена с рядом трудностей, обусловленных, прежде всего, низкой жесткостью инструмента, сложностью подвода в зону резания смазочно-охлаждающей жидкости (СОЖ) и отвода пульпы (смеси стружки и СОЖ). Это приводит к снижению точности и производительности обработки, а также стойкости инструмента.

Авторы спрогнозировали составляющие силы резания в наихудшем положении чашечной фрезы, которая составляла 20 градусов как контактные силы в процессе расточки отверстия большого диаметра и построили расчетную модель. Используя модель Джонсона-Кука в качестве критерия разрушения элементов сетки, были получены проекции сил резания, возникающих в результате обработки отверстия. Устанавливается соотношение между входными и выходными параметрами (напряжениями), задаются критерии оптимизации и выбираются оптимальные параметры составляющих напряжений инструмента. Так же установлено, что усредненные значения силы в начальный момент (врезания в заготовку) меняются линейно, затем становясь практически постоянными.

Достоверность модели подтверждает чувствительность силы и температуры резания к изменению скорости резания в соответствии с современными представлениями: с увеличением скорости резания сила резания уменьшается, а температура повышается. Метод оптимизации обходит цикл проектирования, который является дорогостоящим и длительным из-за проведения испытаний прототипов и последующей их доработки.

**Ключевые слова:** вращающийся фрикционный инструмент, обработка больших отверстий, чашечный резец, оптимизация параметров, сила резания, посадка подшипника, расчетная модель, напряжение.

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