TEKA Kom. Mot. Energ. Roln. – OL PAN, 2010, 10, 225–232

METHODS OF CALCULATION OF EXCESS FUEL EXPENDITURES WHEN MECHANICAL CONDITION OF AGRICULTURAL MACHINERY HYDRAULIC DRIVES IS CHANGED

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Summary. Method of calculation of excess fuel expenditures at mechanical condition change of hydraulic drives of agricultural machines is worked out according to open and closed schemes.

Key words: hydraulic drive, mechanical condition, volumetric coefficient of efficiency, fuel, excess fuel expenditures

INTRODUCTION

One of the main conditions of agricultural production efficiency assurance is the efficient use and reduction of fuel and energy resources consumption. Regulatory grounds and work directions in resource saving are provided by the law of Ukraine "About the Energy Saving" [1] and national standards [2, 4].

Application of the hydraulic drive [11-12] enables to enhance operational parameters and technical level of agricultural machinery and energy means. Mechanical condition of hydraulic drive significantly determines the technical and economic indices of machines on the whole, because hydraulic drives used in agricultural machines consume 50-60 % of the engine's power transmitting it to the working elements during the technology processes. Change of the mechanical condition of hydraulic drives leads to unproductive energy expenditures

Unproductive energy expenditures during hydraulic drive operation are the result of energy losses for mechanical friction in articulation joints and service fluids as well as volumetric losses from outer and inner leaks of service fluids. Mechanical losses and losses for friction in service fluids during hydraulic drive operation remain approximately stable. Running value of agricultural machines' hydraulic drives are volumetric losses which are determined by the volumetric coefficient of efficiency (coefficients of delivery rate, hydraulic units and fluid power motors losses). The coefficient of efficiency value in real operation conditions depends on kinematic pairs wear intensity which is essentially effected by the mode of load during operation, service fluid quality, level of maintenance and structural peculiarities of hydraulic units.

Reduction of volumetric coefficient of efficiency and general coefficient of efficiency lead to the losses in the form of unproductive energy expenditures and excess fuel consumption increase.

Coefficient of delivery rate limit value and general coefficient of efficiency for fluid power motors are determined by regulatory documents and do not exceed 20 % of the initial value [3]. However, in real operation conditions and in case of more significant fall of the feed and consumption, hydraulic units are not sorted out. Significant growth of energy carriers costs and requirements of energy resources saving precondition the necessity of the reviewing of approaches to establishing the allowed values of volumetric coefficient of efficiency.

REVIEW OF PUBLICATIONS AND RESEARCHES

Results of research on self-propelled machines mechanical, volumetric and full coefficient of efficiency depending on operating modes, kinematic parameters and service fluid are given in monograph [5]. The effect of hydraulic drive's mechanical condition on its functioning and performance is shown.

Results of research on hydraulic drive operating temperature are given in the works [14-15], hydraulic drives operating temperature graphoanalytical forecasting methodology depending on operational conditions is developed. Researches on determination of optimal and limit allowances of hydraulic drive volumetric coefficient of efficiency are performed in works [8-9, 13]. In the process of development of the methodology of defining the minimal and limit allowances of the volumetric coefficient of efficiency of hydraulic drives, as an intermediate result, the calculations of fuel over-expenditures at lowering of the coefficient of efficiency of agricultural machines hydraulic drives have been considered. But the separate method of calculation of fuel excess expenditures in case of hydraulic drives' mechanical condition change has not been developed.

DEFINITION OF THE RESEARCH PROBLEM

Urgency of the resource and energy saving as well as the efficient consuming of fuel problem shows the necessity of development of the separate method of excess fuel expenditure calculation in case of hydraulic units' mechanical condition change.

