Effective Technologies for Finishing and Cleaning Processing: Innovations Based on Screw Rotors

Aleksandr Sekisov*

Kuban State Technological University, Krasnodar, Russia

Abstract: The results of many years of scientific research in the development of machines, installations, and devices for finishing and cleaning processing of machine parts are presented. Typical diagrams of machines based on screw rotors of classes I-IV are included, along with the types of finishing and cleaning operations performed by screw rotors, requirements for the parts being processed, the processing environments, and the composition of solutions used in the finishing and cleaning of components. Additionally, the methodology and calculations for a continuous operation setup designed for finishing and cleaning parts with specified productivity are demonstrated.

Keywords: Finishing and cleaning processing of parts, Equipment, Loading, burrs, Abrasive media, Processing waste.

INTRODUCTION

The study of the processes of vibratory finishing and cleaning treatment of part surfaces represents a complex task that requires a thorough analysis of previously conducted research and consideration of various approaches to optimizing these processes. In this regard, the results of the scientific research presented in this article are based on a systematic analysis and evaluation of both theoretical knowledge and practical data covering several key areas.

First and foremost, we focused on new rotary-screw systems designed for part processing. The most important aspects of our research included issues related to increasing the efficiency of cleaning and hardening processes, as well as an analysis of the main trends in the intensification of these technological processes. We also paid attention to the optimization of processing parameters and conducted a comparative analysis of various methods, including traditional technologies [1, 3]. This allowed us to identify the advantages and disadvantages of different approaches, which in turn contributed to a deeper understanding of the processes under consideration and the potential for their improvement.

The next direction of our research involved studying new methods for calculating characteristics and designing equipment for part processing, with an emphasis on the technological features of rotary-screw systems [2, 5]. We analyzed how these features affect the design and operation of the equipment, enabling the creation of more efficient and reliable solutions. It is important to note that such calculation methods can significantly enhance the intensity and quality of processing, which is a key factor in modern manufacturing conditions.

Following this, we explored various aspects of rotary-screw systems related to improving their productivity. In this context, our research covered both theoretical foundations and practical applications of rotary-screw technologies [4, 7-10]. This allowed us not only to assess the current state of technologies but also to identify directions for further research and development, which is an important step towards creating more efficient manufacturing processes.

Finally, we conducted a study on the behavior of bulk material particles in screw drums, examining the dynamics of their movement, as well as their interactions with each other and with the screw drum itself [6]. This research is significant as understanding these processes allows for the optimization of equipment operation, improving processing quality and reducing costs.

Based on the analysis of various sources, it is important to note that vibratory finishing and cleaning treatment of part surfaces is generally carried out under the influence of uniform vibrations with an amplitude not exceeding 4-8 mm. However, the complexity and diversity of the motion forms of the bulk materials in the working organs of machines, as well as the increase in their amplitude using methods of descriptive geometry and engineering graphics, open new opportunities for designing working organs using curved or flat elements in the form of screw rotors.

*Address correspondence to this author at the Kuban State Technological University, Krasnodar, Russia;
E-mail: alnikkss@gmail.com

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Nevertheless, the implementation of these approaches faces certain difficulties related to the lack of information about the types of finishing and cleaning operations in screw rotors, the requirements for parts, processing media, and the methodology for calculating such equipment. This creates specific challenges in combining transport and technological operations, necessitating further research and development in this area.

MODELS AND METHODS

Types of operations for finishing and cleaning processing in screw rotors.

1. Cleaning operations: surface cleaning of parts from burnt residues after casting in sand molds, scale after heat treatment, and from corrosion and contaminants; removal of flash from parts obtained by die casting; deburring of parts produced by cold sheet stamping and cutting.

2. Finishing operations: preparation of surfaces of parts for galvanic and paint coatings; polishing.

Requirements for Processed Parts

1. The maximum dimensions of the part must not exceed one third of the diameter of the screw rotor's passage section ($d_{p.\kappa} = 2 \cdot r$).

