Improving the accuracy of electric mechanisms for the manufacture of blanks of agricultural objects

Y S Zagoskin¹ and A T Tsirkunenko²

¹ Emerson, Russian Federation
² RiK-Energo llc, Ekaterinburg, Russian Federation

E-mail: m9191236713@mail.ru

Abstract. The principles of increasing the precision characteristics of an agricultural electric drive are presented in this article. There are achieved by analyzing the requirements for the electric drive by the operating body. The scientific work has a relationship between the parameters of the quality of rolling the blanks for agricultural facilities and the precision parameters of the electric drive in terms of overshoot parameters and absolute positioning accuracy. It is shown that this dependence is non-linear in the position electric drive and depends more on the size of the overshoot and a significantly smaller ratio from absolute accuracy. The permissible overshoot value depends on the absolute accuracy and has range from 5 to 10%. The largest value of the overshoot is achieved with absolute positioning accuracy with an error not exceeding 2%. The obtained values of the control parameters can be successfully applied in the design of the position agricultural electric drive. So, if you provide sufficient positioning accuracy with an error not exceeding 2%, which is achieved by the use of position sensors with a resolution of at least 10 000 pulses per revolution, the modeling electric drive in the position loop can be adjusted with an allowable overshoot of 10%, and therefore, increased system performance while maintaining quality control indicators.

1. Introduction
Agricultural cold rolling makes to achieve a reduction in the cross-section of the billet by 75-85% and to obtain strips, sheets and blanks for agricultural facilities with a thickness of less than 0.4 mm, up to several microns, which is practically unattainable in hot rolling. The competitiveness of this technology is determined by the fact that it is a non-waste way of processing metals by pressure. At the same time, the uniform thickness, increased strength and high quality of the product surface make this rolling the most progressive, which causes its wide distribution.

Nowadays, the world has more than 700 mills of agricultural blank rolling machines, it is more than 200 mills in Russia. The fifth workshop of agricultural rolling plant has two cold-pilgering mill – 450. They allow producing blanks for agricultural facilities of a wide range with a constant or variable cross-section of a finished product with a diameter of 150 to 450 mm. Blanks for agricultural facilities billets can be solid-drawn or seam-welded, from carbonaceous, alloyed or high-alloy steels of high strength, as well as from non-ferrous metals and their alloys.

Rolling technology remains virtually unchanged from the 1960s. The greatest effect can be achieved if we improve the electrical part, which allows improving the accuracy indicators while saving the mill's performance.
Visual model of the mechanical part was created on a scale of 400:1 for clarifying the operation modes of the cold pilgering mill - 450 mill. This prototyping was done in the CAD system.

Rolling of the blanks for agricultural facilities is carried out in parts throughout its length. The main stand 1 [1] is driven by a main circulation system and reciprocates. The rotation of the rollers 2 [2] is made mechanically through the gear engagement 3 [3] on the roll and the rack gear 4 [4] fixed to the frame. Rolls are metal rims of increased strength, having a circumferential stream of variable cross-section. The initial size of the stream corresponds to the outer diameter of the workpiece, the final dimension is the outside diameter of the finished blanks for agricultural facilities. The internal diameter of the blanks for agricultural facilities is regulated by the position of the conical mandrel 5 [5]. In the case of a constant diameter, the position of the working cone remains unchanged during rolling. If, however, it is required to produce a blanks for agricultural facilities, for example, a conical shape, the working cone is shifted in the deformation zone according to the required law during movement of the stand.

The rear end of the workpiece is fixed in the axial direction. At the initial moment, the pusher 6 [6] moves the workpiece 8 [7] towards the stand, by means of the screw gear 7 [8]. This movement is called feeding. When moving the working stand forward, the reduced portion of the workpiece is reduced. Reduction is the process of crimping a blanks for agricultural facilities to obtain a given diameter and wall thickness of a finished blanks for agricultural facilities. When moving forward, the blanks for agricultural facilities are reduced, giving the metal the desired shape. Then the reverse (reverse) is performed. This cycle is called a double stroke. The rolled workpiece rotates by 60-90° in the extreme forward position, i.e. after each double stroke of the working stand. This is done so that the metal that has filled in the previous working stroke of the caliber is rolled out in a round section of the gauge during the subsequent working stroke [9].

