On the development of a base of normative situational clock periods of the rational rolling complex functioning

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Abstract. The main idea of the article is to solve the problem of assessing the normative values of situational clock periods of the rolling complex equipment. The result of the study is a measure of clock cycles, structured by the type of product, technological routes and production situations. An example of rationalization of one of the technological routes of a specific rolling production using situational and normative clock periods is shown, which allows the main technical and economic indicators of the complex to be improved. A situational clock period approach is proposed to build a base of normative indicators for the rolling complex. The following areas of application of the base of indicators are identified: optimization of technological routes, scheduling of the complex, operational planning of the production.

1. Introduction
The tasks of scheduling and operational management of a complex production require the preliminary development of a base of situational and normative indicators of its functioning, in which clock periods are the determining indicators. The paper presents the synthesis of the procedure for assessing the standard values of clock periods taking into account the amount of equipment used and the product mix. The object of the study is a rolling complex, which includes a billet (breakdown) shop and a long product rolling mill, consisting of four parallel processing mills (medium-section and three small-section mills). The connecting link in this complex is an intermediate warehouse of blanks of the breakdown workshop, designed to maintain a rational stock of blanks with the aim of uninterrupted supply of rolling department with metal.

2. Characterization of technological routes of the rolling complex
Currently, the material flows of the studied rolling complex are organized according to six routes (figure 1).

The considered main technological routes No. 1, No. 2 are organized in the system “breakdown mill → refrigerator → billet warehouse → rolling mills”, the so-called “cold charging” of billets coming from the warehouse by the roller conveyor to the heating furnaces of four section rolling mills. In addition, a transit route No. 3 “breakdown mill → mill 450” was organized, providing for the so-called “hot charging” of workpieces coming from 400 tonne cutters through the system of transmitting devices (slippers, roller conveyor) in hot condition immediately to the heating furnaces of mill 450, which greatly saves time and fuel resources. Breakdown bars intended for the production of semifinished products (blooms and slabs) after cleaning surface defects are fed to 1400 t cutters, where they are cut to appropriate lengths, according to customer orders, then the semi-finished products are transported to the storage area for rolled metal products (routes No. 4, No. 5).
Part of the metal enters the rolling complex from the continuous steel casting department of the oxygen converter shop in the form of cast billets with a section of 150×150 mm, which are transported directly to the billet warehouse, from where they are subsequently fed to the heating furnaces of mill 450 (route No. 6).

3. Stages of development of situational-clock models
The methodology for constructing interconnected technically feasible and normative cycles of equipment operation, their classification and application in rolling production are considered in [1, 2].

In order to identify the internal reserves of production, improve the organization, planning and operational management of material flows, a multivariate assessment of the measures was performed for situations characterizing the functioning of the investigated rolling complex on the basis of the developed situational clock models in the following stages.

![Diagram](image-url)
1. The definition of technically possible $T^{p(n)}$ and normative $T^{n}$ clock periods of the main and auxiliary equipment of the complex:

- in the breakdown mill (clock periods of the processes: heating in the department of soaking pits, rolling at blooming and at the CBM, peeling at the scarfing machine, cutting on cutters and cooling on sections of the refrigerator), $T^{p(n)}_{\text{tot(nm)}}$;
- on a medium-section mill 450 (clock periods of processes: heating in walking hearth furnaces, continuous rolling in stands, cooling in the refrigerator, dressing on straightening machines, cutting by cutters and baling), $T^{p(n)}_{450}$;
- on small-section mills 250-1 and 250-2 (clock periods of processes: heating in continuous furnaces, continuous rolling into two billets in stands, cooling in the refrigerator, cutting by cutters scissors and baling), $T^{p(n)}_{250-1}$, $T^{p(n)}_{250-2}$;
- at a wire mill 250 (clock periods of processes: heating in continuous furnaces, continuous rolling into four billets in stands, forming coils in special machines, cooling of coils on a hook conveyor and their strapping), $T^{p(n)}_{250}$.