2. The thickness of the part must not be less than: for class I screw rotors – 3 mm; class II – 1,5 mm; class III – 1,5 mm; class IV – 0,5 mm. In class IV screw rotors, processing of parts with a thickness of less than 0.5 mm is allowed, provided they have sufficient stiffness.

3. For parts obtained by die casting, the thickness of the flash base at the parting line of the mold must not exceed 0,5 mm. If the flash is thicker, processing with forced transportation of the processed parts in special protective devices along the longitudinal axis of the rotating screw rotor is required.

4. The maximum height of burrs along the contours of parts obtained by cold sheet stamping must not exceed 30% of the sheet thickness. The thickness of the burr base must not exceed 1,5 mm.

5. Blind holes and grooves can only be processed if the size of the granules (particles) of the working media does not exceed 0,3 times the diameter of the hole or the width of the groove. Additionally, the depth of holes with a diameter of up to 10 mm must not exceed the diameter, while for holes with a diameter of 10-15 mm, the depth must not exceed two times the diameter. The depth of grooves with a width of up to 10 mm must not exceed its width, and for grooves 10-50 mm wide, the depth must not exceed double its width.

6. When there is external and internal threading, the accuracy must not be higher than class III, and the diameter must not be less than 15 mm.

Processing media. In equipment based on screw rotors, processing media consist of particles of working media and an intensifying solution. Depending on their effect on the surface of the parts, working media are divided into abrasive (natural and artificial) and non-abrasive. Natural and artificial abrasive working media (particles) can have arbitrary or regular geometric shapes (prism, pyramid, cube, cone, etc.). Abrasive particles of arbitrary shape are obtained by crushing natural rocks (for example, baikalite, waste from abrasive wheels, recycling of abrasive tool waste, pieces of electrocorundum, etc.). After crushing, the particles of the working media are sorted into fractions of the required sizes using sieves. Abrasive particles of regular shape are manufactured at specialized facilities from grinding powders, which are mixed with a binder, shaped, and fired. Non-abrasive working media include cast star-shaped pieces, small stamping waste, steel, porcelain, glass balls, wooden cubes, fruit pits, pieces of leather, felt, wool and others.

The choice of material, size, and shape of the particles of working media is determined by the following factors: the purpose of the operation; the material, size, and shape of the parts; the initial condition of the surface of the parts; the required quality of the surfaces of the parts; and the requirements for maintaining the geometry and dimensions of the parts.

The same operation can be performed with various types of particles of working media. It is important to consider that the removal rate decreases with the reduction of the abrasive grain size in the particles of the working media, while the wear of the particles increases with the decrease in the hardness of the binder. Parts and particles of working media should occupy no more than 50% of the volume of the screw rotor. In cleaning operations, the volumes occupied by the parts and the working media should be the same.

In finishing operations, the volume of the parts should be one-third of the volume of the working media, and for parts with low stiffness, it should be about one-fourth of the volume of the working media.

The solutions used in finishing and cleaning operations may contain alkalis and acids. The solutions generally consist of several substances that have a comprehensive effect on the finishing and cleaning process in screw rotors. The solution should be supplied around the perimeter in the central part of the screw rotor, at the entrance (for preliminary washing), and at the exit of the parts from the screw rotor. The precise regulation of the amount of solutions should be such that the circulation of parts and particles of working media is as intense as possible. Increased solution supply is used in finishing operations, as well as when processing parts with low stiffness.

Devices based on screw rotors of classes I-IV are recommended for performing finishing and cleaning operations.

Screw rotors of class I. Devices for finishing and cleaning operations with a class I screw rotor are shown in Figure **1**.

The screw rotor 5 is made up of sections, each section is assembled from triangular shapes of different orientations, which allows for an increased number of screw threads without limitations on their even number, and ensures an increase in the rotor's cross-sectional area. The number of equilateral triangles in a section can be at least six. In this case, an octahedral screw rotor can be obtained, assembled from octahedral voids (Figure **2-4**).

