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# Issues of Determining Energy Efficiency When Replacing Lightly Loaded Motors in General Industrial Mechanisms

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**ABSTRACT**: The article studies the issues of determining energy efficiency when replacing lightly loaded engines in general industrial mechanisms. Software has been created for the methodology for determining energy efficiency when replacing lightly loaded motors. This program is used to design low power motors for general industrial equipment used in industrial plants, cotton gins, oil and gas enterprises. By determining the energy performance of asynchronous motors operating at low loads in general industrial electrical devices, taking into account the operating modes, i.e., power factor and efficiency, and replacing them with a new type of asynchronous motor with low power, the energy performance of the electromechanical system was determined. The program is designed to determine the technical and economic indicators of the system and the payback period for a newly installed engine by reducing active power losses.

**KEY WORDS**: Energy saving, engine, payback period, load factor, Optimum load, active loss, energy efficiency, operating modes, technical and economic indicators, electromechanical system

## I. INTRODUCTION

Energy saving, or rather rationalization of production, distribution and use of all types of energy, has become in the last 15 ... 20 years, along with informatization and computerization, one of the main directions of technical policy in all developed countries of the world. This is due, firstly, to the limited and non-renewable nature of all the main energy resources, secondly, to the ever-increasing complexity of their production and, accordingly, the cost, and thirdly, to the global environmental problems that have emerged recently [1,2].

Energy and resource saving has become one of the primary and most important environmental problems being addressed today in all developed countries of the world. An essential component of this problem has become energy saving in the areas served by electric energy, since this energy is universal and widely used. Energy saving is reduced to the reduction of useless energy losses. An analysis of the structure of losses in the sphere of production, distribution and consumption of electricity shows that the determining share of losses - up to 90% - falls on the sphere of energy consumption, while losses in the transmission of electricity amount to only 9 ... 10% (in the USA - 8%, in Germany and Japan - 4 ... 5%). Obviously, the main energy saving efforts should be concentrated in the sphere of electricity consumption [2-4].

In developed countries, electricity accounts for about 20% of the total energy consumption. The main consumer of electricity is the electric drive (more than 60%), and it is on it that the main attention of the world technical community working in the field of energy saving is paid. German experts believe that the economic potential of energy saving in the electric drive is practically exhausted, if we consider the individual components of the electric drive, they are already quite perfect. At the same time, there remains a huge potential based on improving the design of systems as a whole and optimizing their parameters.

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More than 60% of the expected increase will be covered by energy savings, mainly during the transition to a controlled electric drive. Expert estimates show that a controlled electric drive is cost-effective in 25...50% of all technological installations, although it is currently used only in 10%. Let us consider in more detail the object of energy saving - an electric drive [3-5].

## II. LITERATURE ANALYSIS ON THE TOPIC SURFACE

All electric drives, with the exception of numerous low-power (fractions of kilowatts) electric drives of household appliances, can be divided into two large groups. The first is used in units serving technological processes that are not feasible without fine control of technological coordinates, for example, rolling mills, paper machines, metalworking machines, robots, etc. This group includes no more than 10% of all electric drives, it has always enjoyed the attention of specialists, and, as a rule, modern effective technical solutions have already been implemented in it [7-9].

The second group (about 90% of all electric drives) is used in simple units - compressors, pumps, fans, conveyors, conveyors, etc. Until recently, little attention has been paid to this group, since such units usually use the simplest electric drives with not always correctly selected motors, but it is this group that contains a huge reserve of energy and resource saving. This is mainly due to an objectively existing contradiction: the vast majority of such electric drives (more than 95%) are unregulated, and the technological processes they serve, as a rule, need to be controlled by some technological coordinates: speed, pressure, flow, temperature, etc. This control is carried out energy inefficiently and leads to large energy losses, generates imperfection of the technological process itself - reduces productivity, reliability and quality of the product [10].

An analysis of the operation of existing electric drives shows that most drive motors have an overestimated rated power compared to that which is required from the electric drive to implement the technological process. In European practice, it is generally accepted that the load factor (utilization factor) of engines $k_н$, determined by the ratio of the engine load power $P_c$ to its rated power $P_{ном}$, is about 0.6. In our country, this coefficient is even lower and lies in the range (0.3 ... 0.5).