2. The selection of the technically possible (normative) clock period of the $k$-th unit of the complex, including $n$ of series-connected units of equipment, was carried out in accordance with the rule:

$$T^{p(n)}_{k,n} = \max \{ T^{p(n)}_{k,1}, T^{p(n)}_{k,2}, ..., T^{p(n)}_{k,n} \},$$

where $T^{p(n)}_{k,n}$ is the clock period of the $n$-th equipment of the $k$-th unit, s.

3. Determination of the clock period of the rolling complex according to the $z$-th technological route, taking into account production situations during the joint work of $k$-th units $T^{p(n)}_{z}$.

The possibility of introducing an additional transit route No. 7 of hot blanks on the line “breakdown workshop – wire mill 250” was revealed in order to reduce the consumption of fuel and energy resources on the basis of studying the existing organization of material flows in the rolling complex, plans for the location of technological and transport equipment in the billets warehouse, as well as the obtained estimates of the clock periods of the breakdown workshop and section rolling mills. In this case, breakdown bars with a cross section of 100×100 mm after cutting them by cutters of 150 tonnes, without cooling in the refrigerator, are transferred by a roller conveyor (which must be installed in the warehouse) to the feed roller to the continuous furnace No. 2 of the wire mill. It should be noted that the transit for furnace No. 1 of mill 250 is not provided, furnace No. 1 is located at a great distance from refrigerators, which will lower the temperature of the transit metal during its transportation to this furnace.

The work of the rolling complex can be carried out according to the options that correspond to the following production situations (Sit), figure 2, depending on the type and size of the blanks (numbers correspond to the blocks of figure 1).

The clock periods of the breakdown mill and section rolling mills were simulated for the reduced unit of production (piece) for which an ingot of a certain type was adopted, comparable in weight to a package of workpieces of a given size (by cross-section and length). In this case, possible situations were taken into account, each of which is characterized by technological modes of heating, rolling and cooling, the amount of auxiliary equipment used (heating and cooling devices, cutting and baling units), the combination and direction of material flows.
4. Modeling and selection of rational technological routes

Multivariate modeling allowed the rational conditions for the implementation of technological routes to be determined. Fragments of the results of modeling and evaluation of the clock cycle of the rolling complex are presented for some situations in tables 1-3. Note that the tables show (as characteristic examples) only one of the many options for the developed regulatory database, taking into account combinations of possible modes, the amount of equipment used and product characteristics.

For the trouble-free operation of the rolling mills during the cold charging of the blanks (Sit-1), the clock period of the breakdown mill $T_{tot}^{p(n)}$ should be less than the clock period of the rolling mills (equivalent clock period) $T_{eq}^{p(n)}$ that is, $T_{tot}^{p(n)} < T_{eq}^{p(n)}$

In the inequality, the less than sign indicates that the breakdown mill provides scrap metal not only for the rolling mills, but also produces additional metal for the sale of commercial products (blooms, slabs, billets) and for creation, if necessary, of current and technological stock of blanks in the warehouse.

$$T_{eq}^{p(n)} = T_{250-1}^{p(n)} \cdot \gamma_{250-1} + T_{450}^{p(n)} \cdot \gamma_{450} + T_{250}^{p(n)} \cdot \gamma_{250} + T_{250-2}^{p(n)} \cdot \gamma_{250-2}$$

where $\gamma_{250-1}$, $\gamma_{450}$, $\gamma_{250}$, $\gamma_{250-2}$ – the number of bundles of blanks corresponding to the clock periods of the rolling mills, pcs.
During the operation of the heating furnaces of mill 450 with cold charging of the billets, the breakdown mill can work in two directions, that is, transfer bundles of blanks in transit to the furnaces of mill 450 and to the warehouse into stock heaps (Sit-2) in the following ratio:

\[ T_{450}^{bp(n)} \geq T_{tot(450)}^{bp(n)} \cdot \gamma_{tot(450)} + T_{tot(wm)}^{bp(n)} \cdot \gamma_{tot(wm)}, \]

where \( T_{450}^{bp(n)} \) and \( T_{tot(wm)}^{bp(n)} \) are the clock periods of the breakdown mill during the hot transit of blank bundles to the furnaces of mill 450 and storing the bundles into stock heaps, s; \( \gamma_{tot(wm)} \) and \( \gamma_{tot(450)} \) – the number of bundles of blanks supplied from the breakdown mill to the furnaces of mill 450 and to the warehouse, pcs.

For example, the clock period of the breakdown mill during ingot rolling \( T_{tot(wm)}^{bp} = 42.55 \) s; the clock period of mill 450 when rolling a bundle of billets into finished section (channel steel) is \( T_{450}^{bp} = 128.82 \) s, then according to formula (1):

\[
T_{tot(wm)}^{bp} = \max\{40.76; 38.75; 27.72; 42.55; 30.05; 38.94\} = 42.55 \text{ s (per bundle of blanks)}
\]

\[
T_{450}^{bp} = \max\{10.07; 21.47; 18.9; 18.3; 17.4\} = 21.47 \text{ s (per blanks) or } 128.82 \text{ c (per bundle)}.
\]

Consequently, the breakdown mill must ensure the supply of a bundle of hot billets to mill 450 every 128.82 s, while it can submit two more bundles to the warehouse for further transfer to small-section mills, table 1.

| Table 1. Estimation of the clock period of the rolling complex for Sit-2 (example). |
|---------------------------------------------------------------|
| Breakdown mill | Clock period | Fridge | Clock supply of bundles (\( \gamma = 2 \)) | The clock period of the complex, taking into account the number of bundles (\( \gamma \)) supplied to |
| Mill 450 | taking into account the work of three furnaces | number of sections | mill 450 | warehouse |
|---------------------------------------------------------------|
| 42.55 | 128.82 | 38.94 | 35.05 | 85.1 | 128.82 |
| 47.28 | 140.04 | 44.25 | 39.83 | 94.56 | 140.04 |

When operating a heating furnace No. 2 of wire mill 250 with a hot charge of billets (Sit-5), the following condition for the rational functioning of the complex must be observed (table 2):

\[ T_{250}^{bp(n)} \geq T_{tot(250)}^{bp(n)} \cdot \gamma_{tot(250)} + T_{tot(wm)}^{bp(n)} \cdot \gamma_{tot(wm)} \]

The functioning of the rolling complex during the operation of the heating furnaces of mill 450 and the furnace of mill 250 with a hot charge of workpieces (Sit-6) should be carried out in the ratio:

\[
T_{250}^{bp(n)} \geq T_{tot(250)}^{bp(n)} \cdot \gamma_{tot(250)} + T_{tot(450)}^{bp(n)} \cdot \gamma_{tot(450)} + T_{tot(wm)}^{bp(n)} \cdot \gamma_{tot(wm)}
\]
Table 2. Estimation of the clock period of the rolling complex for Sit-5 (example).

| Breakdown mill | Clock period (per ingot) | Clock supply of bundles (γ = 11) to the warehouse | The clock period of the complex, taking into account the number of bundles (γ) supplied to |
|----------------|--------------------------|--------------------------------------------------|-----------------------------------------------------------------|
| Mill 250 Fridge | Mill 250 | Fridge | one | 42.55 | 510.9 | 31.25 | 468.05 | 510.9 |
|                | taking into account the work of one furnace | number of sections | 10 | | | | |
|                | Technically possible clock periods, s | | | | | | |
|                | Normative clock periods, s | | | | | | |
|                | 47.28 | 601.12 | 35.51 | 520.05 | 601.12 |

Table 3. Estimation of the clock period of the rolling complex for Sit-6 (example).