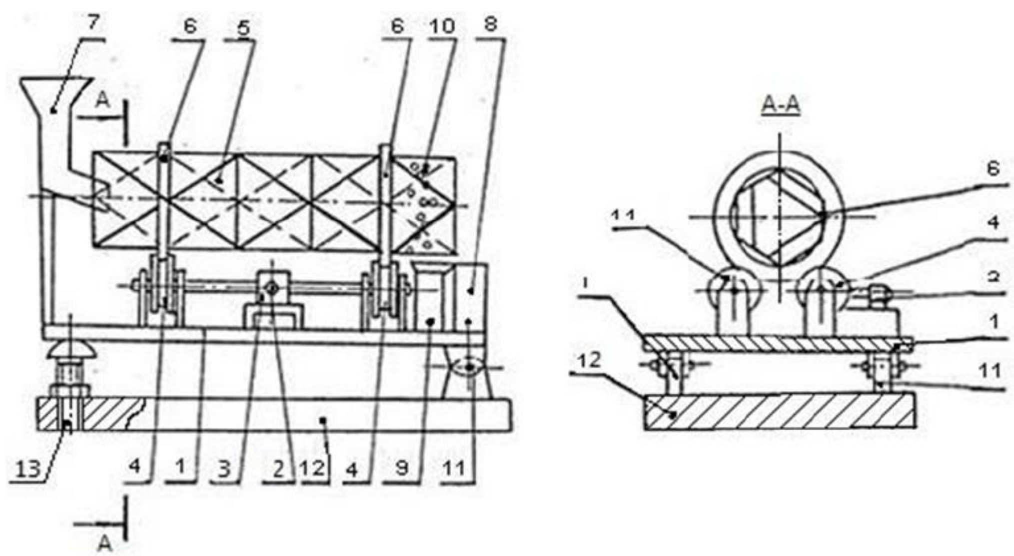

Figure 1: Device for finishing and cleaning parts based on a class I screw rotor:

(1 – base, 2 – electric motor, 3 – gearbox, 4 – roller supports, 5 – screw rotor, 6 – two rims, 7 – loading mechanism, 8 – unloading mechanism, 9 – waste hopper, 10 – holes for waste removal (burrs, metal shavings, scale, etc.), 11 – support, 12 – support plate, 13 – adjustment screws).

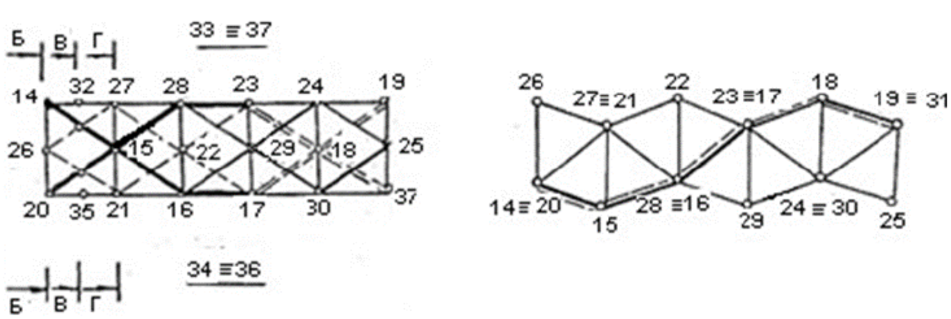

Figure 2: Class I screw rotor (front view and top view):

(14-15-16-17-18-19 – one of the right screw threads, 20-21-22-23-24-25 – second right screw thread, 26-27-28-29-30-31 – third right screw thread).