The ability to quickly break off the blanks for agricultural facilities from the mandrel for the cold rolling mill, providing (3-4) MN, and also positioning the workpiece for a given time will allow to exclude emergency modes. In order to clarify this situation, we will consider in more detail the rolling technology. The main stand is driven by means of a main circulation system by electric drive and performs a reciprocating motion. The main drive operates continuously, which is why the stand is in a position where it is possible to feed or rotate the blanks for agricultural facilities billet less than 5% of the cycle time. There are grooves called yawns on the calibers at the beginning and at the end of the creek, which exclude the contact of the workpiece and the blanks for agricultural facilities with calibers when feeding and turning. At the moment when the blanks for agricultural facilities is within the working zone of the throat, it is necessary to make a blanks for agricultural facilities feed or turn it [10]. Obviously, the greatest trouble is possible in the feed drive, because in the case of its long operation mode, when the blanks for agricultural facilities is already clamped by the rollers, its deformation (twisting or bending) is possible. You can avoid this mode in two ways. The first is to increase the possible positioning time, reducing the speed of the main drive, which will lead to a decrease in the performance of the whole mill, the second - to increase the accuracy of positioning the working body while maintaining the speed of the system.

2. Setting of the problem
Taking into account the importance of the technological object and the level of requirements to the quality of the output of the rolling mill, the scientific and technical task of improving the accuracy indexes can be solved only with an integrated approach to the developed electric drive and includes:

- analysis of the requirements of the technological process from the side of the working body to the electric drive system in terms of loads, work schedule;
- synthesis of a mathematical model that set the relationship between the process variables and the precision characteristics of the electric drive;
- calculation of the dependence of the quality of rolling the blank on the index of the thickness of the machine from the accuracy characteristics of the electric drive.
3. Analysis of the requirements of the technological process from the feed
Table 1 shows the main technical characteristics and technological requirements for the elements and units of the mill. For a long time, the adjustment of the coordinates of the mill mechanisms (speed, position) was carried out mechanically. A.M. Weinger justified and practically realized regulated AC electric drive on the feed mechanism in 1986. Until recently, significant downtime of the mill was due to reliability indicators of electrical equipment elements, which was controlled by analog devices. Solve this problem by the failure of analog control devices and the transition to an "electronic bath" - replacing the analog control system with a digital one while preserving the power elements of semiconductor converters [11].

4. Mathematical description of the regulation object
Analysis of the work and output of the rolling mill - 450, as well as an expert survey, showed that a significant improvement in technical and economic indicators is possible at the expense of improving the quality of cold rolled products. The main requirement for a finished blank is the uniformity of the wall. The study of technical requirements, which were refined by the method of peer review (based on a survey of technological and administrative-technological personnel of workshop №5 of AGRICULTURAL-ROLLING PLANT”), established the requirements for the quality of the different thickness of the blank [12]. Table 1.2 shows requirements for the difference in the finished products for the main categories of the produced assortment are given. This assortment is distributed as follows: about 55% is of the production is made for the manufacture of hydraulic cylinders, 15% is for the nuclear industry (mainly TVELs), and 30% is for the rest [13]. Obviously, the higher the requirements for the quality of products, the higher the cost of the finished blank. So, more than 30% of all output has a very high cost price, while the cost of one blank is more than 1.1 million rubles, so reducing the rejection of the blank will give an economic effect [14].

Table 1. Technical characteristics of cold rolling mill-450.

| Parameter                  | Value  | Units  |
|----------------------------|--------|--------|
| outer diameter of workpiece| 180–480| mm     |
| Length of workpiece        | 3–12   | m      |
| all-weigh of workpiece     | 3.5    | τ      |
| outer diameter of blank    | 140–450| mm     |
| thickness of blank walls   | 2.4–50 | mm     |
| Length of blank            | 6–25   | m      |
| double-stroke number of mill | 10–40 | double-stroke number /min |
| advance for one double stroke | 2–25  | mm     |
| minimum cycle time         | 1.5    | s      |

Analysis of operating modes and interactions of the mill elements on the developed virtual layout. Figure 1 showed that the most "weak" link in the technological process is the feeder mechanism, to which the highest requirements for positioning accuracy are required while maintaining the speed (cycle time not more than 400 ms) and high overload capacity (up to 4MN). An error in the operation of the feed drive, which affects the different thickness of the blank Δs, can be due to both the static error Δh and the overshoot value Δσ. Before evaluating the relationship between the parameters of regulation and the quality of rolled products, it is useful to analyze the sections of the load diagram in the existing drive system obtained by the criterion of the minimum positioning time [15].

The requirements from table 2 show the allowable thickness of the product is 7% of the wall size. The parameters of rolling fuel element allow analytically calculating the thickness of the resulting blank.
Table 2. Technical characteristics of agricultural cold rolling mill - 450.

| Output products     | Wall thickness, mm | Admissible difference, mm |
|---------------------|--------------------|----------------------------|
| longeron            | 5                  | ±0.2                       |
| fuel element        | 2                  | ±0.15                      |
| hydraulic cylinder  | 10                 | ±0.6                       |

The relative longitudinal thickness difference can be determined from expression

\[ \Delta s = \frac{t_K - t_T}{0.5(t_K + t_T)} \times 100\% \]

where:
- \( t_K \) is the maximum wall thickness of the blank section obtained during the rolling cycle [16];
- \( t_T \) is the wall thickness of the finished blank.

