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DEVELOPMENT OF THE ESTIMATING METHODOLOGY OF A 5TDF ENGINE MOTOR RESOURCE CONSUMPTION UNDER DIFFERENT OPERATING MODES OF THE MACHINE

Abstract. The **subject matter** of the article is accounting for the motor resource of the 5TDF tank engine under different operating modes. The **goal** of the study is to development of a methodology for estimating the consumption of a motor resource of a 5TDF engine under different operating modes of the machine. **The tasks** to be solved are: based on the analysis of data on the operating modes of the 5TDF engine, to determine a set of parameters that give empirical and analytical estimates of the consumption of the motor resource of the machine; to request analytical estimates of the consumption of the 5TDF engine motor resource in terms of the number of years' service in different machine operating modes; to propose a mechanism for the processing of numerical values, depending on the results of the statistical processing of these machine operation data. General scientific and special **methods** of scientific knowledge are used. The following **results** were obtained: A continuous functional dependence of the actual number of hours spent by the engine on the values of the meter per hours at different speeds, allow more careful accounting of engine consumption, but will involve the development of special devices based on modern elements has been determined. **Conclusions.** It is possible to make a conclusion about the nonlinear nature of the dependence of the engine life on time with different engine operation at different load modes. Engine operating modes, which are determined by load resistance, are characterized by the number of revolutions of the engine crankshaft and the amount of power developed by the engine, largely determine its energy and economic performance of the engine and engine consumption. The testing ground for the consumption of the motor resource of the machine, depending on the readings of the engine hours counter, can be formed on the basis of the data obtained from the results of the operation of the machine in different conditions. The analysis of the results of the research carried out that finding dependence of a 5tdf engine motor resource can be presented as the sum of two regressions – linear and hyperbolic. The readings of the engine hours counter will be recorded and further processed when the 5TDF engine is running in I-V and VI, VII gears, respectively. Such realization will make it possible to use the regression equation directly for the car crew.

Keywords: consumption of motor resource of the 5TDF engine; regression equation; least squares method; accounting for tank hours counters.

Formulation of the problem and research tasks

A tank diesel engine is a complex multi-component unit with a service life set by the manufacturer. The concept of diesel engine life means a certain number of hours that a new power unit of this type must be guaranteed to work. Under the end of the diesel life should be understood that further operation of the engine becomes impossible without overhaul of the power plant.

The service life of a tank engine depends on the quality of diesel engine oil, timely maintenance, serviceability of the diesel engine fuel system and other internal combustion engine systems. Diesel units are also extremely sensitive to overheating, which requires constant monitoring of the cooling system.

The engine life of an internal combustion engine depends on its design features, as well as individual operating conditions.

In the near future, the 5TDF tank engine and its modifications will remain widely used on AMWE models of the Armed Forces, therefore, the development of methods for more careful accounting of engine life is an urgent scientific and technical task [1].

Analysis of recent research and publications. The issue of accounting for motor resources was indeed one of the "sickest" for the Soviet tank troops. The idea to create a device that can accurately consider the different types of load on the tank engine was proposed by the famous Kalashnikov shortly before World War II, but due to objective reasons, was not implemented. The development of the element base, SAD-tools, tools for collecting data on the state of the engine makes it possible not only to improve the performance of the machine, but also to more accurately assess the consumption of its engine life [2].

Traditionally, the consumption of motor resources is planned for the list number of machines and power units, but not more than the amount provided by the regular purpose, and within the established norms, subject to uniform (stepped) output of machines for repair during the year. At the same time one hour of work of the car (power unit) is equated to run (the specified norm at writing off of fuel and oils is not applied).

The methodology for accounting for the operation of a power plant under more severe operating conditions (for example, when working with a minesweeper, in rough terrain, severe climatic conditions, etc.) is also not complete enough.