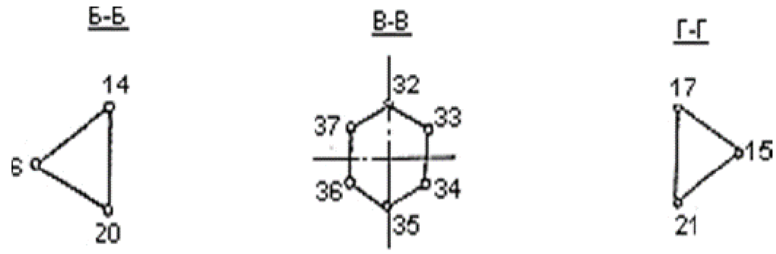

Figure 3: Sections B-B, V-V, G-G in Figure 2:
(6, 14, 20 – vertices of the triangular section of the screw rotor, 33, 34, 35, 36, 37 – vertices of the hexagonal section of the screw rotor, 15, 17, 21 – vertices of the triangular section of the screw rotor).

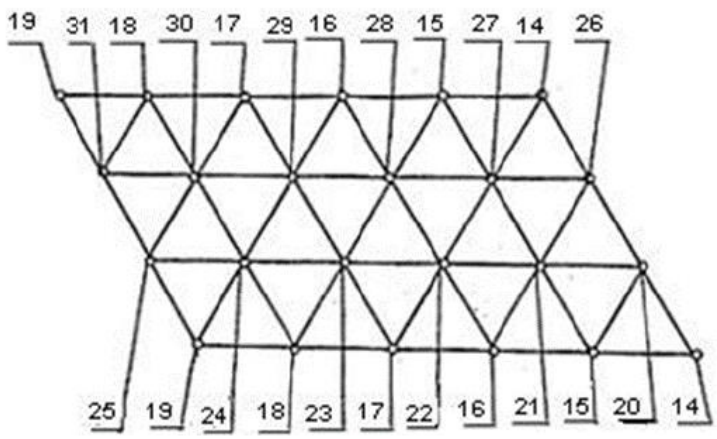

Figure 4: Development of the lateral surface of the class I screw rotor:
(14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31 – vertices of the triangles around the perimeter of the screw rotor).

The vertices of the octahedra 14-31 form a clearly defined right three-way cylindrical screw thread. One pitch of the screw thread contains 6 sections of octahedral voids.

The cross-sectional area of the class I screw rotor changes 12 times along the length during one step of the screw line. In each octahedral section, it changes twice, from a minimum – an equilateral triangle (14, 20, 26) to a maximum – a regular hexagon (32, 33, 34, 35, 36, 37) and so on. As a result, the velocity of the working medium and components changes 12 times during one step of the screw line in the class I screw rotor. The performance of the device, *i.e*. the time components spend in the class I screw rotors, is regulated by the inclination of the base I and the mounted screw rotor 5 relative to the horizontal support plate 12 by rotating the base I in the supports 11 using adjustment screws 13.

The implementation of the screw rotor with opposing screw lines of equal pitch and an equal number of opposing threads significantly increases the energy intensity of collisions between components and particles of the working medium, minimizes the speed of component movement from loading to unloading, allows for increased productivity, and reduces the overall length of the device.

The device operates as follows. Components and the working medium continuously flow into the loading funnel and exit through the outlet into the screw rotor. After processing, the components and particles of the working medium are discharged into the receiving container. The working medium is returned again through the loading device into the cavity of the screw rotor. The angle of inclination of the device is adjusted using adjustment screws mounted in the base. This significant drawback of devices based on class I screw rotors of various modifications allows for the transportation of components and working media inside the screw rotors due to the natural slope of the walls of its perimeter.

Class II screw rotors. Description of the device for finishing and cleaning components. The device

