Determination of device construction design and parameters for copper wire extending methods

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Abstract. This article analyses the factors that affect the surface layers that occur in the stretching methods used for processing on traction machines on copper materials, and the structures of the technological equipment, the causes of which are studied, and provides recommendations. The essence, technical function, basic elements, attachment sequence and principles of operation of the structure of the device recommended for traditional stretching methods are fully stated in the traction machines. In the process of stretching, in the centre of the working part of the device structure, the formulas for determining the compressions, stretches, elongation coefficients, voltages and tensile forces formed by plastic deformation are presented. In the structure of the device, designed with the aim of theoretical substantiation of research, the compression values in the process of stretching copper wires of the M1 brand are determined by the ratio of stretching, and the dependence of the cone angle of the technological unit on the force of gravity is determined by the parameters for the traditional method of stretching Based on these results, to stretch coloured metal wires in a cylindrical shape using ballots, the device structure is recommended as technological equipment for traction machines used in industry.

1 Introduction

Wires made of non-ferrous metals are the main product of processing in drawing machines used in the metallurgical industry and are widely used as products or semi-finished products in all industries of our time. Ensuring technical economic efficiency, increasing the competitiveness of non-ferrous metal wire products replacing real imports, and the main directions of its improvement require the introduction of technological devices and equipment that reduce material and energy consumption in existing enterprises. The production of non-ferrous metal wires includes the following technological operations, structure (heat treatment), preparation of the surface of the workpiece, coating, forming and other finished wire processes. The main form and characteristic operation are stretching. For its implementation, solid, hard alloy balls or roller rollers of various shapes are used. This method has been used for many centuries and has made great progress in the development of the theory and practice of its use. It is equipped with industrial equipment and other

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infrastructure. At the same time, the need to increase the diameter and strength of the produced wire, as well as to reduce production costs, and constantly increase its quality, requires the improvement of technological processes, that is, first of all, the improvement of deformation modes of stretching. In this regard, both the traditional method and the new stretching methods that are currently developing, the cost of its production to increase and reduce the quality of the wire, the determination of the reserves that have not yet been carried out, and the creation of methods for designing combined technological processes of wire production based on the principle of increasing.

Currently, the demand for technologies and equipment of modern production is given to increasing the quality of products in any production conditions, the production of products that meet export requirements [1].

It should be noted that an increase in the quality of products directly leads to an increase in the cost of products. Reducing the cost of a product and gaining its quality is one of the main requirements of the current market economy. Reducing the cost of products depends on the properties of raw materials used in production, as well as on the correct design and selection of device structures [2].

2 Literature analysis and methods

From the application of copper wires in the traditional stretching process, an increase in temperature appears in the surface layer of the wire due to the deformation that occurs in the central part of the equipment. This process was initially carried out by V. Weiss and others [3] and applied to wire production. The traditional stretching process allows you to stretch the wire without using a deforming Matrix. This is important because, in the traditional stretching process, the price of the matrix is very high. In addition, the traditional stretching method has several disadvantages. For example, S. Supriadi and others [4] argue that in this traditional stretch, quality pointers cannot be fully provided because the wire can stretch and vary along the length of the transverse cross-section.

One of the most important advantages of the traditional stretching process is the production of copper wires that are very small in diameter. In this case, The Wire obtained traditionally can be additionally stretched. This makes it possible to obtain a wire of a smaller diameter than an industrial one. This applies especially to copper wires in connection with the development of microelectronics. Currently, wires from copper wires up to 10-12 μm in diameter are produced in large numbers in the industry. The production of a small-diameter wire using the traditional method is associated with the difficulties that arise in traction machines. However, if such a wire is used as a raw material for a continuous stretching process, it is possible to further reduce its diameter.

The implementation of the traditional stretching process requires the solution of two important issues defined below.

