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ANALYSIS OF ENERGY PERFORMANCE OF FERROUS METALLURGYENTERPRISES BASED ON THE SCHEME OF DECOMPOSITION

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ANALYSIS OF ENERGY PERFORMANCE OF FERROUS METALLURGY ENTERPRISES BASED ON THE SCHEME OF DECOMPOSITION

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Annotation. The task of determining specific electricity consumption is complex, as it is necessary to take into account a large number of factors affecting the energy indicators that determine the level of these indicators. At the same time, the type and technical condition of the main and auxiliary process equipment in the process of melting, the nomenclature of metal, the volume of consumed components of the process and secondary energy carriers (compressed air, nitrogen, oxygen and other auxiliary components), etc. are taken into account. The error in taking these factors into account may lead to deviations from the actual values of the predicted power consumption, as well as energy indicators. The energy intensity of products and the level of energy consumption also depends on changes in the structure of energy consumption, the latter depending on the need for such process components as compressed air, oxygen, nitrogen, etc. The article considers the results of the analysis of energy indicators of enterprises of ferrous metallurgy, in particular, electrosmelting shop by types of output products on the basis of decomposition scheme. It is shown that the set task is solved by means of construction of dependences of normative energy characteristics on the volume of output products, and also the final decomposition tree is formed - the tree of tasks designed to achieve solutions of energy problems, including the main one - to obtain the value of specific energy consumption. In addition, the article presents the method of determining the share of participation of auxiliary components of the technological process for example of compressed air, nitrogen and oxygen. At calculations the account of the above-stated components gives the chance to define more precisely specific expense of the electric power.

Key words: specific energy consumption, problem solving tree, technological process components, system analysis of energy indicators.

Energy indicators are considered in the process of expanding the scope of research and the implementation of work on the rational use of energy resources in production, which ultimately comes down to the refinement and comprehensive analysis of energy indicators. In this process, a special place is occupied by determining the dependence of the energy intensity of products on electrical, technological and operational parameters, taking into account their specific features [1-3]. A systematic analysis of the identification of the final results provides a comprehensive solution to the problem, taking into account the whole variety of interrelated factors and events [4].

In general terms, for a complex, an "aggregate-enterprise or association", the research and calculation algorithm is developed in the following logical sequence: aggregate, workshop, enterprise. The features of the object are identified taking into account the operating mode and production characteristics of the studied object and factors affecting the energy intensity indicators.

In particular [5]:

- time mode;
- constant mode of continuous operation;
- variable mode;
- product characteristics (uniform, homogeneous, heterogeneous);
- the main components of the process (compressed air, argon, oxygen, etc.);
- the presence of industrial relations;
- the introduction of measures to save energy.

Based on the analysis, mathematical models of specific power consumption were developed for each type of product (by departments and the enterprise as a whole), providing for the influence of relevant factors on them. Taking into account the real costs during the operation of the workshops and their time parameters, the electric power consumption necessary for the production of a given volume of products and, accordingly, its electric intensity is determined [6-8].

In order to identify reserves of energy savings from the general calculation scheme, the power of units participating in the production process during the maximum load of the power system is allocated. To conduct an effective study of energy consumption in accordance with the approved scenario, decomposition schemes are developed separately for the workshop, enterprise and association [9-11].

First, the decomposition of specific energy consumption indicators is performed. Then the main subtasks are identified, the solution of which ensures the achievement of the goal (Fig. 1).

In general, the diagram of the decomposition of the indicators of specific power consumption (e) of an aggregate producing diverse products ($\Pi_1, \Pi_2, ..., \Pi_n$) with hourly output ($A_1, A_2, ..., A_n$) displays the power consumption of the aggregate (P), average power (P_{av}) for each type of product ($P_{av1}, P_{av2}, ..., P_{avn}$), power of equipment for auxiliary needs (P_{aux}), equipment operating time ($t_1, t_2, ..., t_n$), number of working units (m) for each type of product (m_1 , $m_2, ..., m_n$), as well as the energy consumption (W) for the production of each type of product ($W_1, W_2, ..., W_n$).