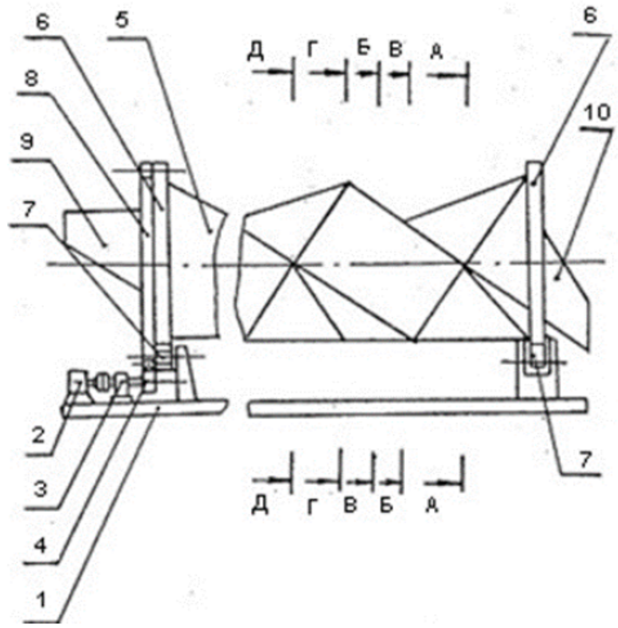

Figure 5: Device for finishing and cleaning processing based on class II screw rotor.

includes a screw rotor 5, secured on the casings 6 and mounted on support rollers 7. One of the casings 6 has a crown gear 3. The device is equipped with loading 9 and unloading 10 chutes (Figure **5**).

At the points where each of the four right-hand screw lines meets the two left-hand screw lines on the surface of the screw rotor, ridges are formed that act as lifts for the components and particles of the working media. As the rotor rotates, the loading slides along the inner surface of the rotor, resulting in cascading movement and intensive mixing.

Figure **6** shows the cross-sections of the screw rotor, where the center of rotational symmetry 0_1 is offset from the axis of rotation of the rotor 0. Along the length of the screw rotor, between sections Д-Д and Г-Г, as well as between sections B-B and A-A, only the dimensions, shape, and position of the center of rotational symmetry relative to the axis of rotation change. Along the length of the screw rotor, between sections Г-Г and B-B, in addition to changes in shape, dimensions, and the position of the center of symmetry, the cross-sectional figures increase abruptly by one-third the number of sides of the cross-sectional figures.

The screw rotor 5 is designed with oppositely directed screw lines, for example (½S) – one screw line at the peaks 11, 35, 28, 20, 13, 37, 30, etc., the second at 19, 22, 36, 29, 21, 14, 38, etc. Figure **7** shows an axonometric projection of one of the class II screw rotors with two broken lines. The common point of these two lines creates a ridge that not only acts as a lift but also facilitates the creation of conditions for changing the direction of the loading movement, increasing the frequency and energy intensity of collisions.

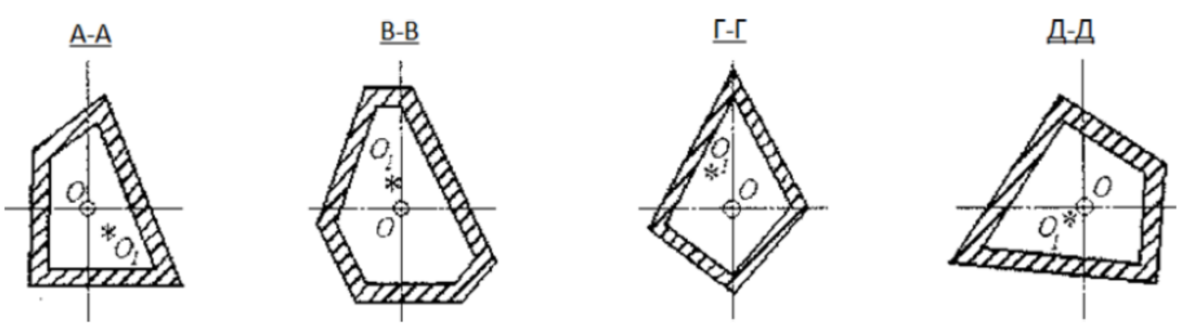

Figure 6: Cross-sections of the class II screw rotor in Figure 5.