## III. METHODOLOGY

In addition, the electric drives of a number of working machines and production mechanisms work part of their cycle with small mechanical loads or at idle. These include, for example, electric drives of machine tools, forging and pressing equipment, lifting and transport mechanisms.

In both considered cases, in accordance with the existing dependences of the efficiency and power factor cosφ on $k_н$ (Fig. 1), motors under load operate with low efficiency, and asynchronous motors with a reduced power factor cosφ. An increase in these indicators leads to a decrease in energy losses in the electric drive and the power supply system and can be achieved, for example, by replacing lightly loaded motors with motors of lower power.

## IV. RESULT AND DISCUSSION

The replacement of low-load engines is expedient in those cases when there will be a reduction in energy losses in the replacement of the engine and the power supply system, which will make it possible to recoup the capital costs for such modernization in an acceptable time frame. Calculations show that with an overload factor $k_н < 0.4$, in most cases, the replacement of lightly loaded motors is economically feasible, with $k_н > 0.7$ it is impractical, and with $0.4 < k_н < 0.7$, technical and economic calculations are required.

There is a condition under which the engine will operate with maximum efficiency at a given engine load factor kn. The motor efficiency η can be calculated as follows:

$$\eta = k_н P_{ном} / (k_н P_{ном} + K + k_н^2 V_{ном}) \qquad (1)$$

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Let us find the condition for the operation of the engine with maximum efficiency at a given load factor by taking the derivative $d\eta/dk_n$ and equating it to zero. After the transformations, we obtain that the maximum value of efficiency will take place at the optimal load, determined by the following ratio of constant K and nominal variable $V_{ном}$ power losses:

$$k^2_{н.опт} = K / V_{ном} \quad (2)$$

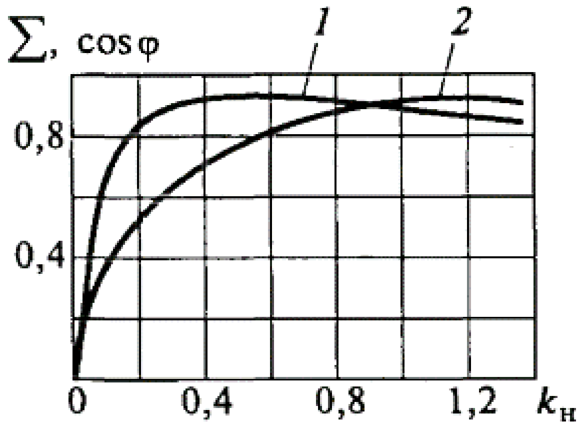


**Fig. 1. Dependences of efficiency 1 and power factor 2 on the motor load factor [2]**

It follows from formula (2) that when $K > K_{ном}$, the maximum efficiency can be obtained with an engine load exceeding the nominal one, which is unacceptable. The values of $k_н$ opt at $K < K_{ном}$ are given in table. 1. Analyzing the operation of an electric drive with a specific motor, it is possible, using formula (2), to determine the motor load at which it will operate with the least power loss, i.e. at a given load with maximum efficiency.

Consider an example of determining the load of an underloaded engine, at which it is advisable to replace it with an engine of lower power.

Example. Determine the optimal load of the 4A180S4 type motor and the load at which it is economically feasible to replace it with a lower power motor.

The 4A180S4 engine has the following ratings: power $P_{ном}$=22 kW; voltage 380/220 V; slip $s_{ном}$=0,02; stator current $I_{1ном}$=41,2 A; Efficiency $\eta_{ном}$=90%; $\cos\varphi_{ном}$=0,87; active resistance of the stator windings $R_1$= 0,219 Ohm and reduced rotor $R'_2$ = 0,112 Ohm. The price of the 4A180S4 engine as of 2022 years is Cust $Ц_{уст}$=12,358 million soums; standard service life (depreciation period) $T_{ср}$=20 years; service life before modernization $T_р$=15 years; depreciation rate $p_а$ = 6,4% per year.

