Justification of dependence of the sprinkler machine power supply system efficiency on the irrigation process parameters

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Abstract. The article considers the problem of choosing the power supply system of the sprinkler machine. The energy supply system can be represented by different types of the drive of the chassis of the machine: hydraulic, electrical and mechanical. Not only types of drives, but also whole systems in terms of an indicator – coefficient of performance (COP) are compared. The COP of the energy supply system takes into account the parameters of the irrigation process: the pressure of irrigation water at the entrance to the sprinkler machine (SM), the remoteness of the reservoir from the fixed support of the SM, the remoteness of the SM from the village. During the analysis, the dependencies of the COP of the hydraulic and electrical (powered from the cable line) systems on the parameters of the irrigation process were established. The conditions for ensuring the action of SM on a hydraulic drive are determined. It was found that the COP of the hydraulic system has a higher efficiency of up to 14.8% at a pressure created by the pump of more than 0.65 MPa with a distance of SM from the pumping station of not more than 4 km. In other conditions of irrigation, the efficiency of the electrical system is slightly higher – from 1.43% to 40.54%. For a reasonable choice of the energy supply system, other parameters should be taken into account, for example, the cost of the energy supply system, the lifespan of the SM, and others.

1. Introduction

Production operation of sprinkler machines is aimed at increasing the yield of cultivated plants due to regular moistening of the soil. There are many operating principles of sprinkler machines (SM), from which the type of action stands out: circular or frontal. It is believed that the work of SM circular action is easier to organize, since one side is fixed motionless, where the water supply and chassis power system are connected [1]. At the same time, a significant number of energy resources is expended.

Technical operation is aimed at maintaining the SM in working condition over the declared service life. Comparison of profit from crop growth with the cost of technical operation determines the effectiveness of SM. Harvest growth is not difficult to determine. When analyzing operating costs, the main share is the cost of energy resources, which depends on the adopted power supply system of the chassis (hydraulic, electric, and mechanical drives).

It is known that, for example, in small household plots it is advisable to use only a hydraulic drive, the principle of which is based on the principle of the hydraulic cylinder SM «Frigate» [2]. At the same time, with an increase in the length of the pipeline, the hydraulic drive has large losses compared with the electric and mechanical drive. Evaluation of the drive action is based on the following
indicators: power consumption, traction moment, as well as coefficient of performance (COP). In this case, the COP of the engine and the entire drive is considered.

According to the reference data [3, 4], it is not difficult to determine the COP of the drive; the electric drive is the best in all respects. However, as noted in the example, for small areas it is advisable to use a hydraulic drive. Therefore, for SM it is necessary to compare the COP of the drive, but of the energy supply system as a whole.

The power supply system of the chassis is characterized by individual indicators, closely related to the irrigation parameters by sprinkling; therefore, the purpose of this study is to substantiate the dependence of the COP of the system on the irrigation parameters of a specific area.

2. Methods of research
To solve this goal, we use the theory of mathematical analysis, comparison, and analysis of the results. The energy supply system has an energy source, an energy receiver, and energy transmission means. COP shows the ratio of useful converted power in the receiver to the total power transmitted from the source. In a hydraulic system, the source is the electric motor of the discharge pump, and the consumed resource is electric energy. In an electric drive several sources can be considered: cable line – the resource is electricity; portable generator – the resource is gasoline (diesel) fuel; a rechargeable battery recharged from a portable generator – the resource is gasoline (diesel) fuel; or a rechargeable battery recharged from solar modules – the resource is solar energy. At the first stage of the study, it is necessary to determine the target function of COP.

We will analyze and consider the objective function of linking the COP indicator with the parameters of the irrigation process:

$$\eta = f (p, l, l)$$

where $p$ – sprinkler inlet water pressure, Pa; $l$ – remoteness of the motionless support of SM from a reservoir, m; $l$ – remoteness of the fixed support of SM from the settlement (transformer substation, warehouse with gasoline (diesel) fuel), m.

3. Results
COP for various systems is considered regarding power consumption. In hydraulic and electrical systems, COP can be determined by estimating energy losses. In mechanical systems, the conversion of internal fuel energy into mechanical energy and the transfer of mechanical energy to the SM working body are difficult to consider, since sprinkler machines with such a system are not found in practice.

In hydraulic systems, a change in COP is slightly different from COP in electrical systems. Let us analyze this dependence and consider the objective function:

$$\eta = \frac{\sum P - \Delta P}{\sum P} = 1 - \frac{\Delta P}{\sum P}$$

where $\Delta P$ – power loss at all stages, W; $\sum P$ – total power supplied by the energy source, W.

We will describe the power loss taking into account the remoteness of the settlement $l_s$ and the reservoir $l_r$ respectively.

