The influence of technological and labor processes on the efficiency of the rolling complex

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Abstract. Studies on the organization of technological and labor processes in the existing rolling complex (long product rolling mill) were carried out. Using normative clock models of equipment operation in the areas of the complex, a “bottleneck” was identified that constrains the work of the human-technical system, which is the packaging section for finished products, where baling is performed by workers manually. In order to eliminate the “bottleneck”, it is proposed to modernize the baling area by introducing units for mechanizing and automating the processing of finished products, to eliminate manual labor, improve the formation of current information. The possibility of improving technical and economic indicators (reducing the number of workers, increasing production, labor productivity, etc.) is shown.

1. Introduction
The production process at a modern metallurgical enterprise is a complex production flow, starting from the receipt of raw materials, materials, semi-finished products and ending with the receipt and shipment of finished products. However, the resulting quantitative and qualitative indicators of this complex production flow is not decided by one unit or person, but by the general totality and optimal coordination in the actions of personnel, the operation of units and the organization of material flows.

2. Analysis of the organization of production and labor by sections in the long product rolling mill
The rolling production is a part a complex production process, which occupies 75% of the total metallurgical cycle, and which is the final stage in the production of finished products [1 – 4].

For a more detailed organizational analysis of the production process, the long product rolling mill of a metallurgical enterprise was selected, which is intended for the manufacture of products of a sectional iron assortment. The conducted comprehensive research and analysis of the organization of production and labor by sections of the mill allowed the following conclusions to be drawn. Highly automated and mechanized equipment operates in the areas of heating, rolling, heat hardening, cooling and cutting. The technological processes proceed continuously, the sections are interconnected by a single hot metal stream; any delays, stops in its operation reduce productivity of the mill, labor productivity, output and profitability of products (figure 1).

In the study of the organization of technological and labor processes, it turned out that the least mechanized and most labor-intensive area using manual labor is the metal baling area, which employs 32 packaging workers and 16 ready-made stampers. Currently, at the bailing site, metal baling is carried out in stationary bins by workers manually. Such work is associated with high physical efforts and performed at elevated temperatures.
The main disadvantages of the existing organization of labor at the baling site are: a significant number of workers due to the large number of manual operations associated with baling, stamping, marking and cleaning of metal; low labor productivity, especially during baling of small-tonnage packs of finished products; a tight connection between the operation of the baling and rolling sections leads to a restraint of the production process, since the time for baling, labeling and cleaning of the steel exceeds the duration of rolling; low quality of rolled metal baling does not always meet the requirements of consumers; the impossibility of tight baling of rolled metal bundles and a durable knot in knitting; lack of automated metal-roll metering in bundles.

3. Clock approach to justification of the bottleneck in the system (mill)

In order to justify the degree of influence of the baling area on the coordinated work of the mill, functioning as a continuous-flow human-technical system, the technically possible and normative clocks time at production sites were determined. The clocks of the system (mill), subsystem (areas), elements (equipment), microelements (mechanisms and actions of workers) have their own internal structure, which corresponds to the structure of technological and labor operations. Clock should be considered as an important temporal characteristic affecting the performance of the system, which is one of the main design elements in planning the volume of production, which means labor productivity and many other technical and economic indicators [5].

The clock period is the time interval between the processing moments of the same name (beginning or end) of two adjacent units of production (blanks, bags or bundles) on the same equipment.

In the structure of a complex production process, each unit of production (equipment, site) works with its own clock period, depending on the type of manufactured product (assortment) and production situations. Situational clock cycles of the system are associated with the corresponding clock cycles of its subsystems and elements. Moreover, each clock cycle has boundaries (“fixing points”), which must be determined during the study of the operation of equipment, process conditions, material flows, and the work of maintenance personnel.

In general, the equipment operation cycle consists of the following elements:

\[ T_{eq} = t_1 + t_2 + t_3 + t_4, \]  

where \( t_1 \) is the time of workpiece feeding (loading) into the unit (equipment); \( t_2 \) – workpiece processing time in the unit; \( t_3 \) – time of unloading of the workpiece from the unit; \( t_4 \) – preparation time of the processed workpiece for the next operation.