| Breakdown mill | Clock period (per ingot) | Clock supply of bundles (γ = 7) to the warehouse | The clock period of the complex, taking into account the number of bundles (γ) supplied to |
|----------------|--------------------------|--------------------------------------------------|-----------------------------------------------------------------|
| Mill 250 Fridge | Mill 250 | Mill 450 | Fridge | one | three | 8 | 9 | 42.55 | 510.9 | 128.82 | 38.6 | 34.5 | 297.85 | 510.9 |
|                | taking into account the work of one furnace | number of sections | | | | | | | | | | | | | |
|                | Technically possible clock periods, s | | | | | | |
|                | Normative clock periods, s | | | | | | |
|                | 47.28 | 601.12 | 140.04 | 43.86 | 39.2 | 330.94 | 601.12 |

5. Conclusion

Thus, the introduction of an additional transit technological line to the wire mill will make it possible, with small capital investments, to reduce the current costs of the wire mill by reducing the heating time and fuel supply rate, since one furnace will work in the preheating mode (Sit-5, 6).

Implementation of the proposed organizational and technical measure (project route No. 7) from the 150 tonnes cutters of the breakdown mill to wire mill 250 will improve the technical and economic indicators of the rolling complex (table 4).

Table 4. Technical and economic indicators of the rolling complex for Sit-5.

| Indicators                  | Units | Normative values |
|-----------------------------|-------|------------------|
|                            |       | breakdown mill   | wire mill | plan | project | plan | project |
| 1. Productive capacity     | t/year| 6702418          | 6756418 | 886627 | 941930 |
| 2. Volume of production     | t/year| 6620133          | 6674133 | 875742 | 930459 |
| 3. Commodity production     | t/year| 1527584          | 1581584 | 871896 | 926613 |
| 4. Mill productivity        | t/h   | 848.3            | 855.2   | 119.2  | 126.7  |
| 5. Specific metal consumption| t/t   | 1.107            | 1.0277  | 1.0253 |
| 6. Rolling costs            | rub/t | 73.52            | 72.82   | 147.20 | 139.56 |
| 7. Cost of production       | rub/t | 1768.79          | 1767.89 | 1998.3 | 1984.32|
| 8. Profit of marketable products | mln rub | 945.69        | 978.62  | 609.82 | 643.54 |
| 9. Product profitability    | %     | 35               | 36      | 35     | 36     |
| 10. Annual savings          | mln rub | –              | 6.00    | –      | 13.05  |
| 11. Capital investments     | mln rub | –              | –       | –      | 2.5    |
| 12. Project payback period  | year  | –               | –       | –      | 0.2    |

The developed mathematical models of the cycles of operation of equipment, sections, mills of the rolling complex, the sequence of which is shown in figure 3, is necessary to solve the problems of optimizing many technological routes, as well as for planning and operational management of production.
1. Creation of a clock model for multivariate operation of the main, auxiliary equipment and production sections of the breakdown mill (by inputs and outputs, by modes and number of units of equipment used).

2. Evaluation of multivariate clock periods of the breakdown mill by technological routes and production situations.

3. The construction of clock models for multivariate operation of the main, auxiliary equipment and production sections of section rolling mills (450, 250-1, 250-2, 250) according to the modes and quantity of equipment used.

4. Determination of situational clock periods of rolling mills by type of products.

5. Evaluation of multivariate clock periods of the rolling complex “breakdown mill – section rolling mills” taking into account end-to-end routes and production situations.

6. Formation of a base of situational normative clock periods (BNCP) for solving the problems of managing the rolling complex operation.

**Figure 3.** An enlarged diagram of the formation of BNCP.

**References**

[1] Musatova A I, Kulakov S M and Kadykov V N 2011 *Steel in Translation* vol 41 No 4 294–300

[2] Kulakov S M, Musatova A I et al 2015 *Steel in Translation* vol 45 No 5 338–346