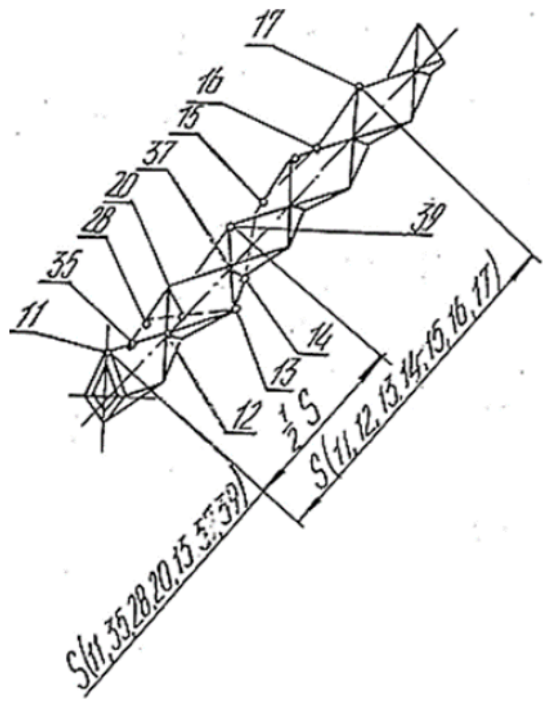

Figure 7: Axonometric projection of the class II screw rotor: (11-12-13-14-15-16-17 – one of the left screw lines, 11, 35, 28-20-13-37-39 – one of the right screw lines).

Figure **8** shows in axonometric projection one of the elements (one of the sections) of the screw rotor in the form of a diagonally cut thin-walled cube.

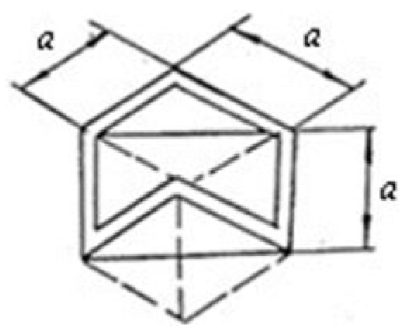

Figure 8: One of the sections of the class II screw rotor: α – side of the section.

Figure **9** shows the sequence of connecting sections during the manufacturing of the screw rotor, with five identical ections А, Б, В, Г, Д being welded, indicated by dashed lines perpendicular to the weld seam.

During the rotation of such a screw rotor, cascading movement and mixing occur. The helical lines are oriented in different directions, and the cross-sectional shape, within which the components and the working medium move, abruptly changes not only the number of sides but also the position of the center of symmetry of the shape relative to the axis of rotation. The flow of falling components and particles of the working medium is non-stationary, and the sizes and locations of the zones of active collisions change significantly during a single rotation, leading to a disruption of the orderliness of the movement process and an increase in the activity of collisions (after processing, they are unloaded into a discharge medium).

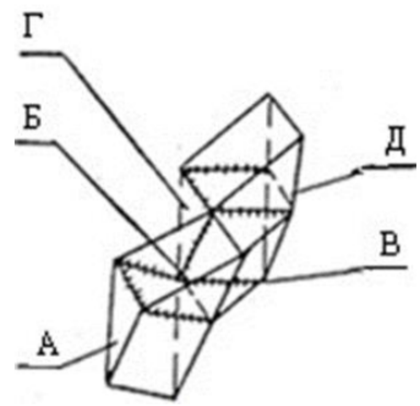

Figure 9: Sequence of connections of sections during the assembly of the class II screw rotor А, Б, В, Г, Д.

Screw rotors of class III. The installation for finishing and cleaning the components based on a class III screw rotor is shown in Figure **10**.

The technical and economic advantages of implementing class III screw rotors arise from increased energy capacity and the frequency of interactions among the processed parts, working medium particles, and the walls of the screw rotor.

Class IV screw rotors. Description of the device for finishing and cleaning with a class IV screw rotor. This device for finishing and cleaning is shown in Figure **11**. In the cross-section of the screw rotor, flat shapes of linear and curvilinear forms are formed, with the number of screw rotor turns equal to three, and the screw strips described by curves.