For electrical system:

$$\Delta P = \alpha \sqrt{\frac{S}{\pi}} + \beta l_s$$

where $S$ – irrigation area, $m^2$; $\alpha$ – specific losses of electricity over the length of the SM pipeline, taking into account losses at power receivers, $W/m$; $\beta$ – specific losses of electricity in the line from the electrical substation to the fixed central support of SM, $W/m$. 
In other electrical systems, for example, powered by a diesel or gasoline portable generator, the remoteness of the settlement is not taken into account in this calculation, since the generators are usually installed next to a fixed support. In cases with battery power, when determining COP, only losses in power receivers are accepted as losses, since the batteries are located next to the electric drive. Losses on the transmission of electricity are reduced to zero.

For hydraulic system:

\[
\Delta P = u \sqrt{\frac{S}{\pi}} + y l_r
\]

where \( u \) – specific losses of energy of fluid movement (irrigation water) per pipeline length of SM, taking into account losses in each rain-forming device and hydraulic drive, \( W/m \); \( y \) – specific losses of energy of fluid movement in the main pipeline from the reservoir to the fixed support of SM, \( W/m \).

Total source power for electric drive:

\[
\sum P = P_0 q + P'S
\]

where \( q \) – irrigation rate, which determines the specific gravity of the irrigation machine with irrigation water; \( kg/m^2 \); \( P_0, P' \) – coefficients depending respectively on irrigation rate and irrigation area, \((W*kg/m^2)\) and \((W/m^2)\).

The regulation of the irrigation rate in practice is carried out by controlling the speed of movement of SM [5], whereas the diameter of the pipeline remains unchanged, then the specific gravity remains constant or:

\[
P_0 q = \text{const} = b
\]

\( b \) – constant power value related to irrigation rate parameter \( q \), \( W \).

Then the COP indicator for the electrical system is following:

\[
\eta_E = 1 - \frac{\alpha}{b + P'S} \frac{\sqrt{\frac{S}{\pi}} + \beta l_s}{\sqrt{\frac{S}{\pi}} + y l_r}.
\]

The total power for the hydraulic system is determined by the power of the electric motor of the discharge pump. For one sprinkler, it is difficult to identify the cost of pump power, which, for example, feeds several sprinklers and / or other irrigation systems. For SM, the main parameter for monitoring the operation of the hydraulic energy supply system is irrigation water pressure \( p \) (\( Pa \)).

Then the power can be defined as:

\[
\sum P_G = xp
\]

where \( x \) – constant value that determines the amount of power consumption per pressure unit for the hydraulic system, \( W/Pa \).

COP of hydraulic system is as follows:

\[
\eta_G = 1 - \frac{u \sqrt{\frac{S}{\pi}} + y l_r}{xp}.
\]

The change in COP for hydraulic and electrical systems is shown in the figure.
As shown in figure 1a, at the lowest pressure of the injection pump 0.2 MPa, the hydraulic system can provide SM action only at a small distance from the pump station up to 1 km. Moreover, the condition must be satisfied for the hydraulic system:

\[ p_{in} = p - \Delta p_i \]
\[ p_{in} \geq \Delta p_{SM} \]

where \( p_{in} \) – inlet pressure in SM, Pa; \( \Delta p_i \), \( \Delta p_{SM} \) – pressure losses, respectively, from the pumping
station to the fixed support of SM and in the pipeline of SM, \( Pa \).

Figure 1b shows the portion in which the hydraulic system does not operate, COP is zero.

4. Conclusion

Thus, the COP indicator of the power supply system of the sprinkler machine estimates the level of energy loss. Comparing hydraulic and electrical (cable line) systems, the change in COP is significantly different. For a hydraulic system, the COP value depends on the pressure generated by the pressure pump and on the distance of SM from the pump station. For an electrical system, COP depends on the distance of SM from the locality where the transformer substation is installed, which, in this case, is a source of electricity. It was established that the hydraulic system is better in COP value up to 14.8\% when the pressure created by the pump is more than 0.65 \( MPa \) with the distance of SM from the pump station not more than 4 \( km \). In other cases, the COP of the electrical system is slightly higher – from 1.43\% to 40.54\%. This difference in COP of the systems under consideration is associated with pressure losses in the pipeline, since irrigation water is also a working fluid in the hydraulic system.

In order to choose the SM energy supply system along with COP, a number of other indicators must also be taken into account. For example, when comparing electrical and hydraulic systems, the COP of the electrical system can be up to 40\% higher, and the cost of laying and the complexity of maintaining the cable line significantly increase the total cost of the system. Thus, when choosing a system, it is necessary to take into account the cost of the source, as well as the service life of the sprinkler machine.

References

[1] Fokin B P and Nosov A K 2011 Current problems of the use of multi-bearing sprinkler machines (Stavropol: Scientific publication)
[2] Sonrell H 1991 Zeitgemusse Beregnung Verringerung des Wasser – und Energienaufwandes bei mobilen Beregnung maschinen Landtechnik 46(5) 209–219
[3] Pirumov U G et al 2003 Mechanical engineering. Encyclopedia (Moscow: Mechanical Engineering. Maths)
[4] Gerasimov V G et al 1982 The use of electrical energy. Electrical reference book (Moscow: Energoizdat)
[5] Eroshenko G P et al 2018 Modes and parameters of electric drives of a sprinkling machine of circular action Journal of Adv Research in Dynamical & Control Systems 10