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A Method for Diagnosing the Condition of Energy Elements, Control And Management Of Energy Efficiency Of Energetic Consumption Systems

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ABSTRACT :*To implement the method of diagnosing the elements of energetic consumption systems (ECS) , all production processes are broken into three categories: basic energy technological processes of obtaining products (ETP1), auxiliary energy technological processes (ETP2) and energy technological processes which ensure living conditions (ETP3).*

Technical diagnostics determines the technical condition of an element which is characterized at a specific time and in certain environmental conditions by the values of parameters defined in the technical documents of the elements. As a result of technical diagnostics, one of two working conditions of elements is determined: usable or unusable. During the energy diagnostics of ECS, the element's condition and ETP are determined by calculating their relative energy consumption and energy efficiency (for example, specific energy consumption per unit of production).

The developed method of diagnostics allows comparing the losses in elements depending on the load which varies with time and determining the increase in energy losses in the element. It also allows determining the proportion of runtime under equal loads, and the load creating the maximum energy loss, i.e., the most energy-consuming mode in which the deterioration of the element's condition has the greatest effect on energy losses in this ETP .Losses are minimized by changing or limiting the operation of or restoring the condition of the element.

Keywords: *energy efficiency, economic effectiveness*

I. INTRODUCTION

To implement the method of diagnosing the elements of energetic consumption systems (ECS) , all production processes are broken into three categories: basic energy technological processes of obtaining products (ETP1), auxiliary energy technological processes (ETP2) and energy technological processes which ensure living conditions (ETP3).

Technical diagnostics determines the technical condition of an element which is characterized at a specific time and in certain environmental conditions by the values of parameters defined in the technical documents of the elements. As a result of technical diagnostics, one of two working conditions of elements is determined: usable or unusable. During the energy diagnostics of ECS, the element's condition and ETP are determined by calculating their relative energy consumption and energy efficiency (for example, specific energy consumption per unit of production).

II. MATERIALS AND METHODS

The method of diagnosing the condition of energy elements, control and management of energy efficiency of consumer energy system, which is based on finite ratio method (FRM) [1], requires the simultaneous and continuous registration of energy values on input and output of elements and ETP [2]. Based on the registered parameters for a representative period of time, the specific energy consumption per unit of production P is determined.

This is achieved by determining the value of energy consumption at the beginning of each line containing ETP:

- Q_{pr} is energy consumed for producing production P in line containing ETP1:

$$Q_{pr} = Q_{el1} \cdot Q_{pr}^{spec} \cdot P \qquad (1)$$

Where: Q_{el1} is the power intensity of the line feeding ETP1;

- Q_{pr}^{spec} is the specific power intensity of a product P;

-Q_{R2} is the energy consumed to achieve the results in the line containing ETP2:

$$Q_{R_2} = Q_{el2} \cdot Q_{R_2}^{spec} \cdot R_2 \qquad (2)$$

Where: Q_{el2} is the power intensity of the line feeding ETP2;

Q_{R2}^{spec} is the specific power intensity of obtaining the result R_2;

- Q_{R3} is the energy consumed to obtain the result R3 in the line containing ETP3:

$$Q_{R3} = Q_{el3} \cdot Q_{R_3}^{spec} \cdot R_3 \qquad (3)$$

Where: Q_{el3} is the power intensity of the line feeding ETP3;

$Q_{R_3}^{spec}$ is the specific power intensity of obtaining the result R_3.

Actual specific energy consumption in line ETP1 per unit of production *P* is defined as:

$$Q_{pr.act}^{spec} = \frac{Q_{pr}}{P} \qquad (4)$$

As well as actual specific energy consumption in line ETP2 per unit of production *P*:

$$Q_{R_2act}^{spec} = \frac{Q_{R_2}}{P} \qquad (5)$$

And actual specific energy consumption in line ETP3 per unit of production *P*:

$$Q_{R_3act}^{spec} = \frac{Q_{R_3}}{P} \qquad (6)$$

Obtained values of actual specific energy consumption per unit of production are compared with archived passport data (which consider regulatory data, requirements of building code, standards and others), and based on the results of the comparison, the ETP with the biggest difference in specific energy consumption per unit of production is chosen.

The ETP with the biggest difference of specific energy consumption per unit of production undergoes an energy audit which simultaneously registers the values of consumed energy on input and output of elements and production or the result obtained in the ETP for a representative period of time *t* (for example, shift, 24 hours, week).

