Improving the reliability of the operation of reclamation pumping stations by using self-starting electric motors

Kudrat Abidov*

Tashkent State Technical University named after Islam Karimov, 100095, Uzbekistan, Tashkent, University St. 2A

Abstract. The results of full-scale studies of unsteady processes during self-starting of electric motors at pumping stations are presented. The simulation of transient processes in the modes of self-starting of an asynchronous electric drive of a pumping unit is considered in order to identify the nature of the change in flow, pressure and moment of resistance on the pump shaft in the noted modes. The transient processes in the run-down modes when the pump loses the drive, as well as the self-starting of the asynchronous electric drive of the pumping unit, are investigated. In order to improve the technical and operational performance of reclamation pumping stations, the necessity of using the self-starting mode of electric drives of pumping units is substantiated.

1 Introduction

Solving the issue of self-starting of electric motors of pumping units is very important for preventing mass shutdown of consumers and ensuring the uninterrupted operation of modern large pumping stations during short-term power outages. Successful implementation of self-starting of electric motors of critical mechanisms after a short interruption of power supply and a deep voltage drop will minimize damage and ensure reliable operation of the station [1-4]. It is convenient and economical to study the main characteristics of the processes of self-starting of electric motors of pumping units by means of mathematical models on a computer [2-6], taking into account changes in the initial parameters. Field studies of the self-starting process of electric motors are more laborious and expensive, however, they are necessary to assess the reliability of the accepted mathematical model. In this regard, this paper presents the results of field studies of unsteady processes during self-starting of electric motors at pumping stations [7-9].

2 Experimental research

To solve the issue of self-starting, experiments were carried out at typical Amu-Zang pumping stations in the Surkhandarya region of the Republic of Uzbekistan, where asynchronous electric motors of the DAZO-15-59-YUY1 type, U_N=6kV, P_N=630kW, n_N=595 rp/m, I_N=80 A.

At these stations, during short-term power outages, all 16 motors are switched off by relay protection. The valves do not close and the pump units run in coast mode [8-10].

This negatively affects many units of the units (gland packings fail, fastening units relax, etc.), which leads to a large expenditure of time and money to restore the working condition of the units.

The experiments were carried out on one pumping unit No.11 at different values of the time delay, which varied within 1.5-14.5 s. The frequency of rotation on the pump shaft, the stator current, the overrun time, and the self-start time were oscillographed [11-13].

Data processing oscillograms self-start motor DAZO are shown in Table 1.

Table 1.

n=595 rp/m, $I_{n,}$=80A	$t_{off,}$c	$t_{self,}$c	$n_{self,}$ rp/m	$I_{self,}$ A
1	1,5	0,4	379	573
2	2,2	0,56	333	640
3	7,5	1,04	153	660
4	11,5	1,16	117	680
5	14,5	1,5	54	693

The pumping station under consideration consists of 16 pumps of the 24 NDS type and asynchronous motors of the DAZO type. All engines of the pumping station are powered by one substation. It can be seen from the oscillogram that the multiplicity of the starting current and the duration of self-starting increase with increasing voltage off time. Oscillograms of the self-starting process for a pause time of 1.5 and 2.2 s are shown in Fig.1.

Although non-return valves are installed on these units, increasing the holding time leads to an increase in the starting current and starting duration. It was agreed to re-close the oil circuit breaker at the input of the substation of transformer T_1, which is 1.5 s, taking this

---

[*] Corresponding author: raxmatillo82@mail.ru

into account, the delay time of the self-starting device was set to 2 s.

In the course of the experiment, an experiment of self-starting on an open valve was carried out. The self-starting process of pumping unit №6 was carried out with a power interruption t_{off}=2.2s. Self-start time t_{self}=2.4 s. The current surge during self-starting was 6.3 I_{nom}. The rotational speed at the moment of self-starting is n_{self}=380 rp/m. The duration of the transient process from the moment the voltage is off is 4.6 s.

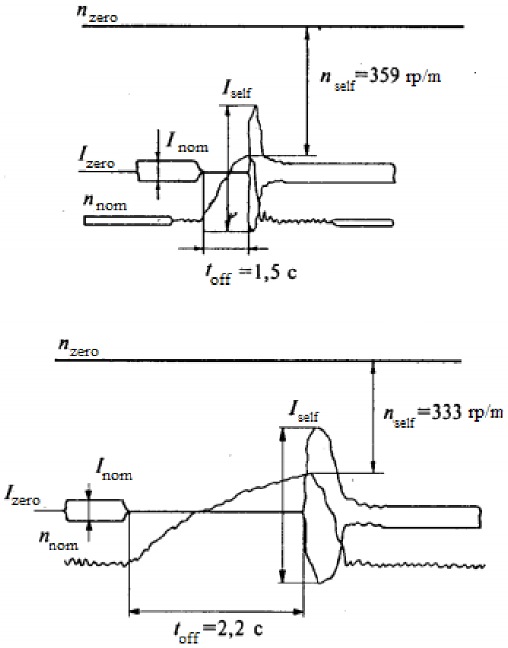

Fig. 1. Self-starting of the asynchronous motor DAZO-15-59-10U1

The maximum pressure value during self-starting on the discharge pipeline is 1.6 H_{nom}. When self-starting, the pressure pulsation on the pressure pipeline is set in 7.3 s. In addition to unit №6, tests were carried out on units № 1,2,4,9, the results of which are given in Table. 2.

