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DETERMINATION OF OPTIMAL PARAMETERS FOR THE TECHNOLOGY OF PRODUCING ANISOTROPIC STRUCTURED FILTERS WITH HIGH PERFORMANCE CHARACTERISTICS UNDER CENTRIFUGAL FORCE BASED ON MATHEMATICAL PLANNING

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Abstract: The article determines the optimal technological regimes for obtaining cylindrical filters with an anisotropic structure possessing high performance and mechanical characteristics from BrOF10-1 bronze powders under the action of centrifugal force using the mathematical planning method. In the study, a comprehensive analysis was conducted on the influence of key factors—such as the relative sizes of powder fractions (d_n/D_0), container rotation speed (V_k), conical hopper movement speed (V_b), and sample thickness (h)—on the filter performance indicators. Based on mathematical modeling and experimental trials, the porous structure was optimized, and the required sintering temperature and time were established. Applying the developed optimal regimes reduced the sintering duration by **3 hours** and increased the efficiency parameter (E_1) and flexural mechanical strength (σ_{flex}) of the filters by **2 times**.

Keywords: Mathematical planning, centrifugal force, anisotropic structure, cylindrical filter, BrOF10-1 bronze powder, sintering regime, interparticle contact, porosity, permeability coefficient, efficiency parameter, mechanical strength.

Introduction. Deep purification of liquids and gases from various mechanical impurities is one of the most critical technological stages in many industrial sectors, including chemical, oil and gas, automotive, and environmental engineering. In this context, creating porous permeable materials (PPM) and filters characterized by high permeability, stable pore dimensions, and high mechanical strength is of paramount importance.

Although a number of technologies have been proposed to produce anisotropic structured filters to date, they retain several main systemic drawbacks:

1. **High raw material consumption:** Expensive metal powders are overconsumed because the optimal powder volume and inter-fraction ratios are not clearly defined.
2. **Uncertainty of geometric parameters:** Optimal indicators regarding the thickness and height of the resulting product are insufficiently grounded.
3. **Technological complexity:** Traditional methods are difficult to automate, requiring specialized and expensive equipment—especially when manufacturing complex geometrical and cylindrical filters.

To eliminate these problems, a specialized device mounted on a lathe machine was developed at the SUE "Fan va Taraqqiyot" of Tashkent State Technical University named after Islam Karimov, enabling the production of cylindrical filters under the action of centrifugal force.

The objective of the research is to determine the optimal technological parameters for obtaining cylindrical filters with an anisotropic structure possessing high performance characteristics

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from BrOF10-1 bronze powders with minimal raw material consumption under centrifugal force using the mathematical planning method.

1. Problem Statement

A number of authors [1, pp. 111–116; 2, pp. 105–108; 3, pp. 190–194] have proposed various technologies in their research to produce filters with high performance characteristics. However, these technologies exhibit several limitations:

- **First**, the optimal volume of powders is not specified precisely, leading to excessive consumption of metal powders during manufacturing;
- **Second**, optimal values for the thickness and height of the resulting products are not provided;
- **Third**, the processes are complex and difficult to automate, presenting substantial technical difficulties in producing cylindrical and complex-shaped items, which in turn demands dedicated machinery and specialized tooling.

The proposed method, along with overcoming the aforementioned drawbacks, enables the production of anisotropic structured cylindrical filters with high operational performance designed for the deep purification of liquids and gases.

For obtaining cylindrical filters under the action of centrifugal force, a specialized unit mounted on a lathe machine—developed at the SUE "Fan va Taraqqiyot" of Tashkent State Technical University named after Islam Karimov—was utilized (Figure 1).