The authors developed the clock models to assess the degree of rationality of the functioning production processes in rolling mills [6 – 9]. Their use makes it possible to solve the problems of improving multivariate standardization, planning, forecasting and operational management of
technological and labor processes. When rationing, a combination of methods was used: simulation modeling, nominal optimum, mathematical analysis, expert estimates, statistical data processing.

The single technically possible (normative) clock period of work of a long product rolling mill was selected from the clock cycles of the areas according to the criterion of the maximum time costs:

\[
T_{s}^{\text{opt}} = \max \left\{ T_{s1}^{\text{opt}}, T_{s2}^{\text{opt}}, \ldots, T_{sn}^{\text{opt}} \right\},
\]

where \( T_{s1}^{\text{opt}}, \ldots, T_{sn}^{\text{opt}} \) – technically feasible (normative) clock period of the site operation, s.

The procedure for selecting technically possible clock cycles of the system (mill) for each section size was carried out by modeling the coordinated work of the main and auxiliary equipment in all areas of the mill. At the same time, a lot of estimated cycles were formed, options for the occurrence of production situations were considered depending on changes in the external and internal conditions of the human-technical system functioning.

According to the developed regulatory model, technically feasible clock periods, durations of operations and cycles were calculated, standard values of equipment utilization coefficients were established, then normative clock periods of areas were determined taking into account the assortment and production situations by formula (1). The results of the implementation of the clock model are shown on the example of the section production, table 1.

**Table 1.** The choice of the clock period of a long product rolling mill on the example of a profile (reinforcing bar No. 14).

| Clock periods of the production areas in the mill | Clock period of the mill |
|--------------------------------------------------|--------------------------|
| Heating in the furnace                           |                          |
| Workpiece rolling in the mill stand             |                          |
| Heat hardenings on the line                      |                          |
| Cooling on the sections                          |                          |
| Cutting by the cutters                           |                          |
| Baling on the line                               |                          |
| one two one two one two one two one two one two |                          |

1. **Technically possible clock periods before modernization, s**

| 30.0 | 15.0 | 42.5 | 21.75 | 41.8 | 20.9 | 33.0 | 16.5 | 36.5 | 18.25 | 119.0 | 23.8 | 23.8 |

**Regulatory utilization rates of equipment before modernization**

| 0.90 | 0.92 | 0.92 | 0.91 | 0.93 | 0.85 | 0.85 |

2. **Standard clock periods before modernization, s**

| 33.3 | 16.7 | 47.2 | 23.6 | 45.4 | 22.7 | 36.3 | 18.7 | 17.7 | 8.9 | 140.0 | 28.0 | 28.0 |

3. **Technically possible clock periods after modernization, s**

| 30.0 | 15.0 | 42.5 | 21.75 | 41.8 | 20.9 | 33.0 | 16.5 | 16.5 | 8.25 | 56.0 | 14.0 | 21.75 |

**Standard utilization rates of equipment after modernization**

| 0.90 | 0.92 | 0.92 | 0.91 | 0.93 | 0.90 | 0.92 |

4. **Standard clock periods after modernization, s**

| 33.3 | 16.7 | 47.2 | 23.6 | 45.4 | 22.7 | 36.3 | 18.7 | 17.7 | 8.9 | 62.2 | 15.6 | 23.6 |

A comparative analysis of the obtained results of technically possible and standard values of the clock periods showed that the “bottleneck” in the continuous flow system is the baling area, which limits the work of the leading rolling area.

In order to improve conditions and reduce manual labor of workers at the baling site, as well as to ensure the clock operation of the mill in a continuous process flow, it is proposed to mechanize and
automate the system for baling the rolled metal into packages, which will make it possible to: improve the quality of finished packages; reduce time spent on getting the finished package; reduce the cost of strapping materials; to increase the competitiveness of products on the market due to presentation and compliance of rolled products with the requirements of world standards; to reduce the number of manual operations by installing tying machines, which eliminates the human factor in the strapping process; to increase accounting, control and tracking of current package information by installing a monitoring tracking system, expand the ability to supply packages depending on the weight, length and number of rods.