Table 2.

Tested pumping unit	$n_{self.}$, rp/m	I^*_{self}	t_{off},c	t_{self}, c	H^*
№6	380	6,3	2,2	2,4	1,6
№6	190	6,4	4,5	3,5	1,6
№1	480	5,5	1,2	1,5	
№2	467	5,9	1,3	1,7	
№4	380	6,3	2,2	2,4	
№9	190	6,4	4,8	4,1	
* Multiple of nominal value					

To study the self-starting process of the pumping unit, as well as to clarify the nature of the flow of hydromechanical and electromechanical processes, an experimental stand was created with a 1.5K-6 pump and a KAM-30 electric motor. Oscillograms of self-starting of the electric motor of the pumping unit are shown in fig. 2, and the data corresponding to the experimental study - in table. 3.

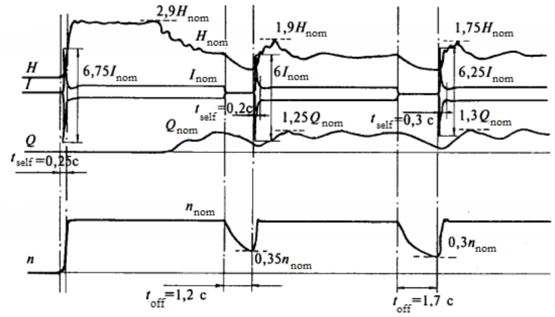

Fig. 2. Oscillogram of self-starting obtained on an experimental stand

Table 3.

Mode	t_{off}, c	t_{off}, c	n_{self} multiple	$I_{n.}$ multiple	$H_{n.}$ multiple	$Q_{n.}$ multiple
Closed valve start	-	0,25	-	6,75	2,9	-
Self start	1,2	0,2	0,35	6	1,9	1,25
Self start	1,7	0,3	0,3	6,25	1,75	1,3
self start	3,3	0,32	0,04	6,33	1,8	1,17
Self start from turbine mode	16,7	0,4	0,3 back hijacking	0,4	1,8	1

The value of the pressure of the hydraulic shock is less than the manometric pressure of the pump developed when it is operated on a closed valve. This is due to the fact that the hydraulic resistance in the pumping unit during self-start does not change instantly. It depends on the starting speed of the machine. Therefore, the hydraulic shock is incomplete. In the experimental setup, the length of the pressure pipeline is relatively short; during self-start, the fluid flow rate changes slowly [13-15].

This paper also considers the simulation of transient processes in the modes of self-starting of an asynchronous electric drive of a pumping unit in order to identify the nature of the change in flow, pressure and moment of resistance on the pump shaft in the noted modes. In these modes, hydraulic, mechanical, electromagnetic transients occur. The results of the study show that the hydromechanical time constant is much greater than the electromagnetic one. Therefore, the electromagnetic time constant of the windings of an asynchronous motor in the self-starting mode is not taken into account.

The hydraulic transient process, taking into account the elasticity of water and the walls of pressure conduits, can be described in the form [14-17], where the relationship between the change in pressure and the velocity of water in the pipeline is determined by the formula:

$$\Delta H = \frac{a}{g}\Delta\vartheta; \tag{1}$$

The hydraulic shock process has a wave character and is described by partial differential equations:

$$\begin{cases} -\dfrac{\partial\vartheta}{\partial t} = g - \dfrac{\partial H}{\partial x} \\ \dfrac{\partial\vartheta}{\partial x} = \dfrac{g}{a^2}\dfrac{\partial H}{\partial t} \end{cases} \tag{2}$$

The general solution of the system has the form:

$$\begin{aligned} &H = H_0 + \varphi - \psi; \\ &\vartheta = \vartheta_0 - \frac{g}{a}(\varphi + \psi); \end{aligned} \tag{3}$$

where H - pressure; ϑ - is the speed of water movement in the pipeline; t - is the time since the occurrence of hydraulic shock; a - is the propagation velocity of shock waves; g- is the acceleration due to gravity; x - is the distance from the origin; φ - equivalent waves of pressure increase; ψ - equivalent pressure reduction waves.