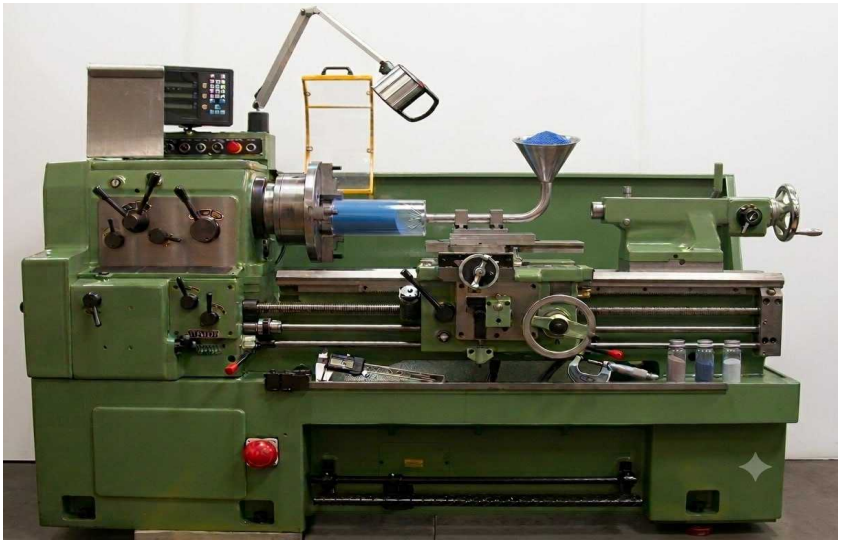


Figure 1. Device mounted on a lathe machine for producing cylindrical filters under centrifugal force (SUE "Fan va Taraqqiyot", TSTU named after Islam Karimov).

2. Research Methodology and Mathematical Planning

Mathematical planning of experiments plays a crucial role in developing a new method for producing cylindrical anisotropic-structured filters with high operational performance from metal powders under the action of centrifugal force. This approach drastically reduces the required number of experimental runs, increases the efficiency of the research, and enables the determination of optimal operating modes for the technological process [4, pp. 149–151; 5, pp. 77–91; 6, pp. 356–388].

The following factors were selected as independent variables in the experiment:

- X_1 — average relative particle size of the 1st fraction powder layered into the container and introduced into the pore spaces (d_1/D_0);
- X_2— average relative particle size of the 2nd fraction powder (d_2/D_0);

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- X_3— average relative particle size of the 3rd fraction powder (d_3/D_0);
- X_4— rotational speed of the container (V_k, rpm);
- X_5— horizontal movement speed of the conical hopper (V_b, mm/min);
- X_6— sample thickness (h, mm).

The factors were varied across 3 levels, and their coded and natural (physical) values are presented in Table 1.

Table 1

Variation levels (range) of factor values

Factors	Variation Level	
	Coded values	Physical Values of Factors
X_1, Average relative particle size of the 1st fraction (d_1/D_0)	+1 0 -1	0,3134 0,2500 0,2000
X_2, Average relative particle size of the 2nd fraction (d_2/D_0)	+1 0 -1	0,1577 0,1250 0,1000
X_3, Average relative particle size of the 3rd fraction (d_3/D_0)	+1 0 -1	0,0793 0,0627 0,0500
X_4, Rotational speed of the container (V_k, rev/min)	+1 0 -1	250 200 150
X_5, Horizontal movement speed of the conical hopper (V_b, mm/min)	+1 0 -1	25 20 15
X_6, Sample thickness (h, mm)	+1 0 -1	5,9 4,1 3,9

Based on practical experience and experimental test results, to ensure high permeability and mechanical strength of the filters, the primary base mass consisting of large particle size powder (+1000…−1250 μm) initially loaded into the mold with a layer thickness of 5 mm was treated as a constant factor, and the average particle size of this fraction was defined as D_0=1125 μm.

To generalize the results obtained in subsequent studies, the average values of the relative ratios d_1/D_0 , d_2/D_0 , and d_3/D_0 sequentially loaded into the container were calculated using Anderson's formula [7, pp. 11–15; 8, pp. 152–154].

The coded mathematical values of all factors were determined using the following equation [9, pp. 320–342; 10, pp. 136–141; 11, pp. 560–572]:

$$x_i=\frac{\tilde{x}_i-\tilde{x}_{i0}}{I_i}$$

where: x_i— coded mathematical value of the factor; $\tilde{x}_i$— natural (physical) value of the factor; $\tilde{x}_{i0}$— natural value of the factor at the base (zero) level; I_i— variation interval ($\frac{\tilde{x}_{max}-\tilde{x}_{min}}{2}$).