Currently, there are 44 people (28 packers and 16 stampers) at the baling site according to the staff schedule and according to the norm of working personnel. As a result of the introduction of production lines, 15 people are freed (9 packers and 6 stampers). After the proposed implementation of the automated production complex, the technically feasible and normative clock period for the baling site was determined.

Due to the fact that the proposed modernization is being implemented in the baling area, the values of the technically feasible and normative clock periods in this area are changing, and in the rest they remain unchanged, this is clearly shown in Table 1.

Based on the simulation of the operation of the main and auxiliary equipment in mill areas, the system clocks (technically possible and normative) for a given assortment were determined (circles with a diameter of 12-14 mm, reinforcing bars No. 10-14, angle section). Then the indicators of the mill production program are calculated, table 2.

| Indicators                      | Unit of measure | Calculated values for PM₁ | Actual values | Standard indicators before modernization | Calculated values for PM₂ before modernization |
|---------------------------------|-----------------|---------------------------|--------------|----------------------------------------|-----------------------------------------------|
| 1. Calendar time               | day             | 365                       | 365          | 365                                    | 365                                           |
|                                 | h               | 8760                      | 8760         | 8760                                   | 8760                                          |
| 2. General maintenance         | day             | –                         | –            | –                                      | –                                             |
|                                 | h               | –                         | –            | –                                      | –                                             |
| 3. Preventive maintenance      | day             | 15                        | 15.83        | 15.83                                  | 12.83                                         |
|                                 | h               | 360                       | 380          | 380                                    | 308                                           |
| 4. Rated time                  | h               | 8400                      | 8380         | 8380                                   | 8380                                          |
| 5. Ongoing downtime:           | h               | 140                       | 164.3        | 158                                    | 158                                           |
| – technical                    | (h)             | (6)                       | (10)         | (7)                                    | (–)                                           |
| – technological                |                 |                           |              |                                        |                                                |
| – organizational               |                 |                           |              |                                        |                                                |
| (including delays in the baling area) |               |                           |              |                                        |                                                |
| – independent                  |                 |                           |              |                                        |                                                |
| Total current downtime         | h               | 685                       | 810.8        | 722.6                                  | 715.6                                         |
| 6. Current downtime at nominal time | %              | 8.2                       | 9.7          | 8.6                                    | 8.5                                           |
| 7. Actual time                 | h               | 7715                      | 7569.2       | 7657.4                                 | 7664.4                                        |
| 8. Mill productivity           | t/h             | 107.3                     | 76.4         | 91.1                                   | 107.8                                         |
| 9. Output                      | t               | 578286.88                 | 697589.14    | 826222.32                              | –                                             |
| 10. Productive capacity PM₁ and PM₂ | t               | 827819.5                  | –            | –                                      | –                                             |

Thus, after the proposed modernization in the baling area by introducing an automated process for baling rolled products aimed at eliminating manual labor, the work cycles of this area will be reduced. As a result, this area will not restrain the operation of the main (leading) section, and the cycle of the
system will correspond to the cycle of the rolling section. After the proposed modernization in the baling area (taking into account capital investments), output will increase by 18%. In addition, the number and wages of workers will be reduced, labor productivity will increase, labor intensity of production will decrease, production costs will decrease, profit and profitability of marketable products will increase.

4. Conclusion
Based on the analysis of technical and economic indicators, a detailed study of equipment, technology, organization of production and labor, comprehensive research at each area of the long product rolling mill it was proved that the efficiency of the production process is affected not only by technological, but also to a large extent by labor processes. The developed regulatory model for the functioning of the long product rolling mill allowed the regulatory framework for technical and economic indicators necessary for planning, forecasting and operational management of production to be formed.

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