The need for such an account was considered by the designers of the T-72 tank. In particular, two hours counters were installed on the T-72M Ural tank. However, the ideology of using unlimited resources and simplifying technology at the end of the Soviet Union, the collapse of the latter and the lack of funding for independence, buried this idea.

Thus, the development of methods for accounting for the engine life of the tank 5TDF engine in different modes of operation is **relevant.**

The **goal** of the study is to develop a method for estimating the consumption of engine life 5TDF engine in different modes of operation of the machine.

This goal defined the following research **tasks**:

−on the basis of the 5TDF engine data on operating modes analysis to define set of the parameters giving empirical and analytical estimations of an expense of a motor resource of the car.

−to offer analytical dependences of an estimation of an expense of a motor resource of the 5TDF engine on quantity of the fulfilled motor-hours at different modes of operation of cars

− to offer the mechanism of calculation of numerical values, proceeding from results of their statistical processing of data of operation of the vehicle.

− to analyze the constructive possibilities of practical implementation of the developed technique in view of the available control and measuring devices installed on the sample T-64B.

Main material

1. Relationship between the operating modes of the 5TDF engine and parameters give empirical and analytical estimates of the consumption of the machine motor resource. To assess the performance of engines when operating at different load modes, it is customary to use the following parameters: effective power; torque, average effective pressure.

Dependences of the basic indicators of work of the engine on turns of a cranked shaft are accepted to name speed characteristics.

The external characteristic of the engine, being the main, allows to estimate:

- limit values of power and torque in all range of change of turns;
- characteristic speed modes;
- the area of the most economical speed modes;
- traction (dynamic) qualities of the engine.

For example, at idle, the specific indicator fuel consumption is about twice as high as at higher loads.

These indicators are indirect in relation to the consumption of the motor resource of the engine, however, based on their analysis, conclusions can be drawn:

There is a direct dependence of the ICE resource on the wear of the cylinder-piston group.

Constant driving at extreme loads or other difficult conditions can reduce the declared engine life by up to 2-3 times. Maintaining the operating temperature of the internal combustion engine is extremely important so that the loaded parts are effectively cooled in order to prevent rapid wear and damage to the mechanism parts, in particular, jamming of the pistons in the cylinders.

In addition, it is possible to make a platoon about the nonlinear nature of the dependence of the engine life on time with different engine operation at different load modes.

Engine operating modes, which are determined by load resistance, are characterized by the number of revolutions of the engine crankshaft and the amount of power developed by the engine, largely determine its energy and economic performance of the engine and engine consumption [3].

2. **Analytical dependences of an estimation of an expense of a motor resource of the 5TDF engine on quantity of the fulfilled motor-hours at different modes of operation of cars.** We'll assume that accounting for the actual consumption of a motor resource depending on the number of hours worked by the engine, in the simplest case, can be carried out according to the general expression:

$$MR(m) = \sum_{i=1}^{k} a_{ni} m_{ni}. \qquad (1)$$

where a_{ni} – load factor having a positive value; k – the number of intervals the engine speed range can be divided $[n_{\min}; n_{\max}]$; m_{ni} – the number of engine hours according to the meter readings when the engine is running at speed in the *i*-th interval $n_i \in [n_{\min}; n_{\max}]$.

Traditionally, the range $[n_{\min}; n_{\max}]$ determines the intervals corresponding to the engine idling speed, operating speed and speed at which the machine operates in difficult conditions at full load. So, we accept $k = 3$.

So, for the 5TDF engine the full range can be assigned as $[800, 3000]$.

