Improvement of the drawing process on the shopfloor taking into account simulation in industry 4.0

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Abstract. The article analyzes the production process and equipment for producing FLRY-25-C wire; simulation experiments were carried out in AnyLogic, which allow assessing the effect of changing various system parameters on the output of the final product. The author identified a number of problems in the production cycle of manufacturing wire FLRY-25-C and proposed measures to improve the efficiency of this process. As a result, it was found that the implementation of the proposed measures helps to reduce the duration of the production cycle for the wire manufacture by 68 hours, respectively and to increase the productivity of the process by 40%.

1. Introduction
The optimal shape of the die working profile does not guarantee the efficiency of the entire drawing process [1]. An important factor is also the rational loading of equipment in the conditions of diversified production. The central part of any electrical conductor is a core. The core can be solid monolithic, or in the form of many thin wires twisted into a bundle, obtained by drawing. In the first case, it is called single-wire, in the second - multi-wire, or flexible. The cross-sectional shape of the conductor can be flat or in sectors, especially for cables and wires of large diameter. In order to optimize the production cycle, a research was carried out on the technological process of manufacturing the FLRY-25-C wire. Each type and size of wire requires a specific manufacturing technology and appropriate equipment. The production cycle of wire manufacturing was investigated at JSC “Samara Cable Company” (JSC SKK).

Within the selected cross-section, the core design should ensure the minimum dimensions of the wire, as well as the optimal values of such important installation and operational characteristics as flexibility, resistance to bending and vibration resistance. Of course, the most economical, in terms of cost and ensuring the minimum dimensions of the wire, is the single-wire construction of the core. However, it can be recommended only for wires of relatively small cross-sections, where, according to the conditions of installation and operation, there are no strict requirements for resistance and bending and vibration resistance.

As for wires of large cross-sections, their conductive cores have a multi-wire structure.
To increase productivity, several technological operations of the wire production process are combined into a single technological cycle. Figure 1 shows the manufacturing chain for FLRY-25-C wire.

Copper wire rod is fed to rough drawing on a VSK-13 drawing machine (figure 1) with an output diameter of 1.59 mm. Technical characteristics of the VSK-13 machine:

- Maximum diameter of copper rod, mm is 8.00.
- Finished copper wire diameter, mm is 1.59.
- The number of drags is 13.
- Drawing speed, m / s is 5-30.
- The number of traction rollers is 7.
- The number of steps on the roller is 3.
- The volume of consumed emulsion, m3 / h is 16.2-33.0.
- Water consumption, l / min is 50-80.

After coarse drawing, the wire goes to multi-wire drawing machines MMX-101. Wires made on MMX lines are deformed in parallel and annealed under the same conditions, which allows obtaining uniform properties and high surface quality with minimal deviations along the entire length. This is an important condition for the subsequent manufacture of the strand. At the output of this operation, we get a bundle of copper wire of 0.196x14, 400 km long.

![Wire manufacturing chain using the example of two standard sizes.](image)

Depending on the type, size and material of the wire in MMX multi-pass drawing machines, it is possible to anneal and to draw up to 48 wires simultaneously. The closed-loop feeding system of the drawing emulsion ensures its optimal supply both to the drawing rollers and to the drawing dies, cooling and lubricating them at the same time. The drawing area and the gearbox are hermetically sealed mechanically to prevent gear oil from entering the drawing emulsion and vice versa. The parts of the machine that come into contact with the drawing emulsion are made of high quality stainless steel.
addition, all parts of the machine are easily accessible for operators and maintenance personnel during maintenance. The operation of MMX multi-pass drawing machines is monitored through a central operator panel, which includes all control and monitoring functions, which helps to reduce the consumption of capital goods, quickly detect and eliminate the causes of failures and keep maintenance costs at a low level.

The RM series multi-pass resistance annealing units are designed in such a way that individual wires moving at the same speed do not touch each other. Annealing attachments of this series allow two- or three-zone annealing: depending on the wire diameter, the annealing attachment switches automatically to the appropriate operating mode and uses the internal heat already present in it for annealing large-diameter wires.