Now mainly two types of hydraulic drives are used in agricultural machines. They are constructively made in accordance with the open or closed scheme. In hydraulic drives made according to the open scheme mostly gear type hydraulic pumps, regulator valves, hydraulic cylinders and gear type or gerotor type hydraulic motors are used. Hydraulic drives with hydraulic cylinders are characterized by cyclic operation, while hydraulic drives with hydraulic motors – by incessant work. 0,08 mm mesh size filters are used for the cleaning of service fluids. Containers with service fluid are equipped with air breather filters, through which the dust from the air can penetrate into service fluid. Motor oils are used as service fluid and they contain mechanical impurities.

In hydraulic drives, made according to the closed scheme, axial-plunger variable delivery hydraulic machines with supercharge pumps are used. All domestic machines are equipped with hydraulic drives GST-33, GST-71, GST-90 and GST-112. 0,01 mm mesh size filters are used for service fluids cleaning. Heatsinks are provided for service fluids cooling. Hydraulic drives are equipped with temperature gages. Service fluid temperature can rise till 80°C. At this temperature the alarm system is activated. Environment factors do not significantly influence the mechanical condition of the hydraulic machines. High fineness of filters and absence of mechanical impurities in service fluid at the stage of supply provide the operation of hydraulic drives without significant change of a machine's mechanical condition. The change of mechanical condition and increase of leaks result from maintenance requirements violation or low-quality repair that leads to a low value of the volumetric coefficient of efficiency

Te peculiarity of hydraulic drives made according to the closed scheme is the fact that the leakage from the high pressure enclosures is compensated by the supercharge pumps. In case of mechanical condition change in the hydraulic drives of hydraulic machines, the value of leakage can increase only to the value of supercharge pump feed, as in case of a further leakage increase the condition of service fluid continuity is violated.

It is expedient to develop the method of excess fuel expenditures calculation for hydraulic drives during the operating shift that is at the fixed current value of the volumetric coefficient of efficiency and for the long-term operation in case of hydraulic units' mechanical condition change and lowering of the volumetric coefficient of efficiency as a result of kinematic pairs wear and leakage increase.

BASIC MATERIAL PRESENTATION

Hydraulic drives used in agricultural machines differ in power, pressure, functioning durability, and number of hydraulic motors connected to the pumps etc.

Power value spent in hydraulic drive due to service fluid leakage at the initial value of the volumetric coefficient of efficiency is determined by the formula [6]:

$$N_{втс} = N_п(1 - \eta_п), \tag{1}$$

where: $N_п$ - power, consumed by the hydraulic drive, kWt; $\eta_п$ - initial coefficient of efficiency of hydraulic drive.

In order to calculate excess fuel expenditures it is necessary to substitute the tension coefficient of the pump rated pressure by the tension coefficient $K_м$ at maximum pressure $P_м$

where: $N_п$ - power consumed by the hydraulic drive, Kwt; $\eta_п$ - initial hydraulic drive efficient factor.

In order to calculate excess fuel expenditures conditioned by the initial coefficient of efficiency, it is necessary to determine energy expenditures during operation time, which are proportional to the power.

Complex assessment of the factors, determining the hydraulic units load mode, namely: operation duration under load, frequency of switching on, pressure in the system, is made by the coefficient of tension $K_н$ [7, 10]:

$$К_н = \frac{P_д}{P_н}\frac{t_ц}{3600}n_ц, \tag{2}$$

where: $P_д$ pressure in the system, MPa; $P_н$ - pump rated pressure MPa; $t_ц$ - technology cycle duration (operation under load); $n_ц$ number of cycles (switching on) per hour.

To calculate the excess fuel expenditures it is necessary to substitute the coefficient of tension of rated pump by the coefficient of tension $K_м$ at maximum pressure $P_м$ from load power in hydraulic system.

Coefficient of tension is calculated on the basis of hydraulic drives operation oscillograms. For example, coefficient of tension for PEA-1H «Karpatets » loader (Fig. 1) is 0,47, for УЕЗ-250 universal energetic means aggregated with « Polissya -3000» mounted forager (Fig. 2) it is 0,90.