To continue the operation of the 5TDF, it is necessary to designate the intervals for changing the wraps, as to allow the idling of the robotic engine, the robotic operation in the normal operating mode, and in the case of robotic navigation:

$$[n_{min}, n_{is}], [n_{os1}, n_{os2}], [n_l, n_{max}], \qquad (2)$$

In the simplest version for practical implementation, it can be assumed that the value of the load factor is constant over the entire *i*-th interval

$$a_{ni} = const, \qquad (3)$$

then expression (1) can be written:

$$MR = a_1 m_{is} + a_2 m_{os} + a_3 m_l, \qquad (4)$$

where m_{is}−the number of hours worked by the engine according to the meter at idle speed in a certain interval; m_{os}− the number of hours worked by the engine according to the meter at operating speed in a certain interval; m_l−the number of hours worked by the engine according to the meter at speeds corresponding to the operation of the engine under load in difficult conditions in a certain interval; a_1, a_2, a_3 − are positive numerical coefficients.

Let's note that the use of expression (1) in practice is not a complicated procedure for the crew of the machine, although it requires minimal design refinement.

The accuracy of the obtained results can be increased by reducing the sampling step over the entire range of engine revolutions $[n_{max}, n_{min}]$.

Undoubtedly, the introduction of a continuous functional dependence of the actual number of motor hours worked by the engine on the values of the motor-hour counter indicator at different revolutions will enable a more thorough accounting of motor resource consumption, but will be associated with the development of special devices based on a modern element base.

In this case, expression (1) will have the form:

$$MR(m) = \int_{n_{min}}^{n_{max}} a(m)\, dn. \qquad (5)$$

Since the dependence M(m) is non-linear, it is appropriate to consider its derivative as its qualitative characteristic $\frac{\partial MR}{\partial m} \cdot \frac{\partial m}{\partial n}$, based on the fact that the reading of the engine hours counter is a function of the engine revolutions. That is,

$$a(m) = \frac{\partial MR}{\partial m} \cdot \frac{\partial m}{\partial n}. \qquad (6)$$

Provided that the assumption (3) is made, it is possible to accept the expression in a close examination

$$a(m) = \frac{\Delta MR}{\Delta m};$$
$$\Delta MR = MR_{beg} - MR_{fin}; \qquad (7)$$
$$\Delta m = m_{beg} - m_{fin},$$

m_{beg}– the value of the engine hours counter indicator at the beginning of the *i*-th interval;

m_{fin}– the value of the engine hours counter indicator at the end of the *i*-th interval.

Expression (7) can be transformed as follows:

$$a(m) = \frac{MR_{кінц} - MR_{поч}}{m_{кінц} - m_{поч}} = = \frac{\frac{MR_{кінц}}{MR_{поч}} - \frac{MR_{поч}}{MR_{поч}}}{\frac{m_{кінц}}{m_{поч}} - \frac{m_{поч}}{m_{поч}}} = \frac{\frac{MR_{кінц}}{MR_{поч}} - 1}{\frac{m_{кінц}}{m_{поч}} - 1}. \qquad (8)$$

The relation follows from expression (8)

$$\frac{MR_{кінц}}{MR_{поч}} - 1 = a(m)\left(\frac{m_{кінц}}{m_{поч}} - 1\right). \qquad (9)$$

To simplify the procedure of statistical processing of operating data, we accept

$$\frac{MR_{finish}}{MR_{start}} \approx a(m)\left(\frac{m_{finish}}{m_{start}}\right) \qquad (10)$$

and, taking into account the energy and economic indicators of the engine, we will assume

$$\frac{MR_2}{MR_1} \approx \frac{Gf_2}{Gf_1} \approx \frac{S_1}{S_2} \approx \frac{v_1}{v_2} \approx a(m)\frac{m_2}{m_1}, \qquad (11)$$

where *MR* – engine resource consumption, engine hours; *Gf* – hourly fuel consumption kg/h; *S* – range, km; *v* – vehicle speed, km/h; espectively at revolutions n_1 and n_2, ($n_2 > n_1$).

Expression (10) is the most suitable for processing statistical data obtained during machine operation.

The relationship between *MR*, *Gm*, *v* and *S* values is determined based on the design of the machine's power plant and accepted standards of its operation.