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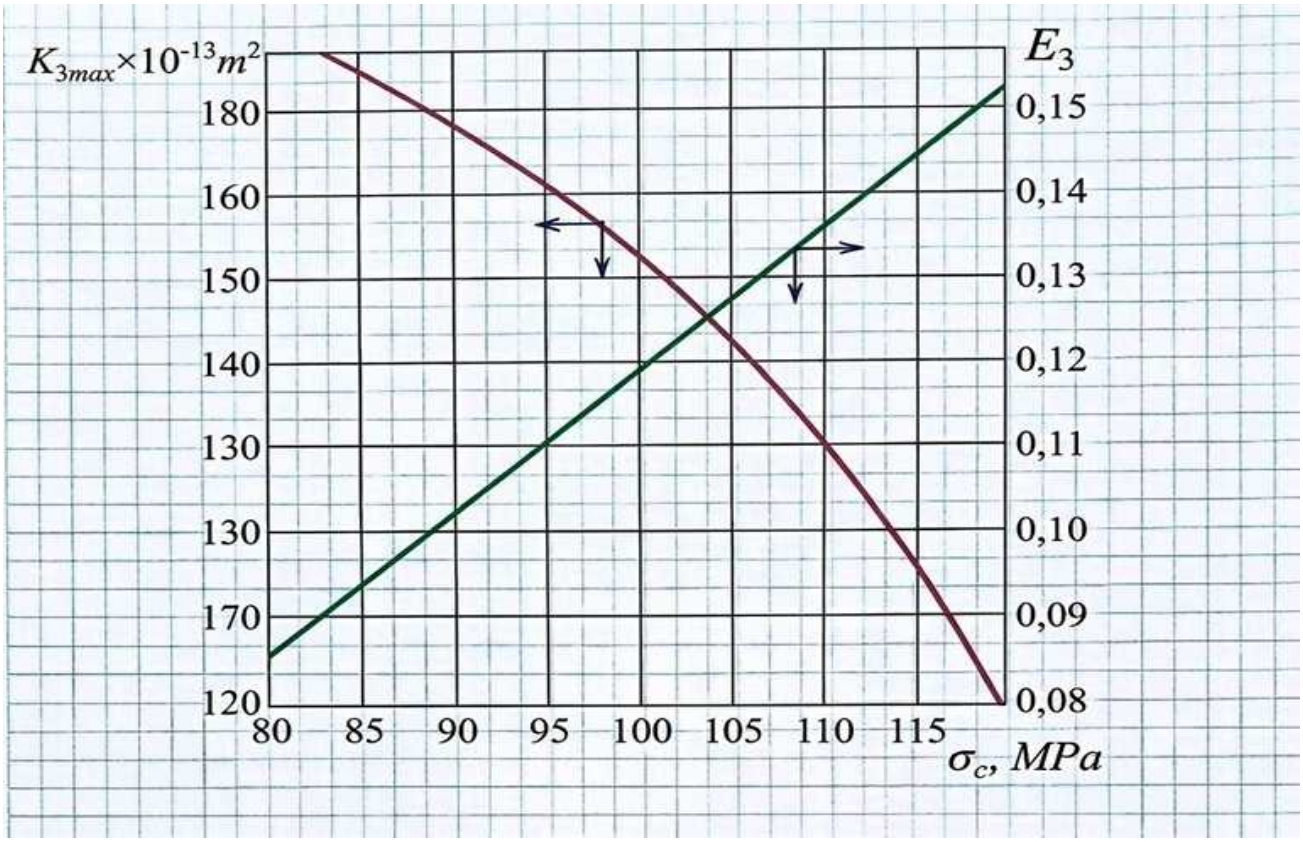
3. Results and Discussion

Regression equations were derived based on the experimental results for the process of obtaining anisotropic-structured cylindrical filters under centrifugal force by sequentially loading metal powders into a container. The adequacy of the mathematical models was verified using Fisher's criterion (F-test), which confirmed that the regression equations accurately fit the experimental data.

During the research, the characteristics of 32 raw material samples were investigated. The structure of a sintered preform made from BrOF10-1 grade bronze powder with pore arrangements corresponding to the +1000…−1250 μmfraction and the stages of introducing small particles into the pore interspaces were analyzed.

Through mathematical modeling, regression dependencies were established between the key independent factors and the primary performance indicators of the sample—namely, the efficiency parameter (E_1), permeability coefficient (K_1), and flexural strength limit (σ_{flex})—following the 1st, 2nd, and 3rd stages of introducing fine particles into the pore spaces.

Based on the regression equations, a nomogram was constructed to determine the local maximum values of the permeability coefficient and efficiency parameter at a fixed value of mechanical strength for an average pore diameter of d_{pore}=20 μm(Figure 2).