Conditions for solving the problem:
• smaller power motors are selected from the AIR series;
• as a tariff for electricity, a one-part tariff for Uzbekistan for 2022 is accepted, equal to 800 soums/kWh;

**Table 1.**
**Values $k_{н.опт}$ at different ratios $K/V_{nom}$**

| $K/V_{nom}$ | 0,1 | 0,3 | 0,5 | 0,7 | 0,9 |
|---|---|---|---|---|---|
| $k_{н.опт}$ | 0,32 | 0,55 | 0,71 | 0,84 | 0,95 |

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• the salary of service personnel after modernization does not change;
• the cost of dismantling the existing engine is not taken into account;
• the costs of transportation, installation and commissioning of a new engine are accepted in the amount of 35% of its cost.

The engine being replaced becomes a standby engine at the plant and its salvage value is zero.
1. Determine the idle speed, rated speed and torque of the 4A180S4 engine:

$$\omega_0 = 2\pi f_1 / p = 2 \cdot 3{,}14 \cdot 50 / 2 = 157 \ \text{rad/s}$$

$$\omega_{ном} = \omega_0 (1 - s_{ном}) = 157(1 - 0{,}02) = 154 \ \text{rad/s}$$

$$M_{ном} = P_{ном} / \omega_{ном} = 22000 / 154 = 143 \ N \cdot м$$

2. We find for the nominal mode the total, variable and constant power losses

$$V_{ном} = M_{ном} \omega_0 s_{ном} (1 + R_1 / R_2') = 143 \cdot 157 \cdot 0{,}02(1 + 0{,}219 / 0{,}112) = 1327 \ \text{W}$$

$$\Delta P_{ном} = P_{ном}(1 - \eta_{ном}) / \eta_{ном} = 22000(1 - 0{,}9) / 0{,}9 = 2444 \ W$$

$$K = \Delta P_{ном} - V_{ном} = 2444 - 1327 = 1117 \ W$$

3. The optimal engine load is determined by the formula (2):

$$k_{н.опт} = \sqrt{K / V_{ном}} = \sqrt{1117 / 1327} = 0{,}92$$

4. The efficiency of the engine at this load in accordance with formula (1) will be:

$$\eta = k_н P_{ном} / (k_н P_{ном} + K + k_н^2 V_{ном}) = 0{,}92 \cdot 22000 / (0{,}92 \cdot 22000 + 1117 + 0{,}92^2 \cdot 1327) = 0{,}903$$

5. Determine the residual value of the installed engine:

$$Ц_{ост} = Ц_{уст}(1 - T_p / T_{сл}) = 15{,}448(1 - 15/20) = 3{,}86 \ \text{mln sum}$$

6. We determine the payback period when replacing this engine for load factors $k_н$=0.25; 0.5; 0.75 and engine operating time per year $T_p$ = 1500, 3000, 4500 and 6000 hours. The payback period is calculated by the formula

$$T_{ок} = (КЗ_{нов} + КЗ_{ост} - КЗ_{ликв}) / (c_э T_p \Delta P_{экон} + (Ц_{уст} - Ц_{нов}) p_a) \quad (3)$$

where $КЗ_{нов}$ - capital costs for a new engine, $КЗ_{НОВ} = Ц_{нов} + З_{дем} + З_{тр} + З_{монт} + З_{нал}$; $Ц_{нов}$ - The price of a new engine, $З_{дем}$, $З_{тр}$, $З_{монт}$, $З_{нал}$- the costs, respectively, for the dismantling of the replaced engine, transportation, installation and commissioning of the new engine; $(Ц_{уст}-Ц_{нов})P_a$ - The difference in depreciation charges before and after modernization.

In accordance with the conditions for solving the problem $З_{дем} = З_{тр} + З_{монт} + З_{нал} = 1{,}35\ Ц_{нов}$. Then formula (3) takes the form

$$T_{ок} = (1{,}35 Ц_{нов} + 3{,}86) / (1{,}3 T_p \Delta P_{экон} + 0{,}064(15{,}448 - Ц_{нов})) \quad (4)$$

The results of calculation by formula (4) are given in Table. 2.