Next, the measurement data is compared with the archived passport data and based on the results of the comparison, the element with the biggest difference in specific energy consumption per unit of production is chosen. The time of registration of the entire actual load range of the element of the energy circuit is established and measurements are carried out on the element by simultaneously registering the energy values on the input $Q_s=f(t)$ and the output $Q_e=f(t)$.

Let us consider one example of the method of diagnosing the condition of an energy element. Figs.1a and 1b depict the graphs of dependences of measured energy and calculated power on input, output and losses on elements since the time *t*.

Energy losses $\Delta Q(t)$ on the element are determined according to the following formula:

$$\Delta Q(t) = Q_s(t) - Q_e(t) \qquad (7)$$

Representative runtime *t* of the element is divided into *N* intervals of time with a step of Δt. The number of time intervals N is determined according to the formula:

$$N = t / \Delta t \qquad (8)$$

where Δt is the step of differentiation which depends on the shape of the curves $Q_s = f(t)$ and $Q_e = f(t)$ (for example, $t = 1 \ldots 100$ s).

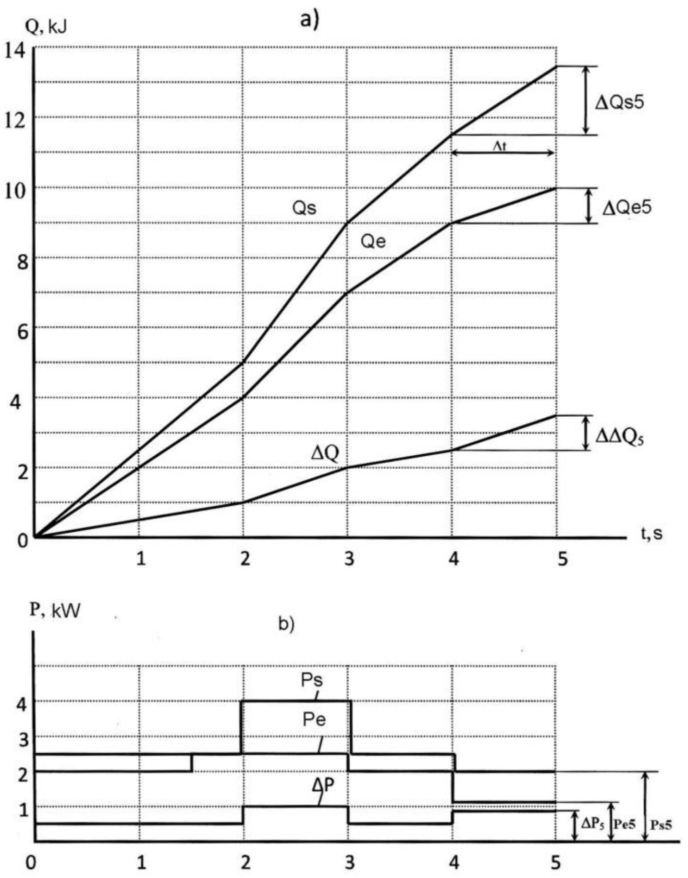

Fig. 1. Graphs of the dependence of energy and power of elements on time *t*:

a) Input energy – *Qs*(*t*), output energy – *Qe*(*t*) and losses – Δ*Q*(*t*);

b) Input power – *Ps*(*t*), output power – *Pe*(*t*) and losses – Δ*P*(*t*).

The values of increase in dependences $Q_s = f(t)$, $Q_e = f(t)$ and $\Delta Q = f(t)$ are determined in each of N time intervals:

$$\Delta Q_{si} = Q_{si} - Q_{si-1}, Q_{s0} = 0; i = 1 \ldots N$$
$$\Delta Q_{ei} = Q_{ei} - Q_{ei-1}, Q_{e0} = 0; i = 1 \ldots N \quad (9)$$
$$\Delta\Delta Q_i = \Delta Q_i - \Delta Q_{i-1}, \Delta Q_0 = 0; i = 1 \ldots N$$

Fig. 1a depicts the fragments for determining the increase in energy:
- on the input of the element – ΔQ_{s5},
- on output of the element – ΔQ_{e5},
- losses in element $\Delta\Delta Q_5$ in time interval $i = 5$.

