MATHEMATICAL MODEL OF THE PUMPING UNIT OF MACHINE WATER LIFTING SYSTEMS

Kudrat Abidov[1],*Nargiza* Khamudkhanova[2]

[1]*Head of Department, Tashkent State Technical University, Tashkent, Universitetskaya str. 2, Uzbekistan*
[2]*Assistant, Tashkent State Technical University, Tashkent, Universitetskaya str.2, Uzbekistan*

Abstract. Pumping stations have been investigated as objects of control and energy saving. Methods for determining energy-efficient processes of functioning of water-lifting pumping stations with the formation of their energy-saving modes are given. Mathematical methods have been developed for describing and modeling a pumpingunit for machine water lifting systems.

1. Introduction

Nowadays, one of the main sources of meeting the growing demand of the economy of the Republic of Uzbekistan for electricity should be energy and resource conservation. Therefore, the tasks of developing energy-saving technologies in the sectors of the economy of the republic, in particular, at such energy-intensive objects as irrigation pumping stations of machine water lifting systems acquire a decisive importance. It is known that the main technical and economic indicators of the operation of a pumping unit as indeed of the entire pumping station are the efficiency of the pumping unit (station) and the specific power consumption spent on the supply (pumping) of a unit of water volume into the hydraulic pressure network [1]. It was determined [2] that when forming a mathematical model of a pumping unit for machine water lifting systems to ensure energy-saving modes of operation, as a criterion for assessing the efficiency of its work, it is necessary to take the minimum specific consumption of electrical energy for water supply with appropriate restrictions imposed on the conditions of its operation. Due to the fact that in the overwhelming majority of pumping stations of machine water lifting systems pumping units are operated as a group of pumping units structurally combined to work together in a common pressure pipeline, the value of the specific electricity consumption for pumping units is initially determined.

2. Experimental research

As is known [3], the specific power consumption for the supply of 1 million m3 of pumped water to a height of 1 meter of water column for pumping units is determined by the following formula:

$$\Delta E = 2{,}724/\eta_{PUi}, \quad \text{kW*h/mln. m}^3 * \text{m}, \quad (1)$$

where

$$\eta_{PU.i} = \eta_i * \eta_{D.i} * \eta_{T.i}. \quad (2)$$

There η_{PUi} - efficiency of i-th pump unit as part of a pumping unit;
η_i - pump efficiency of i-th pump unit;
$\eta_{D.i}$–efficiency of the drive motor i-th pump unit;
$\eta_{T.i}$- transmission efficiency.
The current value of the efficiency of the pump by taking into account the cavitation-abrasive wear of its working bodies can be determined by the expression [4]:

$$\eta_i = K_{wear} * \eta, \quad (3)$$

where
K_{wear}–the wear factor of the pump's working bodies, calculated as $K_{wear}=e^{-0.00000833*T}$;
T–the duration of the pumping unit;
η – the value of the efficiency of the pump determined for each specific operating condition of the pump unit in accordance with [5].
The value of the efficiency of the pump drive motor by taking into account its load can be determined by the formula:

$$\eta_{D.i} = \frac{1}{1+(1/\eta_{D.r}-1)*(K_{Z.i}+A_T/K_{Z.i})/(1+A_T)}, \quad (4)$$

where
$\eta_{D.r}$– therated value efficiency of the drive motor;
A_T– loss factor of the electric motor.
For an asynchronous motor:
at $n \leq 1000$ RPM A_T=0.5,
at $n \geq 1000$ RPM A_T=0.7;
and for a synchronous motor:
at $n \leq 1000$ RPM A_T=1,
at $n \geq 1{,}000$ RPM A_T=2).
$K_{Z.i}$–the load factor of the drive electric motor of the pump unit is determined by the expression (5):

$$K_{Z.i} = \frac{1}{K_{wear}*Kt} * \frac{P_{M.i}}{P_{D.r}}, \quad (5)$$

Kt –the coefficient that takes into account the change in the rated power of the electric motor depending on the ambient temperature (t0), which is determined in accordance with the following expression:

$$Kt = 1.24 - 0.000196 * t_0^2; \quad (6)$$

$P_{D.r}$– the rated power of the drive electric motor of the pump unit;

$P_{M.i}$–the mechanical power of the pump is determined by the expression (7) [5]:

$$P_{M.i} = A_{P_i} * Q_i - B_{P_i} * Q_i^2 + C_{P_i}, \quad (7)$$

where

A_{Pi}, B_{Pi}, C_{Pi} –constant approximation coefficients of the$i$-th pump;

Q_i–capacity (performance) of the$i$-thpump at the steady-state operating point.

The combination of the above formulas makes it possible to calculate using the expression (1) the specific consumption of electrical energy of each of the pumping units, combined for joint operation into a common hydraulic pressure network as a part of a pumping unit. The specific flow rate of the pumping unit of machine water lifting systems as a whole can be determined as:

$$\Delta E = 2{,}724/\ \eta_{PU}, \text{ kW*h/mln. m}^3 \text{*m}, \quad (8)$$

where

η_{PU}– the efficiency of the pumping unit.