The technical and economic advantages of implementing unidirectional screw rotors arise from the reduction of defects when processing parts with low rigidity, improved processing quality, and increased productivity of devices based on class IV screw rotors made of screw strips with convex curvilinear shapes, which allow for an increase in the cross-sectional area of the class IV screw rotor by up to 20%.

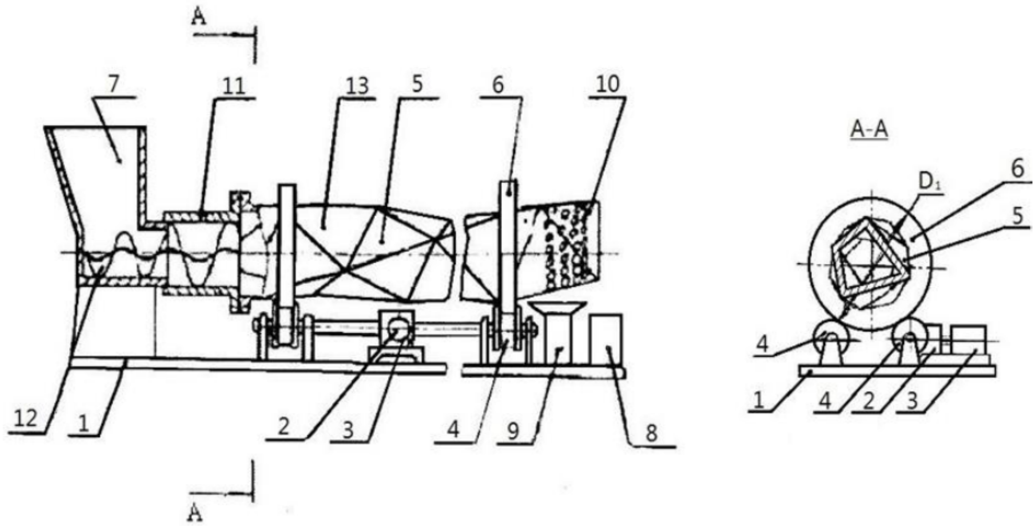

Figure 10: Device for finishing and cleaning parts based on a class III screw rotor:
(1 – base, 2 – electric motor, 3 – gearbox, 4 – roller supports, 5 – screw rotor, 6 – support roller, 7 – loading device, 8 – unloading device, 9 – device for receiving working medium and waste, 10 – holes for discharging production waste and abrasive media, 11 – cylindrical casing, 12 – two-stage screw winding, 13 – small diameter screw winding).

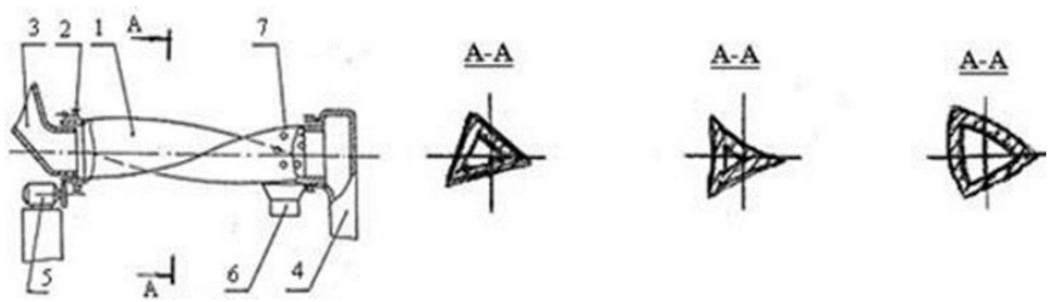

Figure 11: Device for finishing and cleaning based on a class IV screw rotor (front view and section A-A):
(1 – screw rotor, 2 – bearing, 3 – feed pipe, 4 – discharge pipe, 5 – drive, 6 – waste hopper, 7 – holes for processing waste).