So, based on the values of *Gm*, *v* and *S* obtained during the operation of the car in different road conditions and under different loads, the values of *MR* are calculated, which we will consider as the starting point for finding the coefficients *a*, *b*, *c* of the regression equation (4). When collecting statistical data, it is suggested to keep track of the selected gear in which gear the car is moving: $p = \overline{1, P}$, P – the number of gears the car moves.

Thus, the testing ground for the consumption of the motor resource of the machine, depending on the readings of the engine hours counter, can be formed on the basis of the data obtained from the results of the operation of the machine in different conditions (table 1). The value of MR (column 6) is calculated based on the data of columns (2)-(5) under different operating conditions of the machine.

Table 1 – **Statistical data on motor resource consumption based on the results of machine operation in various operating conditions**

Measurement number, *i*	The crankshaft winding frequency, *n, turns/min*	Hourly fuel consumption, *Gf, kg/h*	Range *S, km*	Vehicle speed *v, km/h*	Engine resource consumption *MR, hours;*	The number of the selected gear the car moves, *p*	The value of engine hours counter indicator, *m*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
i_{nmin}	n_{min}	G_{nmin}	S_{nmin}	v_{nmin}	MR_{nmin}	p_{nmin}	m_{nmin}
…	…	…	…	…	…	…	…
i_{n1}	n_1	G_{n1}	S_{n1}	v_{n1}	MR_{n1}	p_{n1}	m_{n1}
i_{n2}	n_2	G_{n2}	S_{n2}	v_{n2}	MR_{n2}	p_{n2}	m_{n2}
….	…	…	…	…	…	…	…
i_{nmax}	n_{max}	G_{nmax}	S_{nmax}	v_{nmax}	MR_{nmax}	p_{nmax}	m_{nmax}

3. The regression coefficients calculation. To find the regression coefficients a_1, a_2, a_3 of the equation (4) by the method of least squares, statistical data were obtained according to the table. 1:

It is proposed to calculate the regression coefficients in a matrix manner.

Let's present the simulation data and regression coefficients in matrix form

$$M = \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1m} \\ m_{21} & m_{22} & \dots & m_{2m} \\ \dots & \dots & \dots & \dots \\ m_{n1} & m_{2m} & \dots & m_{nm} \end{bmatrix}, \qquad (12)$$
$$A = \begin{bmatrix} a_1 \\ a_2 \\ \dots \\ a_n \end{bmatrix}, \quad E = \begin{bmatrix} e_1 \\ e_2 \\ \dots \\ e_n \end{bmatrix}, \quad MR = \begin{bmatrix} MR_1 \\ MR_2 \\ \dots \\ MR_n \end{bmatrix},$$

where MR – an n-dimension column of the independent variable; X – an n x m -dimension matrix of the tank engine hours counter indicators; A –an n-dimension column vector of the regression equation coefficients; E – is a n-dimension column vector of deviations of the dependent variable y_i from similar values obtained by the regression equation:

$$\widehat{M}R_i = a_i m_{i1} + a_i m_{i2} + \cdots . + a_i m_{in}. \quad (13)$$

In the matrix view we obtain:

$$e = Y - MA. \quad (14)$$

By the least square's method

$$\sum_{i=1}^{n} e_i^2 = e^T e = = (MR - MA)^T (MR - MA) \rightarrow min. \quad (15)$$

It can be shown that the front of the mind is concatenated, as if the Vector

$$A = (M^T M)^{-1} M^T MR. \quad (16)$$

After solving equation (15) we obtain the values of the coefficients of the regression equation A*.

The coefficients of equation (10) can be found as follows:

$$A = (A^*)^T. \quad (16)$$

Thus, based on the obtained values the regression equation (1) and the known $M=\{m_1, m_2, ..., m_m\}$ values of the tank's engine hours counter, it is possible to calculate the consumption of the machine's motor resource, taking into account the peculiarities of its operation in different conditions [4-7].

