Increasing the efficiency of the working process of a forest fire ground-sweeping machine with an energy-saving hydraulic drive of the throwing rotor

P I Popikov¹, M A Gnusov¹,², V P Popikov¹, and A V Sharov¹

¹Voronezh State University of Forestry and Technologies named after G.F. Morozov, Timiryazeva 8, Voronezh, 394087, Russia
E-mail: mgnusov@yandex.ru

Abstract. The article deals with the problem of creating machines and units for the prevention and suppression of forest ground fire. The purpose of the study is to increase the efficiency of the working process of the soil-throwing machine by substantiating the parameters of the energy-saving hydraulic drive of the rotor-thrower. The rational values of the pre-charging pressure and the working volume of the pneumohydraulic accumulator have been established, which ensure the reduction to a minimum of the number of operation of the safety valves when the rotor-thrower meets obstacles. The optimum charging pressure of the pneumohydraulic accumulator is 6 ... 7 MPa, the working volume is 5 ... 8 dm³, while the energy-saving hydraulic drive stores energy of about 15 ... 17 kJ during the working cycle, pressure surges do not exceed 13.3 MPa, and the recovered energy at density of obstacles up to 200 pcs / km due to the reduction in the number of operation of safety valves can be about 3000 kJ per 1 km of strip laying. The productivity of the forest fire ground-throwing machine with a new energy-saving hydraulic drive increases by 16-22% while reducing energy consumption by 7-8%.

1. Introduction

Currently, in the forestry complex, the most common way to prevent and extinguish forest ground fires is the laying of mineralized strips and ditches using forest plows PKL-70, PL-1, PLO-400, milling ground-throwing machines PF-1 and ALF-10 and GT-3, however, forest plows are not capable of creating a mineralized strip of sufficient width in one pass of the unit, milling soil-throwing machines are energy-intensive and ineffective, since it are aggregated with tractors with creeper creepers to obtain particularly low operating speeds, and milling working bodies work with the upper turfy layer, which is significantly reduces the effectiveness of fire suppression [1]. Therefore, the tools with combined working bodies appeared, with preliminary preparation of the soil shaft with passive working bodies and cutters - throwers. However, ground-throwing machines are equipped with a bulky mechanical drive, which significantly reduces the reliability of the tool. Currently, on construction and road machines, an energy-saving hydraulic drive of technological equipment and active working bodies is widely used, which makes it possible to achieve a reduction in dynamic loading and a decrease in energy consumption by returning the accumulated energy in the accumulator back to the hydraulic system [2]. The currently known theoretical and experimental studies of the working processes of forest machines that use in its design an energy-saving hydraulic drive of the working bodies do not fully describe the dynamics of the processes that occur in the hydraulic system during the interaction of active working bodies with the soil and obstacles [3, 4]. All this greatly
complicates the process of creating new forest fire equipment with active working bodies for throwing soil [5-7]. Therefore, it is necessary to carry out additional theoretical and experimental studies of new designs of forest fire ground-throwing machines with an energy-saving hydraulic drive of active working bodies, which make it possible to improve the technology of laying mineralized strips and extinguishing forest ground fires.

The aim of the study is to increase the efficiency of the working process of the soil-throwing machine by substantiating the parameters of the energy-saving hydraulic drive of the rotor-thrower driving the rotor.

2. Material and methods

We have carried out theoretical studies aimed at developing a mathematical model for the joint work of passive and active working bodies with an energy-saving hydraulic drive of a forest fire ground-throwing machine, whose design is protected by a patent for a utility model (Figure 1) [8].

Figure 1. Structural (a) and hydraulic (b) diagrams of a forest fire ground-throwing machine with an energy-saving hydraulic drive. 1 - frame; 2 - linkage mechanism; rotor-thrower - 3; blades - 4, casing-ripper - 6; ploughshare - 7; windows - 8; safety knives - 9; support ski - 10; hydraulic motor - 11; distributor - 12; pressure hydraulic line - 13; hydroaccumulator - 14; check valve - 15; pump - 16; safety valves - 17 and 18.

Mathematical model of the working process of the energy-saving hydraulic drive of the rotor-thrower, flowing in the hydraulic and mechanical subsystems:

$$\left( J_M + J_R + J_P \right) \frac{d^2 f_R}{dt^2} = \frac{Q_M(t)\left(P_M - P_0\right)}{df_R} - \sum_{i=1}^{n_{s0}} r_{iG}^e F_{iG}^e - \sum_{i=1}^{n_{sO}} r_{iP}^e F_{iP}^e - \left(M_{CT} + R \frac{df_R}{dt} \right)$$

(1)

where JM, JR, JP – the moments of inertia of the hydraulic motor, rotor, transmission, reduced to the axis of rotation of the rotor; QM – hydraulic motor working fluid flow; PM и P0 – pressure in the pressure head and drain hydraulic lines of the hydraulic motor; NEG и NEP – number of soil elements; ri – distance from the rotor axis to the i-th soil element or obstacle; FrGi и FrPi – tangential components of the force of action of the i-th soil element and obstacles on the rotor; MCT – the moment of the dry friction force during the rotation of the rotor; kBT – coefficient of viscous friction.