The first is the optional selection of temperature and deformation parameters to achieve maximum formation limit and uniformity of diameter along the length of the wire. The traditional stretching concept proposed by A. Milenin allows for solving this problem [5]. This idea requires the implementation of a multi-stage continuous stretching process. In multi-stage continuous traction machines, the material being processed must be in conditions of maximum deformation with each pass. This makes it possible to ensure the axis of the diameter along the length of the wire, as well as to increase the boundary of the formation of the material in the technological process. However, its effectiveness depends on the tension deformation of the material, the rate of tension and the temperature.

Second, during conventional stretching, due to the absolute and relative compression of the wire, an increase in roughness occurs on the surface of the surface (Fig. 1). Due to this problem, as a result of the deviation of the processed wire from the geometric shape, the

tortuosity affects the forming limit of the wire diameter. Thus, to solve these problems, it is necessary to correctly design the construction of the device used in continuous drawing machines as a result of the study of plastometric studies of the material.
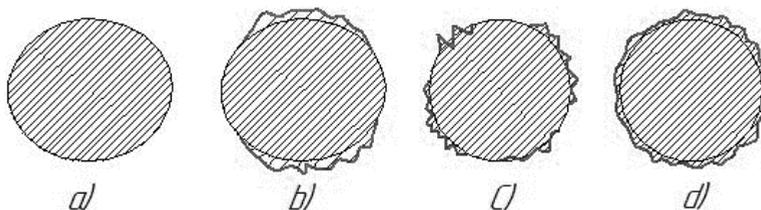
Fig. 1. Changes in the geometrical shape of copper wires during pulling

High requirements are placed on the construction of the device used for the production of copper wires by the traditional stretching method. For this reason, the stretching of copper wires of various shapes is carried out in plastic deformation processing structures. An important aspect of plastic deformation processing constructions is that even if the geometric shape of wires changes as a result of deformation, its structure, and physical and mechanical properties remain unchanged [6]. This is one of the effective methods of the copper wire processing industry.

At present, obtaining shaped profiles as a result of plastic deformation processing of copper wires by traditional methods is mainly carried out using ball devices. Identifying the shortcomings of these methods and devices, analyzing them, and making recommendations for the effective methods of the stretching process and the production of new technological equipment through the design of constructions serve as the main tasks of the article.

In the industry, non-standard ball constructions are known, which are mainly used for obtaining round, triangular, rectangular, square and other shaped profiles, and in these constructions, the working surfaces of the rollers are formed partially or completely on the surfaces of rotating balls, their o are wrapped with sliding or rolling bearings [7].

Fig. 2. Profiles formed in the process of stretching copper wires

The main disadvantages of the devices used to obtain shaped profiles are the need to ensure the constancy of the dimensions of the form formed in them and the use of radial and Axis adjustment devices when installing non-standard balls on dies, and when generating rotational movement, equipment with a special-driven Rotary volock holder.

In the device that produces shaped profiles with ball dies, the billet is compressed between the balls rotating around the axis of the workpiece under the influence of the stretching force through the rotating dies, while the diameter of the workpiece is reduced under the influence of the amount of compression Figure 3. It will be necessary to ensure that the number of balls is at least six in order to avoid residual stresses that form between the working balls when compressing the billet. To avoid the appearance of spiral lines on the surface of the finished wire, it is required that the stretching speed is 2-4% higher than the rotational speed of the ballpoint volock holder [7].
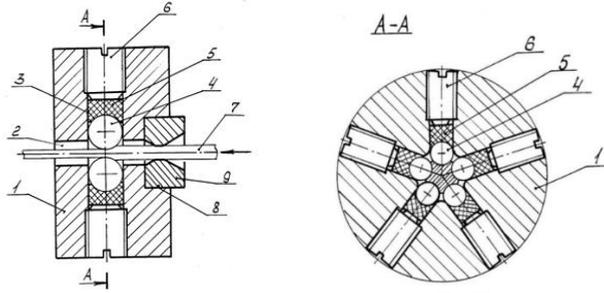
Fig. 3. The device for the production of shaped profiles with ball rollers. 1-body, 2-axial hole, 3-radial hole, 4-ball, 5-anti-friction material (bronze), 6-fastening screw, 7- billet, 8-cylindrical groove, 9-integral roller