The values of power on input P_s, on output P_e and losses ΔP in the element in N intervals (Fig.1b) are determined under the assumption that in the time interval Δt the value of power does not change:
- $P_{si} = \Delta Q_{si}/\Delta t$ – power on the input of the element in time interval i;
- $P_{ei} = \Delta Q_{ei}/\Delta t$ – power on the output of the element in time interval i;
- $\Delta P_i = P_{si} - P_{ei}$ and $\Delta P_i = \Delta\Delta Q_i/\Delta t$ – power losses in element in time interval i.

Table 1 shows the results of the measurements and calculations of energy values (energy and power) of the element by time intervals.

Table 1. The results of measurements and calculations of the element's energy values by time intervals

Name of parameters	Designation, and unit of measurement	Value of parameters				
Number of interval	I	1	2	3	4	5
Value of measuring device on input	Qs, kJ	2.5	5	9	11.5	13.5

Value of measuring device on output	Qe, kJ	2	4	7	9	10
Losses in element	ΔQ, kJ	0.5	1	2	2.5	3.5
Increase in energy on input	ΔQs, kJ	2.5	2.5	4	2.4	2
Increase in energy on output	ΔQ, kJ	2	2	3	2	1
Increase in energy losses in element	ΔΔQ, kJ	0.5	0.5	1	0.5	1
Power on input	Ps, kW	2.5	2.5	4	2.5	2
Power on output	Pe, kW	2	2	3	2	1
Power losses in element	ΔP, kW	0.5	0.5	1	0.5	1
Step	Δt, s	1	1	1	1	1
Current time	t, s	1	2	3	4	5

Figure 2 shows graphs of power dependences on input of element relating to power on its output – $P_s = f(P_e)$.

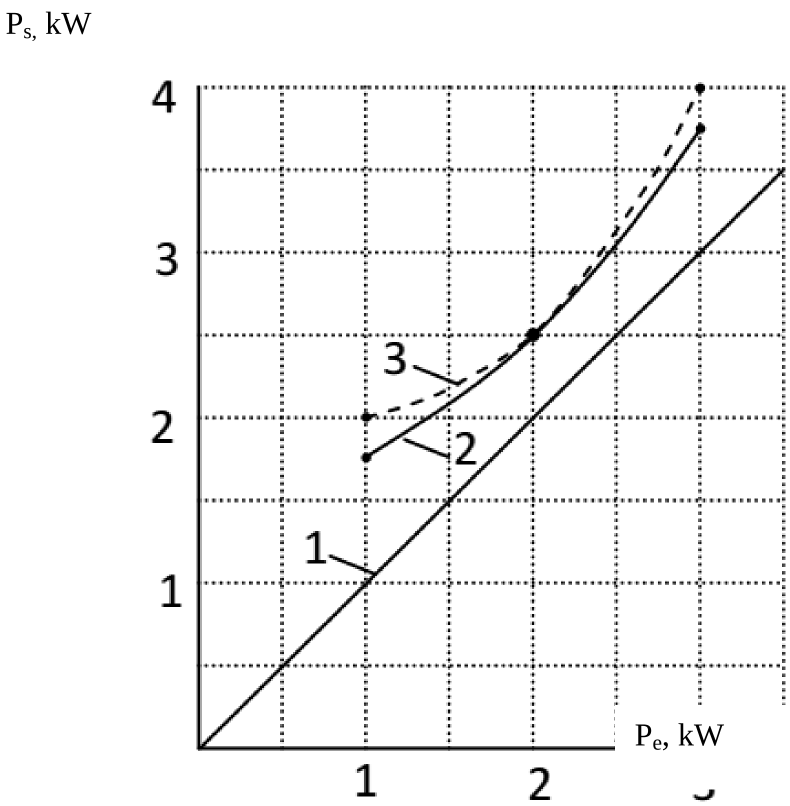

Fig. 2. Dependence of the power on the element's input on the power on the element's output.

$P_s = f(P_e)$: 1 – in a lossless element (for comparing actual and ideal modes);
2 – constructed based on the archived passport data of the element;
3 – constructed based on the results of measurements carried out on the element during the energy audit (for example, induction motor).
The number of time intervals with equal (or approximate) values of power on output of element P_e is then determined. In this example, the number of time intervals with equal (or approximate) values of power on output of element P_e is as follows (Table 2):
- when P_e = 1 kW; there is 1 interval; $n_{j=1} = 1$;
- when P_e = 2 kW; there is 3 intervals; $n_{j=2} = 3$;
- when P_e = 3 kW; there is 1 interval; $n_{j=3} = 1$,

where n_j is the number of work intervals of element with equal power $\left(\sum_{j=1}^{N} n_j = N\right)$.