According to [17]

\[ t_K = \sqrt{t_z^2 + 2V_y \cdot \frac{\tg \alpha \cdot (\tg \phi_n - \tg \alpha)}{\tg \phi_n}} \]

where \( \tg \alpha \) is the slope angle of the mandrel of the mandrel;
\( \tg \phi_n \) - angle of inclination of the cone generator of the pre-prepared section of the stream;
\( V_y \sim \) specific volume of feed

\[ V_y = t_m \frac{R_z + r_z}{R_x + r_x} \frac{mm^3}{mm}; \]

\( t_z \) - thickness of the workpiece;
\( R_z \) and \( r_z \) - outer and inner radii of the workpiece;
\( R_x \) and \( r_x \) - outer and inner radii of the working cone in the section under consideration;
\( m \) is the feed amount [18].

Since the actual feed amount can vary depending on the positioning quality of the workpiece (overshoot in the system, static feed error), the resulting thickness differences will also vary [19]. Figure 1 shows the dependence of the difference in the thickness of the blank \( \Delta s \) on the overshoot \( \sigma \) and on the supply error \( \Delta h \) [20]. As can be seen from the figure, the overshoot in the system affects to a greater extent the magnitude of the differences in thickness [21]. It should be noted, however, that overshooting increases the feed amount, because the blank does not retract, and the blank, moving into the rolling rolls, moves back, which significantly affects the resulting thickness of the blank [22]. The static supply error \( \Delta h \) affects to a lesser extent and is explained by its stable value [23]. Thus, a static supply error \( \Delta h \) leads to a change in the thickness of the rolled product, but practically does not affect the value of the difference in the thickness \( \Delta s \) [24].

Figure 1. The dependence of the difference in the thickness of the agricultural tube \( \Delta s \) on the overshoot \( \sigma \) and from the supply error \( \Delta h \) (1); surface of permissible differences in thickness (2).
Analysis of the requirements of the technological process to the electric drive of the feed allowed to determine the relationship of the control parameters with the quality of the rolled blank [25]. It is established that the magnitude of the difference in the thickness $\Delta s$ is more dependent on the overshoot of the position $\sigma$ of the electric drive and, to a lesser extent, on the absolute supply error $\Delta h$ [26]. This is because the feed drive carriage can only move the blank forward and when it returns to the set position, the blank does not retract [27]. During rolling, the blank, falling into the rolls, is not retarded and moves back to the position of the carriage, which leads to a change in the cross-section of the rolled tube along its axis (different thicknesses) [28]. The static supply error $\Delta h$ influences to a lesser extent the thickness of the resulting blank, since during rolling the blank constantly abuts against the carriage and the blank does not reverse the return movement of the blank when it is crimped by the rolling mill [29].

The analysis of a wide range of semiconductor technology (at the level of the technical documentation and practical testing on laboratory model of frequency converters of different companies), produced by modern engineers, showed that most of them realized the PWM modulation [30] and only in frequency converters of firm ABB [31] with the DTC-control is mainly used FPWM modulation. Typically, the PWM carrier frequency is in the range of 1.5 to 16 kHz. At about the same range varies FPWM frequency converters ACS800, ACS880 [32]. A number of researches are considered the problem of distortion transmitted signal by comparing the PWM and FPWM modulation to control the linear units of the first order [33]. At the same time, it takes attention to the differences of these distortions [34]. However, a winding of electric drive, which operates a semiconductor converter, a first approximation can be represented by the transfer function of the second or third order [35], therefore requires further research of influence pulsed character [36] of power source on the properties of the drive [37]. Moreover, the waveform test near the Nyquist frequency [38] will allow to justify limiting the speed achieved in electric drives with semiconductor [39].

5. Conclusion
The scientific work has a relationship between the parameters of the quality of rolling the blank and the precision parameters of the electric drive in terms of overshoot parameters and absolute positioning accuracy. It is shown that this dependence is non-linear in the position electric drive and depends more on the size of the overshoot and a significantly smaller ratio from absolute accuracy. The permissible overshoot value depends on the absolute accuracy and has range from 5 to 10%. The largest value of the overshoot is achieved with absolute positioning accuracy with an error not exceeding 2%.