The theoretical dependencies of the working processes of a forest fire ground-throwing machine with a pneumohydraulic accumulator (with a PHA) and when the pneumohydraulic accumulator is disconnected (without a PHA) are shown in Figure 2. When the rotor meets an obstacle, when the pneumohydraulic accumulator is disconnected, a surge in the pressure of the working fluid in the pressure hydraulic line of the hydraulic motor increases up to 17,42 MPa, leading to a stop of the rotation of the rotor and the hydraulic motor shaft. When the accumulator is connected, the pressure rises to 13 MPa, this solution allows to reduce dynamic loads by 34% and reduce energy consumption by reducing to a minimum the number of safety valve actuation when the rotor-thrower meets
obstacles.

**Figure 2.** Theoretical dependencies of the working processes of a forest fire ground-throwing machine with a pneumohydraulic accumulator (with PHA) and when the pneumohydraulic accumulator is disconnected (without PHA).

One of the main indicators of an energy-saving energy system is energy EC, stored for the working cycle (the process of deceleration of the rotor-thrower when it encounters an obstacle to a complete stop and its subsequent acceleration). The working cycle is the actuation of the safety valve [9-11], which lasts 2-3 seconds and during this time the cutter-thrower overcomes the obstacle. This indicator is calculated as follows:

\[ E_C = \int_0^{t_{CE}} P_f(t)Q_{PHA}(t) \, dt, \]  

where \( t_{CE} \) – the duration of the computer experiment; \( Q_{PHA} \) – the flow rate of the working fluid entering the pneumohydraulic accumulator.

The charging pressure of the pneumohydraulic accumulator \( P_{PHA} \) affects the intensity of the flow of the working fluid from the hydraulic motor into the pneumohydraulic accumulator, therefore, it should have a significant effect on the amount of energy accumulated during the working cycle [12, 13], and the efficiency of damping pressure surges during emergency braking of the rotor of the ground thrower [14, 15]. A series of computer experiments have been carried out to study the effect of \( P_{PHA} \) on the efficiency indicators of an energy-saving hydraulic drive. Within the series, \( P_{PHA} \) was varied at levels 2, 4, 6, 8, 10, 12 (Figure 3). Figure 3a shows that the optimal charging pressure of the pneumohydraulic accumulator is 6 ... 8 MPa with a volume of 5 ... 8 dm³.

**Figure 3.** Influence of the initial gas pressure in the pneumatic hydraulic accumulator \( P_{PHA} \) on the stored energy during the operation of the safety valve \( E_C \) (a), the amplitude of the pressure surge in the hydraulic system \( P_m \) (b).
(b).

The actuation pressure of the safety valve of the hydraulic motor is 14 ... 15 MPa, but at an initial pressure of charging the accumulator of 6 ... 8 MPa in the mode of locking the rotor-thrower, the pressure in the hydraulic drive becomes 10 ... 12 MPa (Figure 3b) and the safety valve does not work, but the energy is accumulated in the accumulator, the stored energy for a working cycle when overcoming an obstacle is about 15 kJ, which, after overcoming an obstacle, returns to the hydraulic system and provides a faster acceleration of the rotor-thrower by 1.5-2 s, which reduces the length of the flaw when laying strips by 0.8 -1.1 m. At the same time, the productivity of the forest fire ground-throwing plant with a new energy-saving hydraulic drive increases by 16-22% due to a decrease in the length of the flaw in one cycle of overcoming an obstacle. The total stored energy with a density of obstacles of up to 200 pcs/km due to the reduction in the number of operation of safety valves can be about 3000 kJ per 1 km of lane laying, and the energy intensity of the working process is reduced by 7-8%.

While simulating working processes, the influence of the accumulator on the speed of the hydraulic motor shaft under operating conditions was studied (Figure 4). The acceleration time when the rotor-thrower is turned on without a hydroaccumulator lasts about 5 s, with a hydroaccumulator about 4 s, because the accumulator gives up the accumulated energy when overcoming an obstacle to accelerate the rotor-thrower. Within the framework of a series of computer experiments, the rotational speed of the rotor drive hydraulic motor shaft nr/s varied from 1 to 9 with a step of 1 s⁻¹ (Figure 4). The optimal nob/s range is 7… 8 rev/s. At such speed values, the stored energy when overcoming an obstacle is EC = 10 ... 15 KJ, and the amplitude of the pressure surge in the hydraulic system Pm is in the range from 10 to 12.5 MPa, at which operation of the safety valves of the hydraulic motor is not observed.

\[ E_C, \text{kJ} \]
\[ P_m, \text{MPa} \]

Figure 4. Influence of the rotational speed of the hydraulic motor of the rotor-thrower drive on the energy stored during the working cycle EC (a), the amplitude of the pressure surge in the hydraulic system Pm (b).

3. Conclusions

Thus, the optimal charging pressure of the pneumohydraulic accumulator is 6 ... 7 MPa with a volume of 5 ... 8 dm³. With such parameters, an energy-saving hydraulic drive stores energy of about 15 ... 17 kJ during a working cycle, pressure surges do not exceed 13.3 MPa, and the total stored energy with a density of obstacles up to 200 pcs/km due to a reduction in the number of operation of safety valves can be about 3000 kJ per 1 km of strip laying. At the same time, the productivity of the forest fire ground-throwing plant with a new energy-saving hydraulic drive increases by 16-22% while reducing energy consumption by 7-8%.

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