Copper wire with a diameter of 1.59 mm after "rough" drawing is welded on the fly, without stopping the MMX-101 line, to the end of the remaining wire (an empty container is rolled out by a hand trolley, and a container with copper wire is immediately rolled up by an electric trolley onto the vacant space in the transfer overpass). Thus, drawing operations on the VSK-13 and MMX-101 machines are parallel. Sequential passage of these operations occurs only if the original copper wire is completely or partially finished on the MMX-101 lines. Then drawing on the MMX-101 line does not start until the required number of containers with copper wire is made on the VSK-13 machine. As soon as the number of containers with 1.59 mm copper wire required for launching the MMX-101 lines is done, the drawing operations on VSK-13 and MMX-101 continue in parallel. Therefore, it is inappropriate to reduce too much the backlog of the original copper wire 1.59 mm, and always have several containers with copper wire available on 2 lines out of 4 available in the shop.

The cones with the resulting wire after drawing are sent to the operation of stranding the strand-workpiece. To start twisting, 3 cones with a bundle are required, which will be refueled on one D-631 stranding machine.

The features of these machines include a single arc design that reduces energy consumption and noise generation, as well as contactless data transfer within the machine, which significantly reduces the need for maintenance. The twist pitch is infinitely adjustable. The winding force is also adjusted in a smooth mode and is regulated by a dynamometer during the filling of the coil.

The D-631 twisting machine is designed for spools with a maximum flange diameter of 630 mm. This model is designed for stranding strands with a cross section from 0.09 to 6.00 mm² with a twisting pitch from 6 to 100 mm and a maximum speed of 6500 twists per minute.

The stranding process is shown in figure 1. The wires fanned out come from one or more outlets and are passed one by one through the holes on the braiding tile 1. From there, they are passed together in the form of a bundle of wires through the lay nipple 2 and through the rotor shaft 3 enter the machine. Here, the first retraction of the casting by the rotor takes place. On the rotary yoke, the 4 litz wire is brought inward through the guide roller 5. At this point the litz wire is retracted a second time. The direction of the twist can be selected: “left” (S-weave) and “right” (Z-weave).

The FLRY-25-C wire strand requires 3 cones with a bundle of 14 wires to start the stranding operation on the D-631 twisting machine, as the strand consists of 42 wires. If necessary, you can take the original cones with different lengths into work (if there are remnants of the beam from the previous operation). Then, if a cone ends earlier, or the length remains on it less than that required for the blank strand, then this cone is removed and a new one with the same bundle is installed instead. An important condition is to obtain a blank strand on 19 cones of exactly the same length, so that at the subsequent stranding operation, on the PO-CES line, the mismatch in length does not lead to excess waste.

After stranding on the D-631 machine, the blank strand is sent to the stranding operation on the PO-CES line (two strands). The finished core is insulated on a Soficam extrusion line. The linear velocity of the copper conductor when the insulation is applied is 30 m / min.

The received product is sent to the quality control department (technical control department) for the operational control, and then to the finished product warehouse.

As previously stated, the MMX-101 multi-wire drawing machine lines, like the D-631 twisting machines, can be simultaneously used to manufacture wires of a different standard size, since the
production plan includes many different brands and standard sizes of wire, and it is required to use the available equipment as efficiently as possible for the fastest execution of the production task.

At the same time, the twisting operation on the PO-CES line cannot run in parallel with the same twisting operation, since this line is the only one that is used for this purpose. Soficam line is also the only one for wire insulation.

Between operations, the coils are moved on an electric trolley (over relatively long distances - from one section to another), as well as by rolling (from MMX-101 lines to D-631 twisting machines).

Thus, the combination of technological operations of the wire production process into a single technological cycle represents an integrated single automated production process, including the collection of information about the means of production and the control of the material flow process. Combination possibilities for different materials [2,3,4], parallel and continuous running of individual operations, also contribute to the optimization of productivity, profitability and quality in cable production.

2. Optimization of the production cycle of wire manufacturing based on simulation

To increase productivity, several technological operations of the wire production process are combined into a single technological cycle [5,6,7]. Creation of automatic flow lines significantly increases productivity, reduces labor intensity and improves product quality not only for the drawing process, but for other technological processes [8,9,10]. However, the creation of such lines is difficult due to the large difference in the time required for the corresponding operations [11,12,13,14,15]. Thus, it is necessary to take into account the features of each operation, which is part of the overall production cycle. Decisions regarding the development, optimization or reorganization of production are determined by many factors. It is often difficult to estimate in advance the potential profit or loss from the implementation of such decisions. Therefore, the implementation of the strategy of updating fixed assets, integrated with the support systems for IT-technologies [16,17], includes the direct implementation of the IT-technologies themselves at all levels of production [18,19].

The professional tool AnyLogic is currently the leader in simulation technologies due to its flexibility and its distinctive feature - multi-approach simulation. The main advantage of using AnyLogic is the ability to use this tool to make optimal decisions throughout the entire production cycle.