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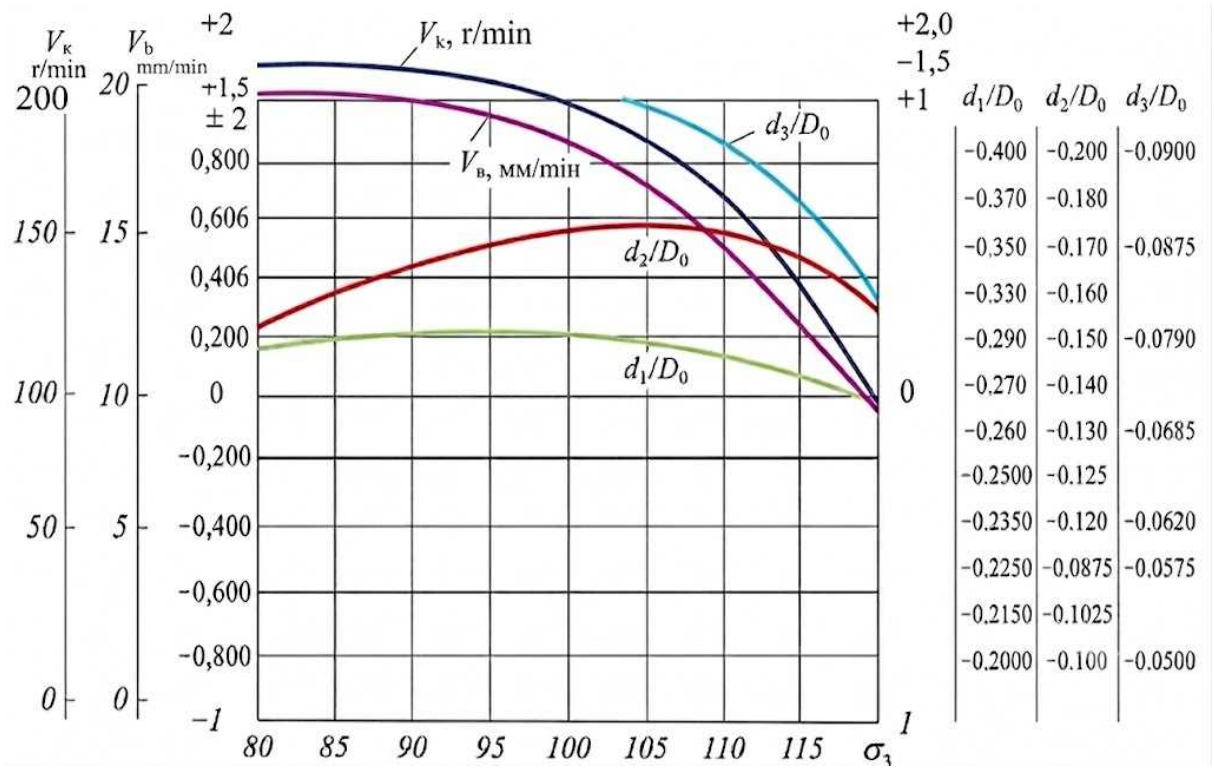


Figure 2. Nomogram for determining the local maximum values of the permeability coefficient and efficiency parameter for the sequential loading method of powders into a container under centrifugal force at an average pore diameter d_{pore}=20 μmand a specified mechanical strength.

Based on the experiments conducted, the following regression equation was derived for obtaining cylindrical filters with an anisotropic structure under the action of centrifugal force by sequentially loading metal powders into a container:

$P = 38{,}4+1{,}01 \cdot x_1+0{,}059 \cdot x_6+0{,}06 \cdot x_2 \cdot x_3-0{,}063 \cdot x_3 \cdot x_5+0{,}11 \cdot x_3 \cdot x_5;$

$D_p^{max} = 32{,}35-14{,}94 \cdot x_1+136{,}28 \cdot x_1^2+21{,}39 \cdot x_3^2+10{,}99 \cdot x_5^2+9{,}1 \cdot x_6^2;$

$D_p^{cp} = 20-5{,}21 \cdot x_1-12.36 \cdot x_2 +5{,}62 \cdot x_4 – 9{,}2 \cdot x_1 \cdot x_2 +11{,}71 \cdot x_2^2 +25{,}61 \cdot x_3^2+12 \cdot x_5^2;$

$K = 128-0{,}13 \cdot x_1-0{,}125 \cdot x_2- 0.88 \cdot x_3+0{,}17 \cdot x_4 +0{,}11 \cdot x_5 +1{,}25 \cdot x_1^2;$

$E_1 = 0{,}14 – 0{,}007 \cdot x_1^2 – 0{,}008 \cdot x_2^2 – 0{,}07 \cdot x_3^2 – 0{,}011 \cdot x_4^2 – 0{,}012 \cdot x_6^2;$

$\sigma_{изг} = 115{,}6 + 5{,}17 \cdot x_2 + 5{,}27 \cdot x_3 + 7{,}16 \cdot x_2^2 – 8{,}18 \cdot x_4^2 – 8{,}77 \cdot x_6^2$

The efficiency parameter (E_1) is an indicator characterizing the permeability of the material and the performance of the filtration process, determined by the following formula:

$$E_1 = \frac{K_1}{d_{pore}^2}$$

where: K_1— permeability coefficient, m^2; d_{pore}— average pore diameter, μm.