The portion of the element's runtime at loads with similar (or approximate) values of power (as a ratio of the number of intervals with equal values of power to the number of intervals N) is determined.
The portion of the element's runtime at power values:
- P_e = 1 kW: $t_{p(1\ kW)} = n_{j=1}$/N=1/5=0.2;
- P_e = 2 kW: $t_{p(2\ kW)} = n_{j=2}$/N=3/5=0.6;
- P_e = 3 kW: $t_{p(3\ kW)} = n_{j=3}$/N=1/5=0.2.

Increase in energy losses in intervals with similar (or approximate) values of power on the output of the element P_e in relation to the archived data of the power on the output of the element P_e is determined (Fig. 1; Table 2).
Table 2. The results of comparing archived data with data from calculations during energy audit of the element

Data	$P_{s(arch)}$, kW	$P_{e(arch)}$, kW	ΔP_{arch}, kW	ΔP, kW	n_j, instances	Proportion of runtime, t_p	ΔQ, kJ
Archived (passport) data	1.75 2.5 3.75	1 2 3	0.75 0.5 0.75	- - -	- - -	- - -	- - -
Data	$P_{s(meas)}$, kW	$P_{e(meas)}$, kW	$\Delta P\Delta P_{meas}$, kW	ΔP, kW	n_j, instances	Proportion of runtime, t_p	ΔQ, kJ
During energy audit	2 2.5 4	1 2 3	1 0.5 1	0.25 0 0.25	1 3 1	0.2 0.6 0.2	0.25 0 0.25

In this example, increase in energy losses at time intervals with the same power values on the output of element P_e has the following values (Table 3):
- The runtime of the element at P_e = 1 kW is $t_{p(1\ kW)}$ = 0.2. Increase in power losses Δ_p is determined as the difference of values of power losses at the energy audit ΔP_{meas} and power losses according to archived data ΔP_{arch} using the formula:

$$\Delta_p = \Delta P_{meas} - \Delta P_{arch} = 1 - 0.75 = 0.25 \text{ kW} \quad (10)$$

The actual power loss value exceeds the archived (passport) data by 0.25 kW. The value of the increase in energy losses ΔQ is determined according to formula:

$$\Delta Q = \Delta_p \cdot \Delta_t \cdot n_{j\text{-}1} = 0.25 \cdot 1 \cdot 1 = 0.25 \text{ kJ} \quad (11$$

- The runtime of the element at P_e = 2 kW is $t_{p(2\ kW)}$= 0.6.
The actual value of power losses and power losses according to archived passport data on element are equal. The increase in energy losses ΔQ at this load is zero;
- The runtime of the element at P_e = 3 kW is $t_{p(3\ kW)}$= 0.2.
Increase in power losses Δ_p is:

$$\Delta_p = \Delta P_{meas} = \Delta P_{arch} = 1 - 0.75 = 0.25 \text{ kW} \quad (12)$$

The actual power loss value exceeds the archived (passport) value by 0.25 kW. The increase in energy losses ΔQ is determined according to the formula:

$$\Delta Q = \Delta_p \cdot \Delta_t \cdot n_{j\text{-}1} = 0.25 \cdot 1 \cdot 1 = 0.25 \text{ kJ} \quad (11)$$

The results of the energy audit have shown that at a load of P_e = 1 kW for a proportion of runtime $t_{p(1\ kW)}$= 0.2 and P_e = 3 kW for a proportion of runtime $t_{p(3\ kW)}$ = 0.2, there is an increase in energy losses equal to ΔQ = 0.25 kJ.

III. Conclusion

The developed method of diagnostics allows comparing the losses in elements depending on the load which varies with time and determining the increase in energy losses in the element. It also allows determining the proportion of runtime under equal loads, and the load creating the maximum energy loss, i.e., the most energy-consuming mode in which the deterioration of the element's condition has the greatest effect on energy losses in this ETP.
Losses are minimized by changing or limiting the operation of or restoring the condition of the element.

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