Disadvantages of ball bearing rollers include the impossibility of using balls of standard ball bearings, the inability to adjust the size of the calibre, the limitation of the stretching speed due to the difficulty of ensuring high rotation speed of the ball rollers, the large ratio of the length of the stretched wire to its diameter. because the working part of the rollers is not sufficiently rigid, which does not allow the billet to be greatly compressed in the working part [7].

The process of stretching copper wires is one of the main technological operations in the production of non-ferrous metal wires.

As can be seen from the following diagram presented in Figure 4, under the influence of the tensile force F, the cross-section of the wire decreases, as a result, its length increases, and the volume of the metal remains constant after tension.
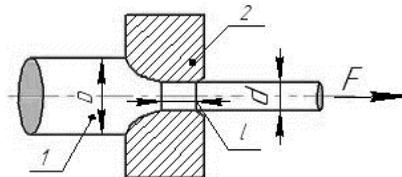
Fig. 4. Scheme of stretching process. 1-copper wire, 2-solid wire

We determine the main parameters of the stretching process by defining D0, l0, S0, respectively, the diameter, length and cross-sectional area before stretching, and d1, l1, S1, the diameter, length and cross-sectional area after stretching. These parameters include compression, elongation and elongation factor.

Compression is the difference between sections before stretching and after stretching.
Absolute compression

$$\delta_{abs} = S_0 - S_1 \qquad (1)$$

and relative compression

$$\delta_{rel} = \frac{(S_0 - S_1)}{S_0} = \frac{(D_0^2 - d_1^2)}{D_0^2} \qquad (2)$$

Relative compression can be expressed as a percentage.
Elongation refers to the difference in the length after stretching and before stretching.
Absolute stretching

$$\lambda_{mut} = l_1 - l_0 \qquad (3)$$

and relative elongation

$$\lambda_{nisb} = \frac{(l_1 - l_0)}{l_1}$$

(4)

Relative elongation can be expressed as a percentage.

The value of the elongation coefficient is determined by the ratio of the length before stretching to the length after stretching.

$$\mu = \frac{l_1}{l_0} = \frac{S_1}{S_0} = \frac{d_0^2}{D_0^2}$$

(5)

Based on the condition of the constant volume of the stretched wire, the equality between the above relationships is determined.

$$\delta = \frac{\left(D_0^2 - d_1^2\right)}{D_0^2} = \frac{\lambda}{\lambda + 1} = \frac{\mu - 1}{\mu}$$

(6)

$$\lambda = \frac{\left(D_0^2 - d_1^2\right)}{D_0^2} = \frac{\delta}{\delta - 1} = \mu - 1$$

(7)

$$\mu = \frac{l_1}{l_0} = \frac{d_0^2}{D_0^2} = \frac{1}{1 - \delta} = \lambda + 1$$

(8)

The value of the coefficient of compression, elongation, and elongation obtained on drawing machines by plastic deformation in the working part of one technological device by the traditional stretching method is called unit values δ, λ, μ [8].

As a result of analysis and studies, the design of the device we recommend consists of assembled ball rollers, increasing the service life of expensive technological equipment by using the balls of standard bearings, reducing compressions that occur in the working part of the rollers, axial and radial adjustment of ball rollers due to the reduction of time, the increase of the geometrical accuracy of the cylindrical color metal wires formed by stretching due to the presence of the calibrating part in the colloidal ball rollers, and the reduction of the cost of the device due to the absence of non-technological surfaces in the design of the colloidal ball and calibrating rollers.