3. Calculation of numerical values, proceeding from results of their statistical processing of data of operation of the vehicle. Statistical data on operation in various conditions were subject to research are as follows:

- movement of the machine on concrete,
- operating with attached equipment of the mine trawl, etc.

The analysis of the results of the research carried out according to formulas (11)-(16) showed that when finding *MR* as a dependence of *MR=f (Gm, v, S)* under different operating conditions, expression (9) can be presented as the sum of two regressions – linear and hyperbolic:

$$\frac{MR(m_1)}{MR(m_2)} = MR_1\left(\frac{m_1}{m_2}\right) + MR_2\left(\frac{m_1}{m_2}\right), \quad (17)$$

where

$$MR_1\left(\frac{m_1}{m_2}\right) = b_1 + b_2\left(\frac{m_1}{m_2}\right) - \quad (18)$$

linear regression;

$$MR_2\left(\frac{m_1}{m_2}\right) = b_3 + b_4\left(\frac{m_2}{m_1}\right) = b_3 + b_4\left(\frac{1}{\frac{m_1}{m_2}}\right) - \quad (19)$$

hyperbolic regression

Note that when reduced to a common denominator, expression (17) can be defined as a polynomial regression equation.

By setting different values of m_1 and m_c, it is possible to study the motor resource consumption under different loads and engine operating modes. As an example, the dependence graph is given $\frac{MR(m_1)}{MR(m_c)}$

In this case, the range of speed changes was in the interval $[0{,}2v_{max}; 0{,}8v_{max}]$ corresponds to the machine speed movement of the on the terrain during military operation. As m_2, the value of the engine hour counter indicators when the car is moving on a paved concrete road is taken.

The obtained results qualitatively coincide with those obtained during stand and natural tests (Fig. 1).

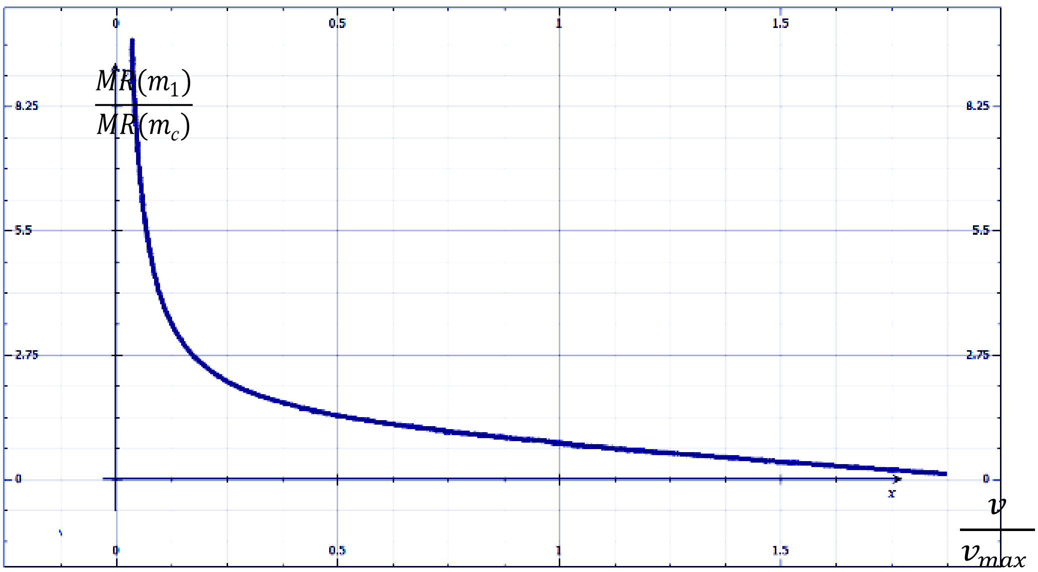

Fig. 1. Motor resource consumption under different loads and engine operating modes