Conclusion

Using the method of mathematical planning, a new method for producing cylindrical anisotropic-structured filters with high operational performance under centrifugal force was developed, and the optimal technological regimes were determined:

1. **Container rotational speed:** V_k=200 rpm.

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2. **Horizontal movement speed of the conical hopper:** V_b=20 mm/min.
3. **Powder size ratios by layer (for BrOF10-1):**
   - 1st layer: +1000…−1250 μm (D_0=1125 μm);
   - 2nd layer: $0.15 \le d_1/D_0 \le 0.25$;
   - 3rd layer: $0.063 \le d_2/D_0 \le 0.080$;
   - 4th layer: $0.040 \le d_3/D_0 \le 0.050$.
4. **Pore penetration depth:** In the 1st, 2nd, and 3rd layers, it equals **1.5**, **0.5**, and **0.25** times the average powder particle diameter of the respective layers.
5. **Sintering regime:** Sintering at **810 °C** in a hydrogen atmosphere for **1 hour**. At a temperature of **800–810 °C**, the relative size of the interparticle contact neck was F=0.15…0.20.

As a result, the technological processing time was reduced by **3 hours**, while the efficiency parameter (E_1) and mechanical strength (σ_{flex}) of the samples increased by **2 times**.

References

1. Negmatov S.S., Pilinevich L.P., Karshiev M., Yunusov N.S., Sattarov A.A., Yunusalieva K.I., Rakhimov M.Yu. Theoretical description of the deposition process of spherical composite metal powders into a porous blank under vibration // Composite Materials. — Tashkent, 2020. — No. 1. — Pp. 111–116.
2. Rakhimov M.Yu., Abdusattorov D., Karshiev M., Negmatov S.S., Sattarov A.A., Yunusov N.S., Salimova S.A., Yunusalieva K.I., Fayzieva N., Ruzmatova G. Technological process for manufacturing porous permeable material (PPM) allowing to obtain products with increased permeability and mechanical strength values for a given pore size // Composite Materials. — Tashkent, 2020. — No. 4. — Pp. 105–108.
3. Sattarov A., Yunusalieva K.I., Karshiev M., Begatov Zh.M., Etmishev A.A. Regeneration of filters made of bronze metal powders for drinking water purification by ultrasound method // Composite Materials. — Tashkent, 2023. — No. 1. — Pp. 190–194.
4. Sadovnichaya I., Khoroshenkova E. Mathematical Analysis. — Moscow, 2018. — Pp. 149–151.
5. Brodsky V.Z. et al. Tables of Experimental Plans for Factorial and Polynomial Models. — Moscow: Metallurgiya, 2002. — Pp. 77–91.
6. Seber G.A.F. Linear Regression Analysis. — Moscow: Mir, 2000. — Pp. 356–388.
7. Yunusalieva K.I., Karshiev M. Creation of highly efficient PPM with anisotropic pore structure by the method of layer-by-layer filling of metal powder into a mold // Universum: Technical Sciences. — 2024. — Vol. 8(125). — Pp. 11–15.
8. Yunusalieva K.I., Karshiev M., Negmatov S.S. Study of properties of PPM obtained by introducing small particles into a porous blank under vibration // Proc. Rep. Sci.-Tech. Conf. "Progressive technologies for obtaining composite materials based on local and secondary raw materials". — Tashkent, September 14–15, 2023. — Pp. 152–154.
9. Seber G.A.F. Linear Regression Analysis. — Moscow: Mir, 2000. — Pp. 320–342.
10. Sadovnichaya I., Khoroshenkova E. Mathematical Analysis. — Moscow, 2018. — Pp. 136–141.
11. Kostornov A.G. Parameters of the porous structure of permeable materials. I. Theoretical premises and model studies // Powder Metallurgy. — 1978. — No. 4. — Pp. 34–40.