The technical function of the recommended device is as follows: In the device, which includes a tool for plastic deformation of non-ferrous metal wires through working balls and a calibrating roller equipped with a hard alloy, a special gear is used to create the rotational movement of the assembled rollers. There is a spherical slot on its torest surface, which serves to hold the working balls in a circle. To limit the circumferential movement of the working balls, the conical surface of the torest surfaces has spherical slots equal to the diameter of the standard balls and is achieved by the arrangement of the numbered rollers according to the number. The geometric dimensions of the wires formed as a result of deformation are carried out by calibrating rollers, and the adjustment of the device is carried out by means of fixing screws, which serve to connect and fix the assembled rollers formed along the axis. Fig. 5.

The main elements of the device: The following main elements of the device for stretching non-ferrous metal wires using balls in a cylindrical shape: 1-wheel, 2-roller, 3-standard balls, 4-hard alloy, 5-calibrating die, 6-fastening screws, 7-billet [9].
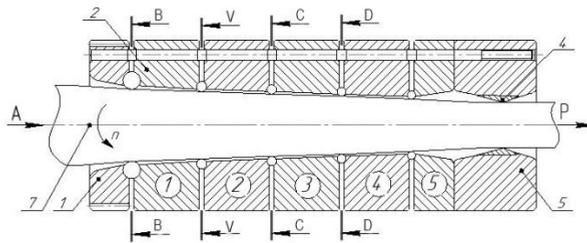
Fig. 5. Design of the device for stretching non-ferrous metal wires in a cylindrical shape using balls;
1-shesternya, 2-dies, 4-hard alloy, 5- calibration die, 7-billet
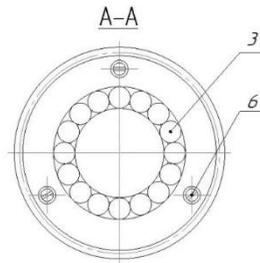

Fig. 6. A-A view of the construction of the device for stretching non-ferrous metal wires in a cylindrical shape with the help of balls; 3-standard balls, 6-fastening screws
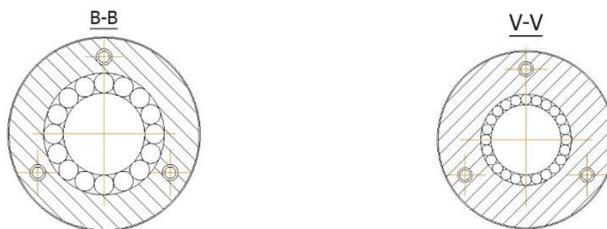
Fig. 7. B-B and V-V views of the construction of a device for stretching non-ferrous metal wires into a cylindrical shape using balls

Fig. 8. C-C and D-D views of the construction of the device for stretching non-ferrous metal wires into a cylindrical shape with the help of balls
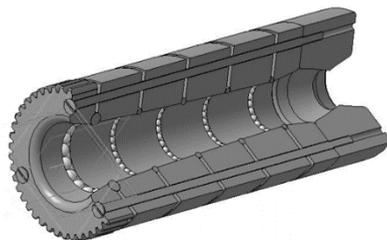
Fig. 9. 3D view of a device for stretching non-ferrous metal wires in a cylindrical shape using balls.

The structural elements of the device and the execution sequence: The recommended device consists of a gear (1) with a spherical slot on the torest surfaces, which has holes for fastening screws. Conical with a central hole having open holes to match these holes, the torest faces have spherical slots for circumferential placement of standard balls and consist of numbered (2) rollers. Between each numbered coils (3) standard balls are used to create compression in the surface layers of non-ferrous metal wires. In order to eliminate the spiral lines formed on the surface layer of non-ferrous metal wires due to compression and to ensure the geometric size of the wire (4), there is a calibrating roll equipped with a hard alloy (5), for adjusting and fixing the device during the process of picking up these rolls. (6) consists of a set screw. Fastening screws (6) are passed through three axial holes of a gear (1) with a spherical slot on the torest surfaces. Balls (3) of standard bearings that fit into the spherical housing are placed circumferentially. The diameter of the balls is found by the following formula.

$$D_{ball} = (D-d) \cdot 0.3 \qquad (9)$$

where D is the outer diameter of the bearing;

d - the inner diameter of the bearing.