Based on the results of solving equations (12)-(16) the expression is obtained

$$\frac{MR(m_1)}{MR(m_2)} = 1{,}125 - 0{,}625\left(\frac{m_1}{m_2}\right) + 0{,}3\left(\frac{m_1}{m_2}\right). \quad (20)$$

Here

$$b_1 + b_3 = 1{,}125; \quad b_2 = -0{,}625; \quad b_4 = 0{,}3. \quad (21)$$

Next, the coefficients of the equation (4) were obtained as follows:

$$A^{*} = (1{,}001; 1{,}125; 1{,}73333) \qquad (22)$$

4. Constructive possibilities of practical implementation of the developed technique in view of the available control and measuring devices installed on the sample T-64B. The standard equipment of the T-64 tank is equipped with one 228 - 110 engine hour meter.

As a prototype, it is proposed to consider the organization of accounting in the T-72M sample. According to the operation of the machine's electrical equipment, the operation of the engine hours counter "under load" is based on an electrical signal from the neutral selector sensor (Fig. 2 a, b).

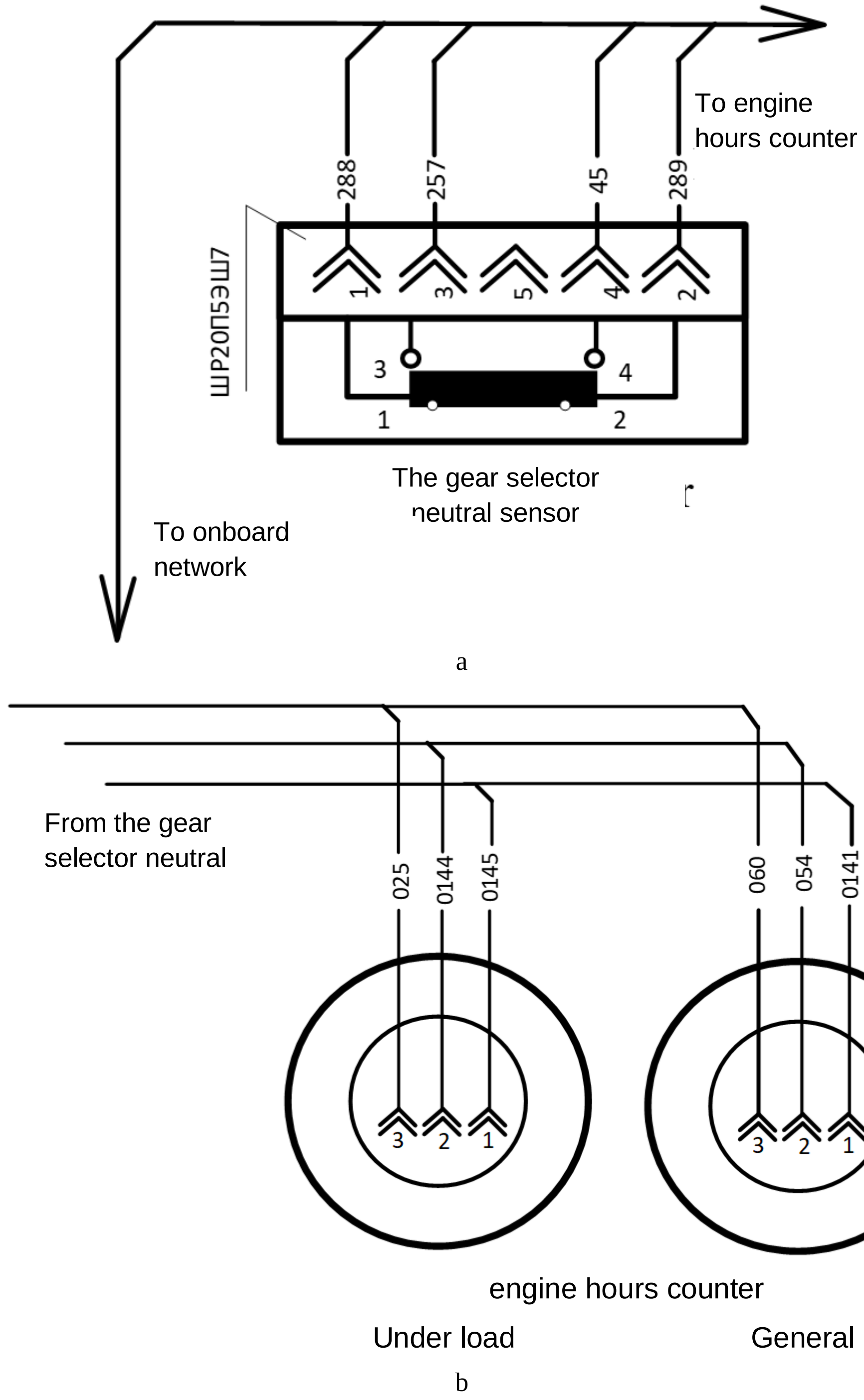

Fig. 2. Electrical diagrams for connecting the neutral sensor of the gear selector of the T-72 tank and the engine hour counters

Unlike the T-72M sample, the T-64B does not have a neutral selector sensor. Without additional installation of such a sensor, the necessary signal can be obtained from the block of switching of the stage (Fig. 3), which is identical for both machines. In this case, the readings of the engine hours counter will be recorded and further processed when the engine is running in I-V and VI, VII gears, respectively.