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**Table. 2.**
**Data on the calculation of the payback period when replacing the engine**

| Index | Calculation formula | $k_н$ =0,25 | $k_н$ =0,5 | $k_н$ =0,75 |
|---|---|---|---|---|
| Load power at a given $k_n$, kW | $P_c = k_н P_{ном}$ | 5,5 | 11 | 15,4 |
| Power losses in the replaced engine, kW | $\Delta P = K + M_C \omega_0 s_c (1+R_1/R_2)$ | 1.2 | 1,45 | 1,87 |
| Engine replacement | AIR series | 112M4 | 132M4 | 160S4 |
| Power loss in the new engine in nominal mode, kW | $\Delta P_{ном} = P_{ном}(1-\eta_{ном})/ \eta_{ном}$ | 0,933 | 1,071 | 1,668 |
| Price of a new engine (including VAT, 2022), thousand soums | | 3 667 | 5 588 | 10 288 |
| Reducing power losses during replacement, kW | $\Delta P_{экон} = \Delta P - \Delta P_{ном}$ | 0,267 | 0,378 | 0,2 |
| Payback period at $T_p$=1500 h per year | $T_{ок} = (1{,}35Ц_{нов} + 4825)$: $1{,}3 T_P \Delta P_{экон} + 0{,}064$ x$(19311 - Ц_{нов})$ | 7,5 | 9.3 | 27,3 |
| Payback period at $T_p$=3000 h per year | | 5,6 | 6,3 | 18,6 |
| Payback period at $T_p$=4500 h per year | | 4,4 | 4,8 | 14 |
| Payback period at $T_p$=6000 h per year | | 3,6 | 3,8 | 11,2 |

Figures 3 and 4 show graphs of the dependence of the engine load factor on the active power loss and on the payback period when replacing with a lower power engine

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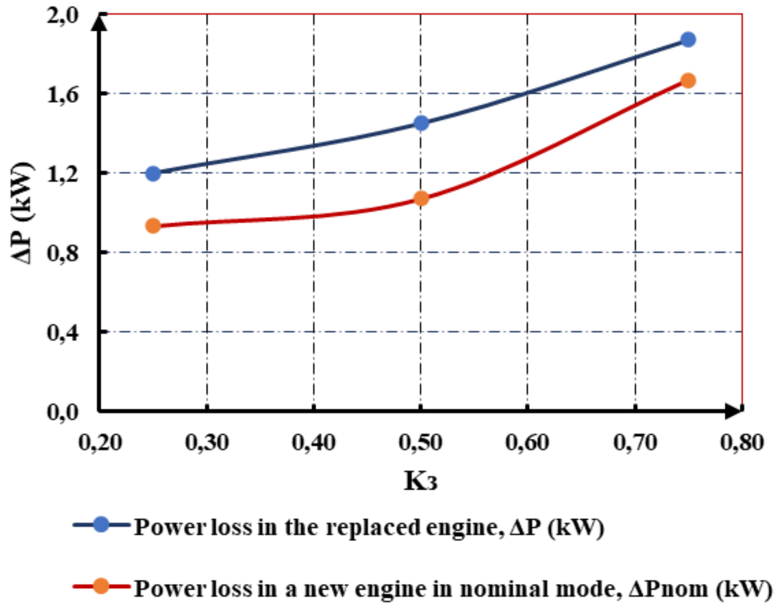