There are three main approaches to creating simulation models of production: system dynamics, discrete-event and agent-based modeling. AnyLogic allows you to use all of them, including any combination of them. This gives a specialist the freedom to choose the method that suits the particular project. Simulation experiments with the use of information technology helps to assess the impact of changes in various parameters of the system and make the right decision [20-22].

Figure 2. Wire production model creation in AnyLogic.
To draw up a model of the production chain for the manufacture of 5 km of FLRY-25-C wire (with a total weight of 1104 kg), photographs of the workplace were used by the method of direct measurements of the time spent for each operation. To start the twisting on the D-631 machine, the workpiece strand requires 3 cones with a bundle of 14 wires, since the strand for the FLRY-25-C wire consists of 42 wires. Thus, to obtain the required amount of wire for cones with a bundle of 0.198X42, 3 cones of 96 km / 368 kg were required.

Let's list the objects required to build a production model when using the AnyLogic tool:
- The Source object in which orders are created (in the model, this is a warehouse with wire).
- The Queue object models a queue of claims awaiting acceptance by objects following the data in the flowchart, or a store of claims. A queue is added to store incoming material until it is placed on the production line.
- The Conveyor object transfers requests along a path of a given length at a given speed, maintaining their order and leaving specified gaps between them (in the model, material feeding into the machine for processing).
- The Sink object destroys the requests (in the model of a warehouse for finished products, figure 1).

Then the parameters for solving the model in the AnyLogic computing tool are set (figure 2): total wires: 1500 kg; wire on cones MMX-101: 1104 kg.

According to the production process, the wire production is divided into two parts. Next, it is necessary to solve the model in AnyLogic. The received result is shown in figure 3.

![Figure 3](image)

**Figure 3.** Solution of the model for the production of wires of two standard sizes.

In the process of analyzing the production cycle using the AnyLogic computing tool, the following drawbacks were identified:

- The productivity on the MMX-101 line is reduced by 25% due to a decrease in the drawing speed from 27 to 20 m/s, due to increased wire breakage.
- The productivity of stranding on the D 631 machine is reduced due to the ineffective use of the number of stranding machines (one machine is used instead of two or four).
- Long storage time of a copper strand-billet in workshop No. 4 before operation on the stranding machine and before transportation to workshop No. 1, since the stranding line was busy with another task, and the workers were not informed about the readiness of the copper strand.
• There is an extra intermediate destination of the copper vein at site 1 of workshop No. 1 before being sent to site 16) of the same workshop due to the sub-optimally built transport chain.

After the carried out simulation using the AnyLogic computing tool and the subsequent analysis of the technological process operations, the following measures were proposed to eliminate the identified deficiencies in order to optimize the wire production process:

• Strengthen quality control of wire rod supplied to rough drawing;
• Apply highly effective lubricants to reduce the possibility of wire breakage;
• Carry out preventive replacement of worn out traction bands on coarse drawing machines to prevent the ingress of steel particles of wear into the copper wire intended for multi-wire drawing;
• Control the modes of wire annealing to avoid over burning and breakage during drawing;
• To optimize the used number of stranding machines;
• Introduce the procedure of electronic applications with a mark on the execution of the order and informing the customer (site manager, foreman) about the current status of the order;
• Optimize the transport chain, excluding the intermediate destination at site 1 of workshop No. 1.

When implementing these measures, a new model of the production cycle of wire production was proposed with an increase in speed on the MMX-101 line to 27 m / s, using the maximum possible number of twisting machines (4 pieces) and reducing the downtime of wire cones between operations (figure 4, figure 5).

**Figure 4.** Solution of the FLRY-25-C wire production model using the AnyLogic computing tool when implementing the proposed measures.
Based on the results of simulation modeling using the AnyLogic computing tool, it was found that the implementation of the proposed measures will reduce the duration of the production cycle of the FLRY-25-C wire by 68 hours, and thereby increase the manufacturing productivity by 40%.

3. Conclusions
As a result of the study, the following conclusions can be made:

- An analysis of the production process and equipment for obtaining the FLRY-25-C wire has been carried out.
- Simulation experiments were carried out in AnyLogic, which allow evaluating the effect of changing various parameters of the system on the output of the final product.
- A number of problems in the production cycle of the FLRY-25-C wire production were identified and measures were proposed to increase the efficiency of this process.
- It has been established that the implementation of the proposed measures allows to reduce the duration of the production cycle for the manufacture of wires by 68 hours, respectively, to increase the productivity of the process by 40%.

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