Design of obtaining information about the operation of the engine on the model of the T-64 tank is similar to the T-72.

So, the electrical signal from the T-72 neutral selector sensor to the engine hour meter "under load" passes through circuit *0145-0141-078* and "general" hour meter through circuit *025-25-289* (Fig. 2).

By analogy, in the model of the T-64 tank, data on the operation of the engine "under load" is proposed to be obtained from the circuit of the EM-30 *123* electromagnet or from the corresponding circuits of the D-20 sensors (Fig. 3).

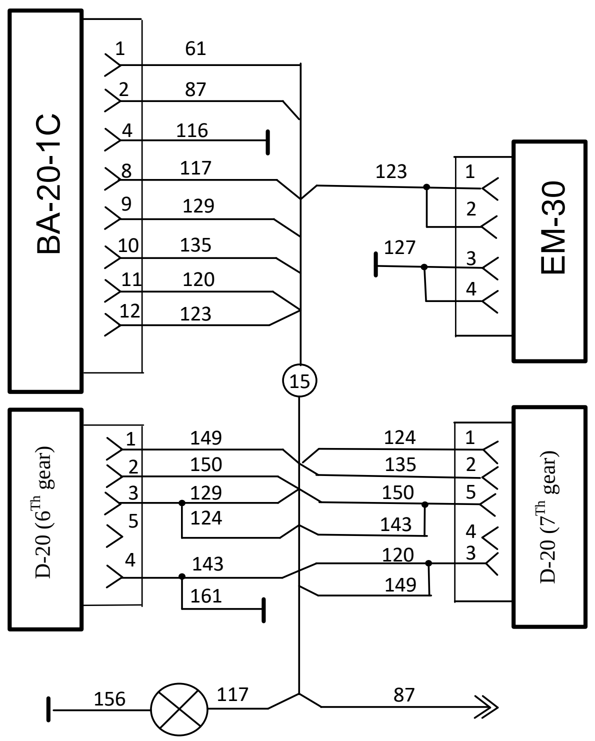

Fig. 3. Electrical diagram of the T-64 and T-72 tank rocker switch unit

The obtained values of coefficients $a_1=1.00001$; $a_2=1.125$; $a_3=1.7333$ provide accounting of engine operation at idling speed, normal operating speed and when working under load.

To differentiate the operation of the engine at idling speed, it is proposed to generate a fuel consumption signal. Such a signal can be, for example, an electrical signal from a fuel gauge sensor. In this case, it will be possible the "logical" combination of values using the rules of Boolean algebra and the installation of additional microprocessor equipment on the machine.