After that, the roller marked with the first number (2) is passed through the fixing screws and placed on the balls, after the balls of the standard bearings corresponding to the spherical nest formed on the surface of the torest of this roller are placed around the circle, the roller marked with the second number passing through the fixing screws, it is placed on the balls, and the diameter of the ball corresponding to the spherical slots formed on the torest surfaces of the remaining third, fourth and fifth rollers is placed between each roller along the circumference. The hard alloy (4) calibrating roller (5) that gives the shape is attached to the last part of the device in order to ensure the accuracy of the geometric shape of the processed wires and the formation of spiral lines as a result of deformation through the balls placed in the working part of the processed non-ferrous metal wire rollers. As a result, a pre-sharpened non-ferrous metal wire is passed between the assembly rollers, adjusted to size and fixed to the threaded holes on the surface of the calibrating roller (5) by means of fixing screws (6). The size-adjusted device can be installed on the roller holder of the traction machine and the rotation speed of the device can be adjusted taking into account the engagement of the gear wheel (1).

The proposed device works as follows: The proposed device is installed on the handle of the traction machine. The first part of the non-ferrous metal wire to be processed is passed through the hole of the assembly roller and the calibrating roller (5), and then the billet (7), which is processed using the traction device of the drawing machine, is placed in the working part of the assembly roller with balls (3) and is weighed by the help of the forming calliper (5). At the same time, depending on the changes in the size of the initial billet in the assembly roller, the service life of the working balls (3) is increased due to the small amount of compression in the working part of each roller according diameter of the billet. The total amount of compression on the device is 0.8÷8%. This reduces the ovality of the billet and

creates counter-tensions that help to additionally correct and centre the billet on the ball rollers, therefore, the sudden disconnection of the wires under the influence of traction force due to the reduction of stresses in the working part by creating a rotational movement in the device through the pinion (1) [9].

In the process of drawing, the dimensions of non-ferrous metal wires may deviate from the maximum deviation. In this case, the weighing machine stops and the calibration roller of the device are replaced by another one, i.e. the calibration roller (5) equipped with a pre-prepared hard alloy (4).

3 Results

The distribution of internal stresses in a stretched wire depends on the taper angle and the compression at each stretch. The value of the distribution parameters Δ along the height of the stress plastic deformation zone during the stretching of non-ferrous metal wires on tension machines is determined as follows [10].
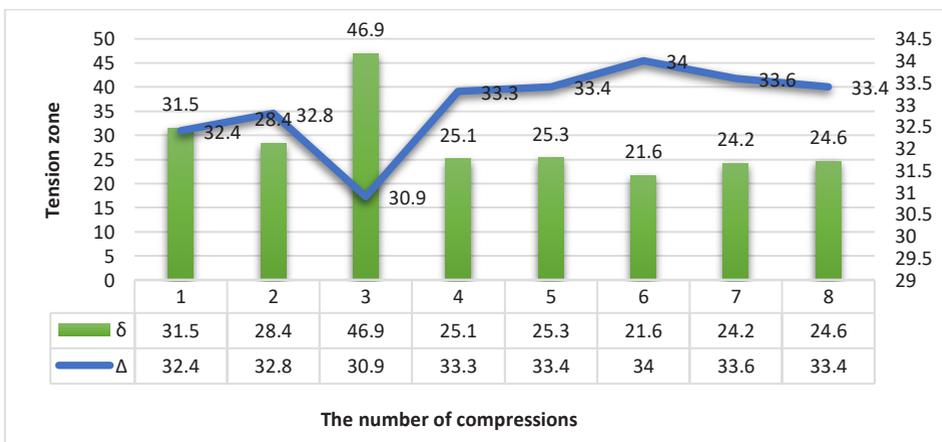
$$\Delta = \frac{2\alpha}{\delta}\left(1+\sqrt{\delta-1}\right)^2$$

(10)

where α - is the angle of the working cone, (degrees);
δ - is the value of compression at each pass for cylindrical profiles, %.

$$\delta = \left(1-\left(\frac{d}{D}\right)^2\right)\cdot 100\%$$

(11)

Fig. 10 shows the distribution parameter of the tension generated on the working cone surfaces of the value of the compressions generated between each pass during the thick stretching of M1 copper wires on VSK-13 drawing machines.