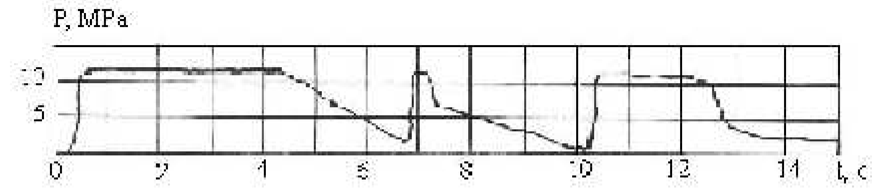

Fig. 1. «Karpatets» loader hydraulic drive operation oscillogram

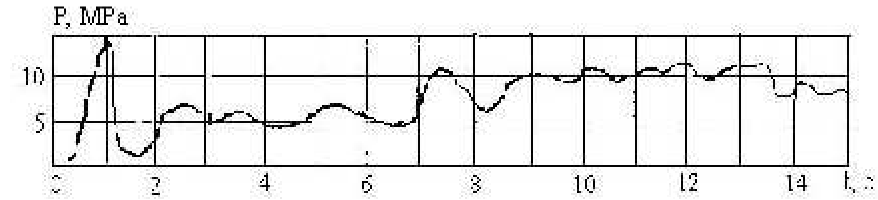

Fig. 2. УЕЗ-250 universal energetic means, aggregated with «« Polissya -3000» mounted forage, hydraulic drive operation oscillogram

Excess fuel expenditures by the machine's engine for hydraulic drive at the initial value of the volumetric coefficient of efficiency is determined by the formula:

$$G_n = N_{nm} q K_n / \rho(1-\eta_n), \tag{3}$$

where: η_s - specific fuel expenditures by the engine, kg/kWt hour; η_n - initial value of hydraulic drive volumetric coefficient of efficiency, ρ - density of diesel fuel, kg/l.

There are no excess fuel expenditures at the initial values of the volumetric coefficient of efficiency, though unproductive expenditures happen. It is necessary to reduce such losses by way of high quality manufacturing of hydraulic drives and especially of their sealing kinematic pairs.

It ought to be noted that a number of domestic hydraulic drives and motors have design peculiarities which allow to significantly enhance the initial values of η. For example gear type hydraulic pumps with compensators, which were tested in their time, had the initial value of the volumetric coefficient of efficiency higher than 0, 96 against 0,90 specified by the standard [3].

Mechanical condition change in the hydraulic drive of hydraulic units leads to losses in the form of unproductive excess fuel expenditures.

After a pump drive's engine is switched on, the performance of the hydraulic drive is characterized by the gradual rise of the service fluid temperature from the ambient temperature value to the temperature at which the heat exchange balance between the surfaces of hydraulic drives in hydraulic units and the ambient medium is reached. With the temperature rise of the service fluid its viscosity is weakened and, accordingly, the leakage is increased and the volumetric coefficient of efficiency drops. Diagrams of the service fluid temperature changes T_n and the volumetric coefficient of efficiency - η_n at the beginning of operation and after running hours $t - T_T$ and η_T ,accordingly, are shown in Figure 3.