According to the authors, this will allow more accurate accounting of the machine's motor resource, avoiding "engine tarnishing", etc.

In the simplified case, taking into account the possible option $a_1=1.00001$; accounting for m_2 (general) and m_3 (under load) is proposed.

$$MR(m) = 1.125m_{gen} + 1.7333m_{under\ load}. \quad (23)$$

Such realization will make it possible to use the regression equation (18) directly for the car crew [8, 9].

Conclusions

1. It is possible to make a conclusion about the nonlinear nature of the dependence of the engine life on time with different engine operation at different load modes.

Engine operating modes, which are determined by load resistance, are characterized by the number of revolutions of the engine crankshaft and the amount of power developed by the engine, largely determine its energy and economic performance of the engine and engine consumption.

2. the testing ground for the consumption of the motor resource of the machine, depending on the readings of the engine hours counter, can be formed on the basis of the data obtained from the results of the operation of the machine in different conditions

3. The analysis of the results of the research carried out that finding dependence of a 5tdf engine motor resource can be presented as the sum of two regressions – linear and hyperbolic:

4. The readings of the engine hours counter will be recorded and further processed when the 5TDF engine is running in I-V and VI, VII gears, respectively.

Such realization will make it possible to use the regression equation directly for the car crew..

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Розробка методики оцінки витрати моторесурсу двигуна 5ТДФ за різних режимах роботи машини

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Анотація. Предметом вивчення в статті є облік моторесурсу двигуна танка 5ТДФ на різних режимах роботи. **Метою статті є** розробка методики оцінки витрат моторесурсу двигуна 5ТДФ при різних режимах експлуатації машини. **Завдання дослідження**: на основі аналізу даних про режими роботи двигуна 5ТДФ визначити безліч параметрів, що дають емпіричні та аналітичні оцінки витрат моторесурсу машини; запропонувати аналітичні оцінки витрат моторесурсу двигуна 5ТДФ від кількості відпрацьованих мотогодин при різних режимах експлуатації машини; запропонувати механізм розрахунку числових значень, виходячи з результатів їх статистичної обробки даних експлуатації машини; проаналізувати конструктивні можливості практичної реалізації розробленої методики з огляду на наявні контрольно-вимірювальні прилади, встановлені на зразку Т-64Б. Методологічною основою дослідження стали загальнонаукові та спеціальні **методи** наукового пізнання. **Отримані наступні результати:** Визначена безперервна функціональна залежність фактичної кількості годин роботи двигуна від значень лічильника за годину на різних швидкостях, що дозволить більш ретельно вести облік витрати двигуна, але передбачатиме розробку спеціальних приладів на основі сучасної елементної бази. **Висновки.** Можна зробити висновок про нелінійний характер залежності ресурсу двигуна від часу при роботі двигуна на різних режимах навантаження. Режими роботи ДВС, що визначаються опором навантажень, характеризуються числом обертів колінчастого валу і величиною потужності, що розвивається двигуном, значною мірою визначають енергетичні та економічні показники двигуна та витрату його ресурсу. Полігон значень для дослідження витрати моторесурсу машини в залежності від показань лічильника мотогодин може бути сформований на основі даних, отриманих за результатами роботи машини в різних умовах. Аналіз результатів проведених досліджень показав, що знахідну залежність моторесурсу двигуна 5TDF можна представити у вигляді суми двох регресій – лінійної та гіперболічної. Показання лічильника мотогодин будуть записуватися і оброблятися, коли двигун 5TDF працює на I-V і VI, VII передачах відповідно. Така реалізація дасть можливість використовувати рівняння регресії безпосередньо для екіпажу танка.

Ключові слова: витрата моторесурсу двигуна 5ТДФ; рівняння регресії; метод найменших квадратів; облік показників лічильника мотогодин в танку.