An expressionη_{PU} can be obtained for any number of operating pumping units, structurally combined for joint parallel operation into a common hydraulic pressure network.

$$\eta_{PU} = \frac{\sum_{i=1}^{N} Q_i}{\sum_{i=1}^{N} \frac{Q_i}{\eta_{HA.i}}}, \quad (9)$$

where

N –the number of operating pumping units as part of a pumping unit.

Thus, the expression (8), obtained on the basis of (9), allowing to calculate the efficiency of the pumping unit depending on the number of jointly functioning pumping units, as well as taking into account the equations that determine the corresponding performance characteristics of the pumps [5] and (1), (4) for the efficiency of the pump and the drive motor of each of the pumping units, together with the restrictions imposed on the parameters of the pumping unit functioning in the form of:

$Q \geq Q_{schedule}$;

$H_{min} \leq H_c \leq H_{max}$; (10)

$$n_{min} \leq n \leq n_{max},$$

where

$$H_c = H_{CT} + R_{HC} * Q^2;$$

Q–pump capacity;

$Q_{sc\ edule}$ – therequired amount of water flow in accordance with the schedule water consumption of irrigated land areas;

H_c, H_{max}, H_{min}–current, minimum and maximum values of the created pressure permissible under the conditions of the pumping unit functioning;

$n_{\min}$ –minimum speed of the pump unit in accordance with the set operating mode of the pump unit:

$$n_{\min} = n_r * \sqrt{H_{\min} / H_{\max}};$$

$n_{\max}$ –maximum permissible speed according to the conditions of the pump, frequency rotation of the pump unit;n_r – rated speed of the pump unit;

H_S–static head spent on raising water for a given geometrical height, determined by the difference in the elevation of the horizons of the levels of the upperpond – $\nabla_{UP}$and lower pond–∇_{LP} of pumping stations of machine water lifting systems;

R_{PN} –the resistance of the pipeline pressure network, which includes the resistances of each of the suction, communication, supply pipelines of pumping units and the general pressure network of the pumping unit. The above defines the analytical mathematical model of the pumping unit.

3.Design Studies

Of the constraints listed (10), a more detailed consideration is required to determine the form of the equation for finding the operating point of the pumping units, located on the pressure networkcharacteristic, which undoubtedly has one of the defining values in describing the technological process of water supply of the pumping unit. The position of the operating point of the "pumping unit - pressure network" system corresponds to its material and energy equilibrium and is characterized by the well-known hydraulic equation that determines the required pressure in the pipeline network:

$$H_{RP} = H_S + h_V + h_k + h_P + h_{ons}, \quad (11)$$

where

h_V – pressure loss in the suction pipeline of pumping units;

h_k – pressure loss in the communication pipeline of pumping units;

h_P –pressure loss in the supply pressure pipeline of pumping units;

h_{ons} – pressure loss in the general hydraulic pressure network of the pumping unit.

To determine losses in pressure pipelines of pumping stations of machine water lifting systems, one should use a number of known hydraulic relationships and reference data [6], as well as the results of experimental studies conducted by F.A. Shevelev [7].

The pressure loss in the suction pipeline of a pumping unit can be determined by the expression:

$$h_{V.i} = R_{V.i} * Q_i^2. \quad (12)$$

Suction line resistance $R_{V.i}$ calculated as:

$$R_{V.i} = K_{COR.i} * A_{REL.i} * L_{V.i}, \quad (13)$$

where

$K_{.CORi}$ –correction factor to the values of resistivity;

$A_{REL.i}$–steel pipe relative resistance of the$i$-th pump unit;

$L_{V.i}$ –suction pipe length of the$i$-th pump unit.

The correction factor is in accordance with the formula: $K_{COR.i} = 0.8144 * \vartheta_i^{-0.0884}$ (14),
where
ϑ_i – the speed of water movement in the pipeline of the i-th pump unit, which is defined as:

$$\vartheta_i = Q_i / [0.785 * (D_{vi}/1{,}000)^2], \quad (15)$$

where
D_{vi}–inner diameter of the suction line of the i-th pump unit.
The specific resistance of a steel pipeline is calculated by the expression:
$A_{REL.i} = 0.001478/(D_{vi}/1{,}000)^{5.226}$ (16)
Head loss in communication pipeline of the i-th pump unit is defined as:

$$h_{k.i} = R_{k.i} * Q_i^2; \quad (17)$$

$$R_{k.i} = K_M * K_{COR.i} * A_{REL.i} * L_{k.i}, \quad (18)$$

where
$R_{k.i}$–pressure head communication line resistance of the i-thpump unit;
K_M–coefficient that takes into account pressure losses in local resistances (gate valve, check valve, places of smooth turning, gradual expansion or narrowing, etc.) of pressure pipelines;
$L_{k.i}$–length of pressure communication pipeline of the i-thpump unit.
For this type of discharge line $A_{REL.i}$, $K_{COR.i}$ are calculated by formulas (16) and (14), respectively, using the size (in mm) of the inner diameter of the communication pipeline $D_{k.i}$.
Due to the complexity of the hydraulic phenomena occurring in the pressure pipelines of the pumping station of machine water lifting systems, each local resistance is characterized by its own loss factor, which is usually determined empirically or, in some cases, can be calculated from theoretical data. Wherein K_M for each specific pumping unit of machine water lifting systems taking into account the design of the entire complex of the pipeline pressure network and bearing in mind the presence of certain types of local resistances, which, as a rule, are determined from special reference literature [6,7,8].Head loss in the supply pressure pipelineof the i-th pump unit is calculated in the same way as above using the formula:

$$h_{P.i} = R_{P.i} * Q_i^2; \quad (19)$$

$$R_{P.i} = K_M * K_{COR.i} * A_{REL.i} * L_{P.i}, \quad (20)$$

where
$R_{P.i}$– thepressure supply line resistanceof the i-thpump unit; $L_{P.i}$–thelength of the supply pressure lineof the i-thpump unit.
For the considered type of design of the pressure pipeline $K_{COR.i}$ and $A_{REL.i}$ are calculated in the same way by formulas (14) and (16) taking into account the size of the inner diameter of the supply pressure pipeline D_{pi}.
Based on the ratios obtained above, the averaged total head losses in the pipelines of the pumping unit of machine water lifting systems to their point of connection to the common pressure network is determined by the expression:

$$h_{\Sigma S} = \frac{\sum_{i=1}^{N}(h_{V.i}+h_{k.i}+h_{P.i})}{N} = \frac{Q_{PU}^2}{N} * \sum_{i=1}^{N}(R_{V.i} + R_{k.i} + R_{P.i}) \quad (21)$$

Provided that all pumping units are equipped with the same type and identical hydraulic power equipment with the appropriate characteristics, the total head loss $h_{\Sigma S}$ can be expressed through the flow rate Q_c pumping unit in thefollowing form:

$$h_{\Sigma S} = \frac{1}{N^3} * Q_T^2 * \sum_{i=1}^{N}(R_{V.i} + R_{k.i} + R_{P.i}). \quad (22)$$

The head loss in the general hydraulic pressure network of the pumping unit of the machine water lifting systems is expressed by the equation: $h_{ons} = R_{\text{íá}} * Q_T^2$, (23)
where
$R_{cmn} = K_M + K_{COR} + A_{REL} + L_{cmn}$; (24)
R_{cmn}–the resistance of the common pressure network of the pumping unit of the machine water lifting systems;
L_{cmn}–the length of the general pressure network of the pumping unit of the machine water lifting systems.
When a pumping unit of machine water lifting systems is operating, the operating point of its operation is determined by the total flow rate-pressure characteristic of the pumping unit and the characteristic of the pipeline hydraulic pressure network in accordance with the equality $H_{curr} = H_{RP}$ .This means that at a given operating point, the pressure developed by the pumping unit of machine water lifting systems is equal to the pressure required by the pipeline network in order to ensure the required supply. Therefore, the equation of the regime point, taken into account in the constraints (10), will take the form:

$$H_c = H_s + [R_{cmn} + \frac{1}{N^3} * \sum_{i=1}^{n}(R_{V.i} + R_{k.i} + R_{P.i})] * Q_c^2. \quad (25)$$

4. Conclusion

Thus, all the necessary analytical expressions required for the formation of a mathematical model of a pumping unit for machine water lifting systems have been determined in the form of the dependence of the specific consumption of electrical energy on the design, operational and technological parameters of its functioning, which allow to optimize and study the operating modes of the pumping unit to ensure energy-resource saving of the system machine water lifting.

References

1. Karelin V. Ya., Minaev A. V. Pumps and pumping stations. -M .: Stroyizdat, 1986.-320 s.
2.Khamudkhanov M.M. Mathematical modeling of a pumping unit for electric machine irrigation systems // Bulletin of Tashkent State Technical University, 2011. № 1-2. S.53-58.
(3) Kamalov T.S., Khamudkhanov M.M. Electric drive system of pumping units for irrigation. -Tashkent: "Fan", 1985. -96 p.
4.Kamalov TS, Khamudkhanov MM, Akhmedov I. Guidelines for standardizing specific rates of electrical energy consumption and forecasting energy consumption by pumping stations, cascades of pumping

stations, wells and by planning levels. - Tashkent: Uzinformenergo, 1990.-- 79 p.
5.Khamudkhanov M.M., Youssef Rabah. Method of calculating constant coefficients of approximation of pump performance // Avtomatlashganelectryuritma. ToshDTUIlmiyIshlarTўplami, -Toshkent, 1994.B. 92-96.
6. Hoshimov, F.A., Bakhadirov, I.I., Erejepov, M., Djumamuratov, B. (2019) Development of method for normalizing electricity consumption *E3S Web Conf* **139** doi:10.1051/e3sconf/201913901074
7. Hoshimov, F.A., Bakhadirov, I.I., Erejepov, M., Djumamuratov, B. (2019) Development of method for normalizing electricity consumption *E3S Web Conf* **139** doi:10.1051/e3sconf/201913901074
8 VilnerYa.M., KovalevYa.T., Nekrasov B.B. Reference manual for hydraulics, pumps and hydraulic transmissions. -Minsk: Higher school, 1985. -384 p.