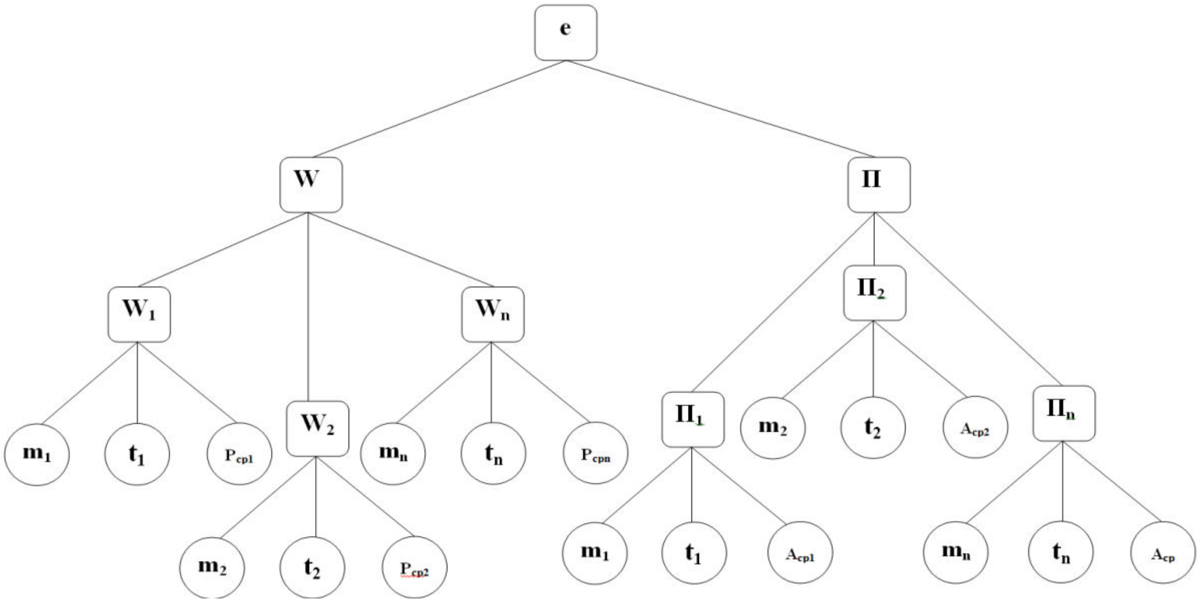

Fig. 1. The scheme of decomposition of specific energy consumption indicators.

To determine the specific power consumption indicators, using the decomposition schemes, the following formulas are used:

When determining the energy consumption (W_i) for output:

$$W_i = m_i \cdot t_n \cdot P_{avi} \quad (1)$$

where m_i is the number of operating units for each type of product;
P_{avi} - average power for each type of product, kW;
t_n - equipment operating time, h
The volume of output of each type of product (P_i) is determined by the expression (2):

$$\Pi_i = m_i \cdot t_n \cdot A_{avi} \quad (2)$$

where A_{avi} - hourly productivity, t / h.

As an example, we determine the specific power consumption indicators of the electric steel-smelting shop (ESSSH) using the decomposition scheme (Fig. 1).

Table 1

The main indicators of production

Name	Assortment machine tools *m, pcs*	Time work, *h*	Productivity, A_{av}, *t/h*	Consumable power, P_{av}, *kW*
Corner 40x4	6	16	7,2	56
Corner 32x4	6	16	6,6	49
Square 16x16	4	16	6,4	43
Square 20x20	4	16	6,8	52
Strip 40x5	8	16	4,6	31
Strip 50x5	8	16	5,1	36

We determine the daily energy consumption for the release of each type of product according to the formula (1):

Corner 40x4 - $W_1 = m_1 \cdot t_1 \cdot P_{av_1} = 6 \cdot 16 \cdot 56 = 5376\ kW \cdot h$;

Corner 32x4 - $W_2 = 6 \cdot 16 \cdot 49 = 4704\ kW \cdot h$;

Square 16x16 - $W_3 = 4 \cdot 16 \cdot 43 = 2752\ kW \cdot h$;

Square 20x20 - $W_4 = 4 \cdot 16 \cdot 52 = 3328\ kW \cdot h$;

Strip 40x5 - $W_5 = 8 \cdot 16 \cdot 31 = 3968\ kW \cdot h$;

Strip 50x5 – $W_6 = 8 \cdot 16 \cdot 36 = 4608\ kW \cdot h$.