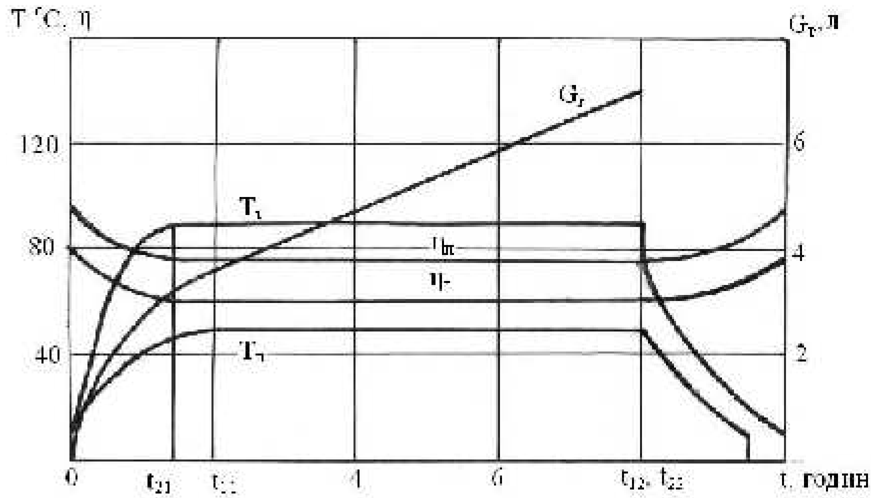

Fig. 3. Service fluid temperature changes, volumetric coefficient of efficiency
and excess fuel expenditures diagrams

Excess fuel expenditures are proportional to energy losses, which depend in their turn on service fluid temperature [6]:

$$W = N_t t = Q_e \Delta p = Q_e \gamma c m \Delta T, \tag{4}$$

where: Q_e - service fluid leakage, m^3/s; Δp - differential pressure in hydraulic drive MW/m^2; Δp- volume weight of the service fluid, W/m^2; c – liquid heat capacity, kj/kg. degrre. m – mechanical heat equivalent, kg.·m/kj; ΔT - temperature difference in degrees.

At the interval of temperature growing from time t=0 to time t_{21} energy losses change and excess fuel expenditures are described by the power function and at the time interval Δt they make:

$$\Delta G_{n1} = k t^{\frac{1}{2}} \Delta t, \tag{5}$$

where: $k = N_n q K_n / \rho(\eta_n - \eta_m)$; η_m - current value of the hydraulic drive volumetric coefficient of efficiency.

The overruns of fuel make:

$$G_{n1} = k \int_0^{t_{21}} t^{\frac{1}{2}} dt = \frac{2}{3} k t_{21}^{\frac{3}{2}}. \tag{6}$$

Excess fuel expenditures reach:

$$G_{n1} = k \int_0^{t_{21}} t^{\frac{1}{2}} dt = \frac{2}{3} k t_{21}^{\frac{3}{2}}. \tag{6}$$

At the other time interval from t_{21} to t_{22}, energy expenditures and, accordingly, excess fuel expenditures have the constant value in time. Including the coefficient of tension of the hydraulic drive operation, the total excess fuel expenditures of machine's engine at the coefficient of efficiency lowering in both intervals during the operation time t are equal to:

$$G_{rc} = N_n q K_n / \rho(\eta_n - \eta_{rc})(\frac{2}{3}t_{21}^{\frac{3}{2}} + t_{22} - t_{21}). \qquad (7)$$

Current value of the volumetric coefficient of efficiency is determined after the measurement of the pump flow rate, service fluid flow rate through regulating valve hydraulic engines by formulae given in the works [6, 11].

For the lasting period of operation, at hydraulic units' mechanical condition change, the volumetric coefficient of efficiency is determined by the following functions [16]:

$$\eta_{rc} = at^2 + bt + c, \qquad (8)$$

where: a, b, c - coefficients; t - running hours.

Progressing excess fuel expenditures conditioned by the drop of the volumetric coefficient of efficiency during the interval Δt taking into account that at $t = 0$ $c = \eta_{rc}$ are:

$$\Delta G_e = N_n q K_n / \rho(\eta_n - at^2 - bt - c)\Delta t. \qquad (9)$$

From here:

$$G_e = N_n q K_n / \rho \int_0^t (-at^2 - bt)dt. \qquad (10)$$

After integration we obtain the final formula for the calculation of the excess fuel expenditures for the lasting period of operation at changed mechanical condition of hydraulic drives:

$$G_e = N_n q K_n / \rho\left(-\frac{at^3}{3} - \frac{bt^2}{2}\right). \qquad (11)$$

Let us consider the calculation of the excess fuel expenditures of «Karpatets» loader during the operating shift at the hydraulic drive volumetric coefficient of efficiency value 0,7 by the formula (7) and for the lasting period of operation by the formula (11).