RESULTS AND DISCUSSION

Overall, the standard machine layouts based on four classes of screw rotors provide processing for a wide range of parts in engineering enterprises. These layouts are designed with various requirements for productivity and flexibility in mind. Each class of screw rotors has its own design features and areas of application. When selecting the processing working medium, the material, weight, and rigidity of the parts being processed are taken into account. The main recommendations for choosing the processing working medium include analyzing the physical properties of the material, its density, and the coefficient of friction. For materials with a high coefficient of friction, it is recommended to use abrasive materials with fine granulation. When working with heavy parts, it is preferable to use non-abrasive materials to reduce the load on the equipment. The rigidity of the processed parts also influences the choice of working medium – softer abrasives should be used for soft materials.

Each of the four classes of screw rotors has its own design features and areas of application. The developed standard machine layouts based on screw rotors have demonstrated high efficiency in processing a wide range of parts. They provide high processing quality, increased productivity, and flexibility in application. At the same time, the production and operating costs of such machines are lower than those of traditional machines. This allows enterprises to significantly reduce costs for tools and consumables.

Based on the developed layouts, it is possible to continue improving the technology for processing parts, increasing its efficiency and versatility. This can be achieved by optimizing the parameters of screw rotors and developing new classes for processing complex materials. It is proposed to explore new classes of screw rotors specifically designed for processing complex materials. Such rotors can provide more precise processing and increased productivity when working with unconventional materials.

One of the key areas of development is the creation of adaptive control systems for the processing process. These systems will be able to automatically adjust processing parameters depending on the type of material being processed and the required quality. The application of artificial intelligence in the development and use of screw rotors will significantly enhance processing efficiency. AI systems will be able to analyze data on productivity and processing quality, proposing optimal solutions for each specific case. An important direction is the optimization of energy consumption of screw rotors. This can be achieved through the development of more efficient drive systems and the use of energy-efficient materials in rotor design. The development of a modular system of screw rotors will allow enterprises to quickly adapt to changes in demand for various types of processing. This will significantly simplify the equipment upgrade process and can reduce production costs.

Particular attention should be paid to safety when working with screw rotors. This includes the development of additional protective systems and the creation of instructions for the safe handling of equipment. It is necessary to explore the possibilities of applying the developed layouts and screw rotors in other industries where the processing of various parts is required. This could open new markets for products and expand the functionality of equipment. An important aspect of development is the creation of appropriate educational programs for specialists working with screw rotors. This will help prepare qualified personnel and ensure the transfer of knowledge to future generations. It is also necessary to explore the possibilities of integrating screw rotors with other processing technologies, such as laser cutting or nano-processing. This could significantly expand the application possibilities of the equipment in various industries.

CONCLUSION

The article presents standard machine layouts based on four classes of screw rotors, which provide processing for a wide range of parts in engineering enterprises. Key recommendations for selecting the processing working medium have been formulated, with abrasive and non-abrasive materials of various granulations being applicable. These recommendations take into account the material, weight, rigidity of the parts being processed, and the class of screw rotors.

The application of standard layouts and recommendations aims to achieve the following results under specific conditions:

1. Increased productivity: the developed standard machine layouts based on screw rotors ensure the processing of a wide range of parts with high speed and accuracy. This allows enterprises to significantly increase production volume without the need for a substantial increase in the number of employees.

2. Enhanced production flexibility: the scalability and versatility of the proposed layouts allow for easy adaptation of equipment to various types of processed materials. This enables enterprises to respond more quickly to changes in demand and expand the range of products offered.

3. Reduced production costs: by using the developed layouts and recommendations for selecting the processing working medium, it is possible to significantly cut costs for tools and materials. This is achieved through more efficient use of abrasive and non-abrasive materials of various granulations.

4. Improved product quality: the main recommendations for selecting the processing working medium consider the physical properties of the materials being processed. This ensures high-quality processing of parts, which is critically important for many industries.

CONFLICTS OF INTEREST

The author declared no conflicts of interest.

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