We determine the specific energy consumption for each type of product according to the formula (3):

Corner 40x4– $\Pi_1 = m_1 \cdot t_1 \cdot A_{av_1} = 6 \cdot 16 \cdot 7{,}2 = 691{,}2\ t$;

Corner 32x4– $\Pi_2 = 6 \cdot 16 \cdot 6{,}6 = 633{,}6\ t$;

Square 16x16– $\Pi_3 = 4 \cdot 16 \cdot 6{,}4 = 409{,}6\ t$;

Square 20x20 - $\Pi_4 = 4 \cdot 16 \cdot 6{,}8 = 435{,}2\ t$;

Strip 40x5 - $\Pi_5 = 8 \cdot 16 \cdot 4{,}6 = 588{,}8\ t$;

Strip 50x5 - $\Pi_6 = 8 \cdot 16 \cdot 5{,}1 = 652{,}8\ t$.

Corner 40x4– $e_1 = \frac{W_1}{\Pi_1} = \frac{5376}{691{,}2} = 7{,}8\ kWh/t$; Corner 32x4– $e_2 = \frac{4704}{633{,}6} = 7{,}4\ kWh/t$;

Square 16x16– $e_3 = \frac{2752}{409{,}6} = 6{,}7\ kWh/t$; Square 20x20 – $e_4 = \frac{3328}{435{,}2} = 7{,}64\ kWh/t$;

Sprit 40x5 – $e_5 = \frac{3968}{588{,}8} = 6{,}74\ kWh/t$; Sprit 50x5 – $e_6 = \frac{4608}{652{,}8} = 7\ kWh/t$.

Based on the foregoing, we find the energy consumption for the billing period:

$$W_{ц} = K\left[W_{aux}(1 + f_i) + \delta \cdot A_{av}(1 + l_i)\right] \quad (3)$$

where K is the amount of cycles in the billing period;

f_i, l_i - respectively, the resulting values of the factors affecting the auxiliary energy consumption and productivity;

W_{aux} - power consumption for auxiliary needs of the unit per cycle;

A_{av} - hourly average unit productivity per hour; δ is a coefficient representing a constant component of the specific energy consumption.

In addition to the scenario for the unit, scenarios are also being developed for the upper levels of management - enterprises, associations (associations) and the control center of the power system. These scenarios according to the existing scheme (task tree) should be developed for each type of production, producing both a single, homogeneous, and heterogeneous products [12-15].

If an enterprise, except for the main products, produces products for delivery to other enterprises, then the energy consumption for the production of these types of products should be normalized separately, and the calculation should include the energy consumption for the production of auxiliary components of the technological process (AC of the TP) generated by auxiliary workshops [16].

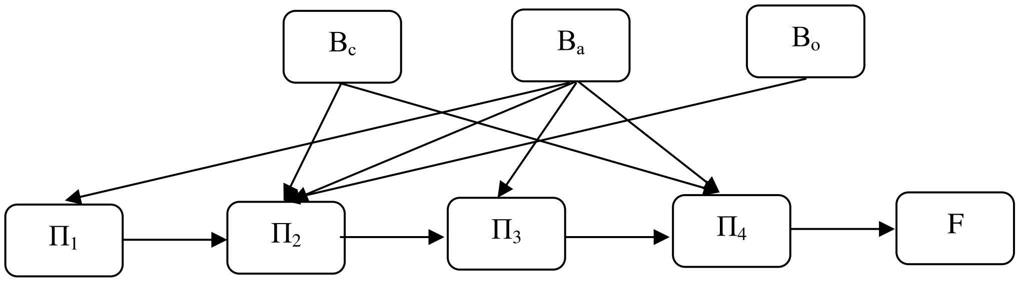

Fig. 2. The scheme of providing workshops AC of the TP

To date, in practice, when determining the share of participation of AC of the TP, it is not taken into account at the stages of production of the final product. One and the same component (compressed air B_c, argon B_a, oxygen B_o, etc.) is consumed at several stages of production output (Fig. 2). In this case, the energy consumption, for example, for the production of compressed air, is:

$$W_c = \omega_c \left(B_{c_1} + B_{c_2} +,...,+ B_{c_n}\right) \tag{4}$$

The estimated formula of the unit of the production unit, taking into account the energy indicators of auxiliary components, is determined by the formula:

$$d_i = \varepsilon_1 \cdot q_1 + \sum_{1}^{m} \varepsilon_2 \cdot q_2 \tag{5}$$

where m is the amount of AC of the TP blocks used in the production of the П shop; $q_2 = \frac{B_i}{\Pi_i}$ - the specific consumption of this type of AC of the TP per unit of production Π_1.

As an example, the general production specific consumption of electricity is determined taking into account the energy indicators of the auxiliary components of the technological process (AC of the TP) according to Fig. 2.

In the technological process at the ESSSH, compressed air, oxygen, nitrogen, argon are used as auxiliary components. The example below shows the calculations for compressed air.

Oxygen compressor 82000 m^3 / h, ASF-100 - $B_m^c = 48542$ thousand m^3/year, imsu - $B_o^c = 28542$ thousand m^3/year. The total power consumption of the compressor station - $P_n = 9450 \quad kW$. The volume of output of the final product $F_{2015} = 626700 \ t/year$.

We determine the specific energy consumption for the production of compressed air ESSSH:

$$\omega_c = \frac{9450}{48542} = 194 \ kWh/1000\, m^3$$

We determine the value of the specific consumption of compressed air per unit of final product:

for ASF-100 - $q^c_{ASF-100} = \dfrac{48542000}{626700} = 0{,}08 \quad m^3/t$;

for IMSU- $q^c_{IMSU} = \dfrac{28542000}{626700} = 0{,}045\, m^3/t$.

We determine the value of the specific energy consumption per unit of final product for individual industries:

for ASF-100 - $\alpha^c_{ASF-100} = 194 \cdot 0{,}08 = 15{,}52 \quad kWh/t$;

for IMSU - $\alpha^c_{IMSU} = 194 \cdot 0{,}045 = 8{,}73 \quad kWh/t$.

The total specific energy consumption per unit of final product will be:

$$e_{ESSSH} = \alpha^c_{ASF-100} + \alpha^c_{IMSU} = 15{,}52 + 8{,}73 = 24{,}25 \quad kWh/t$$

We determine the value of the total energy consumption for the production of compressed air:

$$W_c = 194(48542 + 28542) = 14954\, thousand\, kWh/\, year.$$

The above method makes it possible to carry out calculations for each level. The factors that determine the forecast object described by the above equations provide for the analysis of the initial indicator and identify the relations between energy and technological factors (Fig. 3). Each of these parameters, in turn, is associated with a number of factors that directly or indirectly affect them. Based on experimental studies and statistical analysis of operational materials, we single out the factors that have the greatest impact on energy performance [17-18].

The problem is solved by constructing the dependence of the normative energy characteristics Wот the volume of output *П*. Based on the energy characteristics, the multifactor correlation model is described as follows:

$$e = f(X_1, X_2, \ldots, X_n)\ ; \qquad (6)$$

where $X_1, X_2, \ldots, X_n$ - are the factors correlated with the electric intensity of the products (table 2).

Table 2

Factors correlated with the electric intensity of the products

Indicators	The characteristic structural components of the indicator	Factors
The constant component of energy consumption (independent of performance), W_0	Electric lighting W_{01}, ventilation, air conditioning W_{02}, idling machines	Seasonality X_0, ambient temperature X_1, frequency of repair of machines and mechanisms X_2
Partial specific energy consumption per unit of production,	Specific useful energy consumed, specific load loss of electricity	The temperature of the processed material X_3, humidity X_4, grain size X_5, hardness X_6, pressure X_7, equipment load factor affecting the volume of workshop products X_8
Volume of shop products: natural, *П*; conditional	Range: first product $П_1$, second product $П_2$, *n-th* product $П_n$	Power consumption of certain types of products: $X_{9_1}, \lambda_{a_1}, X_{10_2}, \lambda_{a_2}, X_{10_n}, \lambda_{a_n}$
Factory Production (final): *F*	Range: first product F_1 second product F_2	The electric capacity of individual products, affecting the volume of manufactured