	1	2	3	4	5	6	7	8
δ	31.5	28.4	46.9	25.1	25.3	21.6	24.2	24.6
Δ	32.4	32.8	30.9	33.3	33.4	34	33.6	33.4

The number of compressions

Fig. 10. The distribution parameter of the tension

The tensile force acting on non-ferrous metal wires is very important. This makes it possible to choose the right drawing machines, technological equipment and stretching modes. The optimal energy equation for calculating the traction force in the technological device recommended for stretching copper wires using balls using traditional methods is calculated as follows [11].

$$F_{bul} = S_1 \cdot \Phi_q \cdot \sigma_{e}^{0} \cdot ln\left(\frac{S_2}{S_1}\right) \cdot \left(1 + f \cdot ctg\alpha\right)$$

(12)

where Φ_q - is the coefficient that takes into account the additional work of plastic deformation;

S_1 and S_2 - initial and subsequent cross-sectional area of the wire, mm^2;

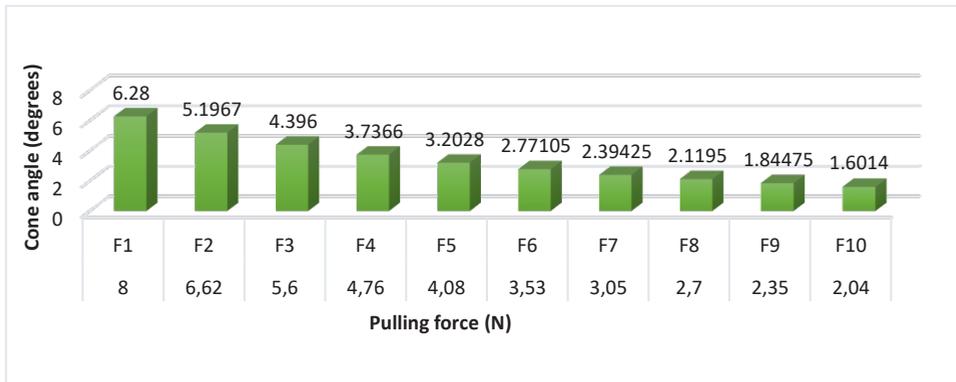σ_{B}^{0} - is the strength limit of the material, MPa;

f - friction coefficient;

α - cone angle of the working part, degrees.

The cross-sectional surface of the wire is determined by the following formula:

$$S = \frac{\pi \cdot d}{4}$$

(13)

Fig. 11 shows the change of the surface section of M1 copper wires based on the following route in the device for stretching non-ferrous metal wires in a cylindrical shape using balls.

|	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Cone angle (degrees)	6.28	5.1967	4.396	3.7366	3.2028	2.77105	2.39425	2.1195	1.84475	1.6014
Pulling force (N)	8	6,62	5,6	4,76	4,08	3,53	3,05	2,7	2,35	2,04

Fig. 11. Stretching non-ferrous metal wires using cylindrical balls

The parameters describing the process of cylindrical stretching of M1 copper wire using a ball roller in the traditional way are presented in Table 1 below.