The obtained values of the control parameters can be successfully applied in the design of the position agricultural electric drive. So, if you provide sufficient positioning accuracy with an error not exceeding 2%, which is achieved by the use of position sensors with a resolution of at least 10 000 pulses per revolution, the modeling electric drive in the position loop can be adjusted with an allowable overshoot of 10%, and therefore, increased system performance while maintaining quality control indicators.

References
[1] Zhuravlev A M and Grigor’ev M A 2018 *Russian Electrical Eng.* 89(4) 222-7
[2] Baranov L A and Maksimov V M 2018 *Russian Electrical Eng.* 89(9) 546-9
[3] Bulychev A V, Dementii Y A and Pryanikov V S 2017 *Russian Electrical Eng.* 88(7) 430-6
[4] Vorob’ev N P, Mozol’ V I and Shanygin I A 2018 *Russian Electrical Eng.* 89(12) 722-7
[5] Chupin S A and Grigor’ev M A 2018 *Russian Electrical Eng.* 89(4) 240-4
[6] Gupta S K, Singh M and Sharma H D 2017 *Russian Electrical Eng.* 88(5) 314-20
[7] Shamanov V I 2018 *Russian Electrical Eng.* 89(9) 536-9
[8] Tikhomirov D A, Kopylov S I 2018 *Russian Electrical Eng.* 89(7) 437-40
[9] Khayatov E S and Grigor’ev M A 2017 *Russian Electrical Eng.* 88(4) 197-200
[10] Kosarev A B and Kosarev B I 2018 *Russian Electrical Eng.* 89(9) 531-5
[11] Golov V P, Martirosyan A A, Moskvin I A and Kormilitsyn D N 2017 *Russian Electrical Eng.* 88(2) 81-6
[12] Bogdanov A O and Litvinenko A M 2018 *Russian Electrical Eng.* 89(6) 393-7
[13] Gryzlov A A and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 245-8
[14] Belykh I A, Grigor’ev M A and Belousov E V 2017 Russian Electrical Eng. 88(4) 205-8
[15] Kim K I and Kim K K 2018 Russian Electrical Eng. 89(10) 598-606
[16] Korshunov A I 2018 Russian Electrical Eng. 89(6) 360-6
[17] Sudakov A I and Kamenskikh I A 2018 Russian Electrical Eng. 89(4) 245-8
[18] Efimov V V and Malikov O B 2016 Russian Electrical Eng. 87(5) 286-8
[19] Afanasyev A A, Efimov V V and Tokmakov D A 2018 Russian Electrical Eng. 89(7) 441-4
[20] Gryzlov A A, Grigor’ev M A and Imanova A A 2017 Russian Electrical Eng. 88(4) 193-6
[21] Ryabtsev G G and Zheltov K S 2018 Russian Electrical Eng. 89(9) 525-7
[22] Ignatenko I V, Konstantinov A M and Demina L S 2016 Russian Electrical Eng. 87(2) 104-6
[23] Kim K K, Panychev A Y and Blazhko L S 2018 Russian Electrical Eng. 89(10) 559-65
[24] Men’shenin A S and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 228-33
[25] Voevodin V V and Sokolova M V 2018 Russian Electrical Eng. 89(8) 480-3
[26] Sivkov A A and Gerasimov D Y 2018 Russian Electrical Eng. 89(11) 680
[27] Belykh I A and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 234-9
[28] Gorozhankin A N, Gryzlov A A and Khayatov E S 2017 Russian Electrical Eng. 88(4) 201-4
[29] Kachesova L Y and Nikol’skii O K 2018 Russian Electrical Eng. 89(12) 681-4
[30] Grigor’ev M A 2017 Russian Electrical Eng. 88(4) 189-92
[31] Belov G A and Semenov Y M 2018 Russian Electrical Eng. 89(8) 445-9
[32] Khokhlov Y I, Safonov V I and Lonzinger P V 2016 Russian Electrical Eng. 87(3) 145-9
[33] Belousov E V, Grigor’ev M A and Gryzlov A A 2017 Russian Electrical Eng. 88(4) 185-8
[34] Sosninkov A A, Migalev I E Titov E V 2018 Russian Electrical Eng. 89(12) 685-8
[35] Drobyazko O N 2018 Russian Electrical Eng. 89(12) 728-32
[36] Bagaev A A 2018 Russian Electrical Eng. 89(12) 703-6
[37] Petrochenkov A B 2018 Russian Electrical Eng. 89(11) 627-32
[38] Alekseev V M 2018 Russian Electrical Eng. 89(9) 528-30
[39] Ismagilov F R, Khairullin I K and Vavilov V E 2018 Russian Electrical Eng. 89(6) 388-92