	nth product F_n	products and types of products: $X_{11_1}, \lambda_{z_1}, X_{11_2}, \lambda_{z_2}, X_{11_n}, \lambda_{z_n}$
Product of processing (raw materials), *G*	Product of processing (raw materials), *G*	The content of useful product X_{12}, the coefficient of extraction of useful product X_{13}
Auxiliary components of the technological process, I_n	Compressed air B_c, oxygen B_o, argon B_a	X_{14} network pressure, X_{15} unit losses, X_{16} network losses, X_{17} temperature and other X_n

Similar models are developed for the whole range of indicators.

After establishing a logical sequence of research procedures, including the development of a calculation scenario, an initial decomposition of the system of specific electricity consumption is performed (Fig. 2).

Next, a set of issues is considered and solved with the implementation of many activities. For this, a further decomposition of the system is used, through which, after a certain number of steps, a final decomposition tree is formed. It is also a tree of tasks, since it is intended to achieve the main task - to obtain the value of e (Fig. 3) [19].

The task tree for determining the specific energy consumption is constructed in stages in such a way that activities of the next level provide a solution to the problem of the previous one. The task tree for determining the specific energy consumption gives a complete picture of the interconnections between tasks, activities, electric power and technological indicators, as well as indicators of the operation of machines and mechanisms, the range of raw materials, etc.

The goals developed in the scenario: indicators of energy consumption by characteristics and consumption groups, volumes of products, taking into account the assortment, specific indicators of consumption of raw materials, process components, specific indicators of electricity consumption, etc. are arranged at appropriate levels in a hierarchical order, taking into account causal relations [20].

To calculate the task tree, the corresponding formulas are proposed:

Constant component of energy consumption (independent of performance):

$$W_o = W_{o_1}(1 \pm k_1) + W_{o_2}(1 \pm k_2) + W_{o_3}(1 \pm k_3)\,; \qquad (7)$$
$$k = f(X_0, X_1, X_2),$$

where W_{01} is the energy consumption for electric lighting, ventilation;

W_{02} - energy consumption for air conditioning;

W_{03} - power consumption for idling of machines and mechanisms;

X - influencing factors: X_0– seasonality, X_1 - ambient temperature; X_2 - the frequency of repair of machines and mechanisms.

Partial specific energy consumption per unit of output δ:

$$\delta = \frac{W - W_o}{\Pi}(1 \pm k_1) \quad \delta_в = \frac{W_в - W_{o_в}}{B_в}(1 \pm k_в)\,;$$

$$k_в = f(X_4, X_5, X_6, X_7, X_8, X_9)\,; \qquad (8)$$

The volume of workshop production: natural Π:

$$\Pi = (\Pi_1 + \Pi_2 + ... + \Pi_n)(1 \pm k_q)\,;$$

$$k_q = f(X_{10_1}, X_{10_2}, ..., X_{10_n}) \qquad (9)$$

where *П*– assortment: the first product $П_1$, the second product $П_2$, *n*-th product $П_n$;
$X_{9_1}, \lambda_{a_1}, X_{10_2}, \lambda_{a_2}, X_{10_n}, \lambda_{a_n}$ - electric intensity of certain types of products.

The volume of factory production (final) *F*:

$$F = (F_1 + F_2 +,...,+F_n)(1 \pm k_z);$$

$$k_z = f(X_{11_1}, X_{11_2}, ..., X_{11_n}) \quad (10)$$

where *F*– assortment: F_1 - the first product; F_2 is the second product, F_n is the nth product.
$X_{11_1}, \lambda_{z_1}, X_{11_2}, \lambda_{z_2}, X_{11_n}, \lambda_{z_n}$ the power consumption of individual products, affecting the volume of manufactured products, types of products.