According to the tests data the power, consumed by the loader's hydraulic drive, is 27,6 kWt, tension coefficient K_n= 0,47, specific power expenditures q is 0,225 kg/kWt/h, diesel fuel density – 0,85 kg/l. According to the measurements results of pump fuel rating coefficient during testing, the approximate function coefficients are determined and they are: $a = -4{,}6\text{x}10^{-8}$, c^{-2}; $b = -2{,}1\text{x}10^{-5}$, c^{-1}; $c = \eta_n = 0{,}967$. Excess fuel expenditures during the operation shift reach 7,0 l. Calculation results are given in Fig. 3.

Calculation results of excess fuel expenditures for the lasting period of operation at hydraulic drives mechanical condition change to hydraulic units' border condition are shown in Figure 4 as a diagram. According to the calculations at the hydraulic drive volumetric coefficient of efficiency value 0,9 excess fuel expenditures reach 75,6 l, at value 0,6 unproductive fuel expenditures reach 464,4 l.

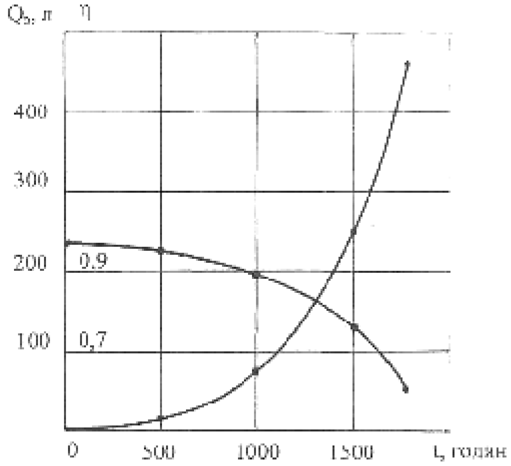

Fig.4. Dependence of excess fuel expenditures $Q_з$ on the volumetric coefficient of efficiency and running hours of « Karpatets » loader hydraulic drive

The power, consumed by УЕЗ-250 hydraulic drive when aggregated with «Polissya -3000» combine at corn harvesting, amounts to 36,0 kWt, tension coefficient $K_н$ = 0,90, at hydraulic drive the volumetric coefficient of efficiency reaches the value of 0,7 , the excess fuel expenditures during the operating shift reach 12,8 l. The excess fuel expenditures during the season at characteristic load 600 hours are 957 l.

CONCLUSIONS

To provide resource and energy saving during the operation of agricultural machines and efficient fuel expenditures it is necessary to use service fluids free of mechanical impurities, filters of high fineness of filtration and air breather-filters of high quality.

A significant growth of energy production cost conditions the necessity of reviewing of approaches to establishing the limit values of the volumetric coefficient of efficiency. It is expedient to choose them on the basis of minimum specific expenditures provision, at which the owner of the machine will have minimal expenditures related to operation time unit. It is necessary to review DSTU 2192 [6] clauses concerning the requirements in order to limit the values of the volumetric coefficient of efficiency.

To prevent the operation of hydraulic drives with the low value of the volumetric coefficient efficiency it is necessary to test the operation of hydraulic drives' hydraulic units in due time and change them if necessary.

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METODY OBLICZANIA NADMIERNEGO ZUŻYCIA ENERGII PO ZMIANIE STANU MECHANICZNEGO NAPĘDÓW HYDRAULICZNYCH W MASZYNACH ROLNICZYCH

Streszczenie. Opracowano metodę obliczania nadmiernego zużycia energii przy zmianie stanu mechanicznego napędów hydraulicznych maszyn rolniczych według schematu otwartego i zamkniętego.

Słowa kluczowe: napęd hydrauliczny, stan mechaniczny, objętościowy współczynnik wydajności, paliwo, nadmierne zużycie paliwa