**Fig. 3. Graph of the dependence of the engine load factor on the active power loss**

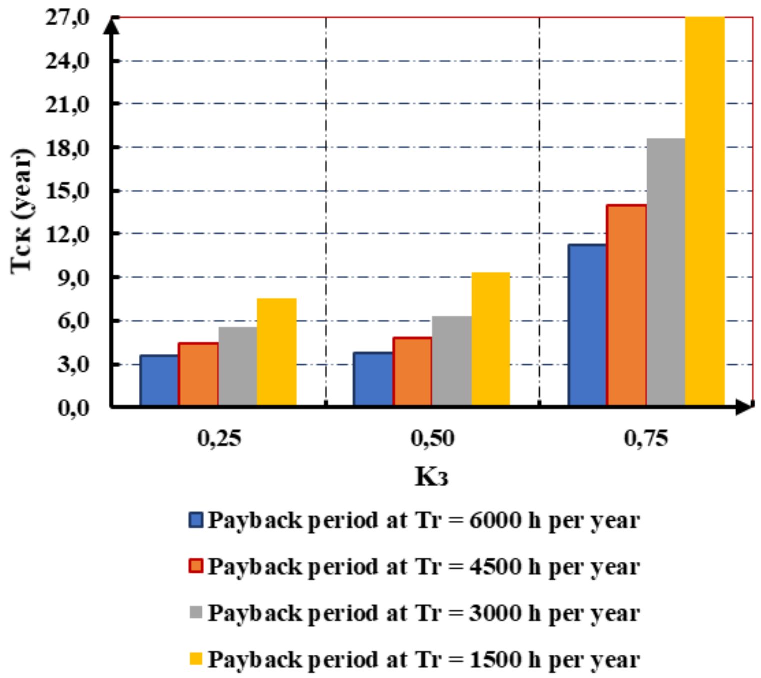


**Fig. 4. Graph of the dependence of the engine load factor on the payback period when replacing with a lower power engine**

Software has been created for the methodology for determining energy efficiency when replacing lightly loaded motors (Fig. 5) [6]. This program is used to design low power motors for general industrial equipment used in industrial plants, cotton gins, oil and gas enterprises.

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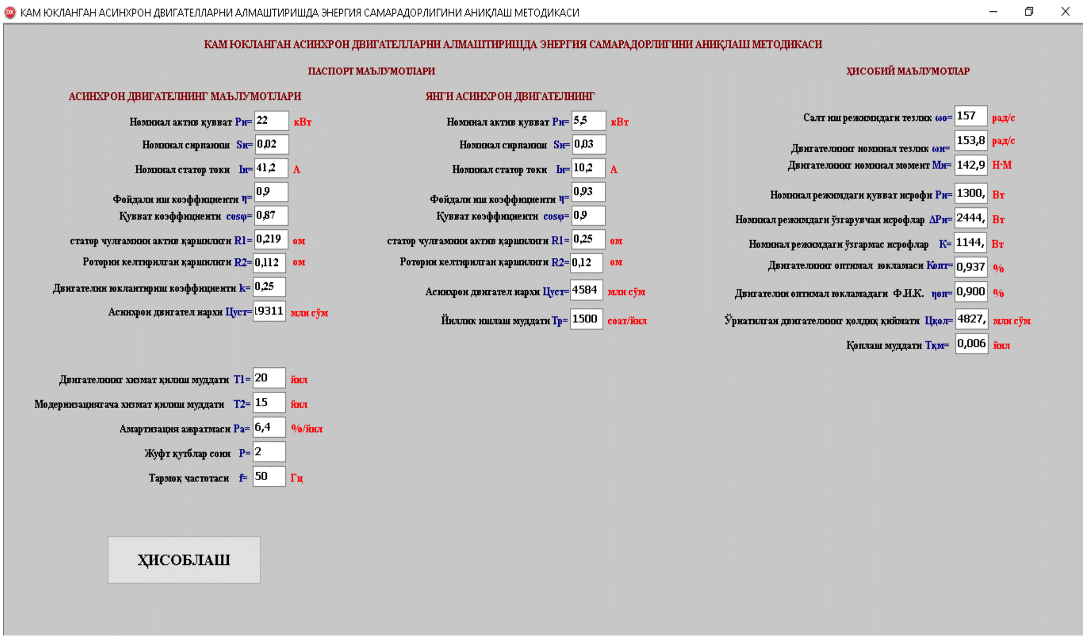


**Fig. 5. Software for the methodology for determining energy efficiency when replacing lightly loaded engines [6]**

## V. CONCLUSION

1. As can be seen from the data obtained, a relatively acceptable payback period is obtained at $k_н$=0,25 and $T_p$=6000 h, which corresponds to the recommendations available in the technical literature. The calculation of the payback period can be refined by taking into account power losses in the power supply system and the salvage value of the replaced engine. Accounting for these factors will lead to some reduction in the payback period. For example, if the replaced engine is sold (sold) after dismantling at its residual value, then the payback period for installing a new AIR112M4 engine at $к_н$ = 0,25 and $T_p$ = 6000 h will be approximately two years.

2. A program has been developed for determining energy efficiency when replacing lightly loaded engines based on Delphi. When replacing lightly loaded asynchronous motors in general industrial mechanisms with low-power motors, the calculation of its technical and economic indicators is performed. As a result, it makes it possible to determine the payback period for capital expenditures, taking into account active power losses and technical and economic indicators of low-power asynchronous motors.

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