Auxiliary components of the technological process, In:

$$в = в_1 + в_2 + ... + в_n;$$

$$в = f(X_{14}, X_{15}, X_{16}, X_{17}, X_n) \quad (11)$$

where *в* is compressed air b_1, oxygen b_2, argon b_3; X_{14} - pressure in the network, X_{15} - losses in units; X_{16} - network losses, X_{17} - temperature; X_n - and others.

When calculating for the forecast period, it is necessary to take into account the projected implementation of new machines and technologies, automation equipment, labor protection measures, etc. Energy assessment of these factors can be carried out by known methods, including the method of expert assessments.

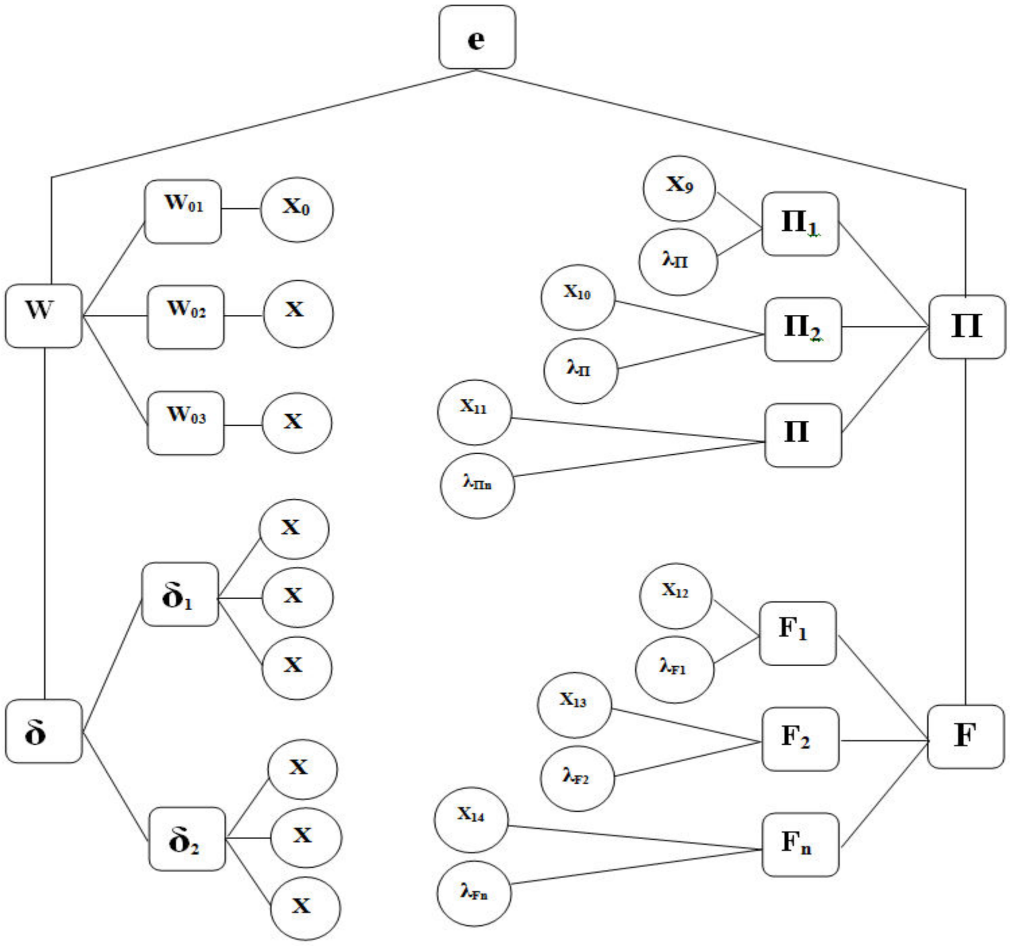

Fig. 3. The task tree for determining the specific energy consumption by dividing it into a number of subsystems (blocks).

As a result, it should be noted that the systematic approach to the analysis of energy indicators allows us to more fully study the trends and patterns of changes in specific and absolute energy consumption, taking into account the complex influence of electrical, technological and operational factors.

The above method of system analysis of energy indicators makes it possible to widely study changes in the specific and total consumption of electric energy, taking into account the influence of electrical, technological and operational factors, which ensures the reliability of the calculations.

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