Table 1. The parameters describing the process of cylindrical stretching of M1 copper wire using a ball roller

Parameters	Characteristics
To calculate the change in shape, it is necessary:	
d – wire diameter, mm;	2.04 – 8.0
α – the half angle of the working cone, degrees;	2° – 12°
f – coefficient of friction;	0.03 – 0.10
υ – stretching speed, m/s;	up to 40 m/s
σ_{B}^{0} – strength limit, MPa.	350 MPa

According to the traditional method, the dependence of the cone angle of the working channel of the dies on the pulling force of M1 copper wires is presented in Fig. 12.
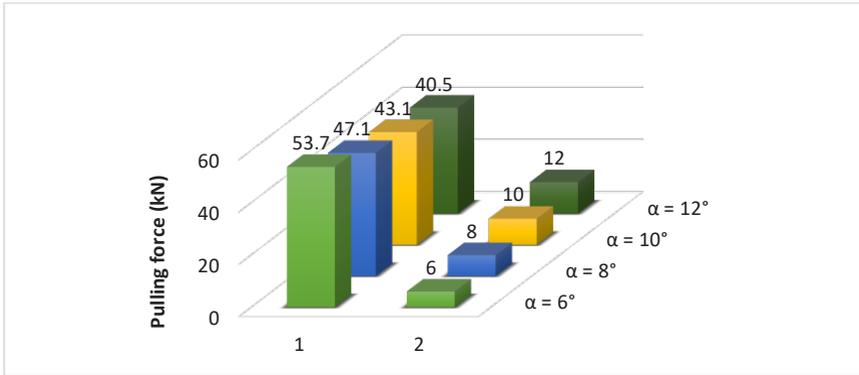
Fig. 12. The dependence of the cone angle of the working channel of the dies on the pulling force of M1 copper wires

4 Discussion

The tension zone of the value of the compressions formed in the working part of the ball calibrating rollers during the stretching of copper materials is presented in fig. 10, in which the height of the plastic deformation decreases as the compression value increases (δ=46.9; Δ=30.9), and as the compression value decreases, the height of the deformation increases (δ=21.6; Δ=34.0). To ensure the proportionality of these values, it is necessary to take into account the elongation ratio. This can be seen in Fig.11, which describes the dependence of the cone angle on the traction force. It can be seen from Fig.12 that the tensile strength of non-ferrous metals increases as a result of reducing the cone angle of the working part. But increasing the cone angle of the working part leads to an increase in the deformable surface area of the non-ferrous metal wires being deformed. This leads to an increase in the friction surface in the process of stretching non-ferrous metal wires, resulting in the appearance of excess temperature, and a reduction in the service life of the working rollers. Taking this into account and as a result of research and research, the most optimal parameter for M1 copper wires is determined.

The results of the identified studies show that in the process of stretching non-ferrous metal wires with ball-calibrating devices, it is necessary to take into account the advantages of the following technological laws in the above formulas, figures and tables.

– ensuring minimal compression as a result of one deformation,
– reducing power consumption as a result of the rational use of electric motors,
– ensuring that the wire does not break when stretching collared metal wires of various shapes,
– increasing the maximum service life of technological devices,
– deformation of the surface during stretching, etc.

5 Conclusion

As a result of scientific research and theoretical research, the advantages of the device design recommended for the proposed method compared to existing devices and the most optimal parameters of stretching due to plastic deformation on drawing machines were determined:
1. Balls of standard ball bearings can be used;
2. No additional tuning device is required to configure the device;

3. In the process of assembling the device, cooling-lubricating liquids are regularly supplied between the working balls through special slits between the rollers, increasing the service life of the working balls, partially reducing the traction force, and preventing the formation of an oxide layer on the surface of non-ferrous metal wires;

4. Due to the meshing of the gear wheel in the device and the gear wheel in the machine, the accuracy of setting the rotation speed of the device through the transmission ratio is high;

5. To ensure the proportionality of plastic deformation and compression values, it is recommended to divide the elongation ratio by 85÷88%.

6. As a result of the analysis of the compression values in the tension zones of the material and the values of the traction force at the working cone angle of the technological device, it is necessary to accept a value greater than a = 8° and effective friction r < 3° as the optimal cone angle (with sufficient lubrication).

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