In addition, the hydraulic transition process is described by the equation of unsteady motion of an incompressible fluid:

$$H{=}H_g{+}h_M{+}h_L{+}h_i \tag{4}$$

where H -is the pump head; H_g - geometric pressure; h_i is the inertial head; $h_M + h_L$ head loss.

The equation of the mechanical transient process is described by the equation of motion of the unit in an unsteady mode:

$$M_{el} - M_g - M_f = \frac{GD^2}{375}\frac{dn}{dt} \tag{5}$$

where M_{el}.-torque of the engine, is determined by the starting characteristic of the engine; M_g - hydraulic moment of the pump; M_f - the moment spent on friction in the seals and bearings of the unit.

The torque of an asynchronous motor is determined by the well-known expression [5, 18-20]:

$$M_{el} = \frac{3(I_2^{'})^2 R_2^{'}}{\omega_0 S}$$

where $I_2^{'}$-is the reduced rotor current; $R_2^{'}$ - reduced active resistance of the rotor; ω_0 - synchronous angular speed of the motor; S - engine slip.

To determine the hydraulic moment M_g, a four-square characteristic of the pump is used in the form of dependencies between the reduced flow rate Q, rotational speed n, hydraulic moment M:

$$\bar{n} = f(\bar{Q});\cdot \quad \bar{M} = f(\bar{Q}). \tag{6}$$

Self-starting will be successful if the motor accelerates to rated speed after voltage recovery and the following conditions are met:

1) normal voltage in the pump impeller;
2) heating of the motor windings at a normal level;
3) the torque of the motor ensures the acceleration of the motor to the nominal speed;
4) allowable value of pressure in pipelines.

3 Research results

Mathematically simulating the process of self-starting and setting the duration of a power interruption at different time intervals, we determine the maximum duration at which self-starting is impossible. In this case, one of the conditions for a successful self-start is no longer fulfilled. Knowing this time, you can correctly set the automatic operation mode when the voltage is restored. To accurately determine the break time limit, it is necessary to simulate a self-start simulation, taking into account all the accepted conditions.

Figure 3 shows the characteristic of the process with a break interval t_{of}=2 s, built according to the calculated data $H{=}f(t)$, $Q{=}f(t)$, $n{=}f(t)$, $M{=}f(t)$ for an asynchronous electric motor of the type DAZO-15-59-10У1, U_N=6 kV, P_N=630 kW, n=595 rp/m, I_N=80 A, and centrifugal pump type 24НДС [8, 21-22]. At the moment the engine is turned off, M_{el} instantly drops to zero. The hydraulic moment of resistance of the pumping unit, M_g, and the frictional moment, M_g, shown as M in the timing diagram, are saved. This leads to a decrease in the rotational speed n of the pump and the developed pressure H, due to which the flow Q decreases. Although the parameters n, H, Q decrease, the unit mode remains "pumping". In this time interval, when the electric motor is turned on, the second stage begins, self-starting. Under the action of the torque M_{el} of the engine, the pumping unit is accelerated to a steady state.

The results of full-scale research and computer simulation in terms of speed parameters n (Fig. 1 and Fig. 3) coincide.

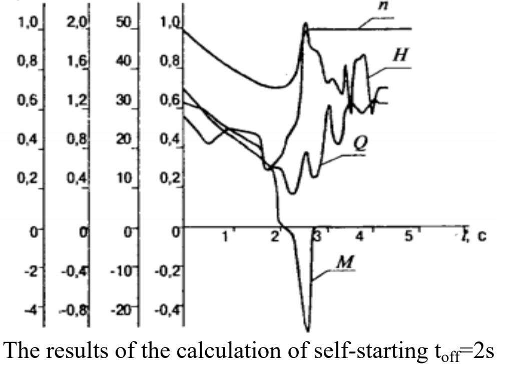

Fig.3. The results of the calculation of self-starting t_{off}=2s

Figure 4 shows the characteristics of the transient process of self-starting at a break interval t_{of} =5 s. The pumping unit operating in the steady state is disconnected from the network - this is the first stage of the calculation and the torque of the M_{el} engine instantly drops to zero, while the hydraulic moment of resistance of the M_g pumping unit and the friction moment M_{f} are preserved.This leads to a decrease in the rotational speed n of the pump and the developed pressure H, due to which the flow Q decreases.At point *b* (Fig.4), the rotation frequency decreases so much that the pump flow becomes equal to zero, then the water begins to move along the conduits and through the impeller from the upstream to the downstream, i.e. in the turbine direction.But the direction of rotation is kept "pumping". Since in this mode the throughput of the pumping unit drops sharply, the pressure in the spiral chamber, the pressure H, the hydraulic moment M_g increase. At point *c*, the electric motor is switched on - the second stage begins. Under the action of the engine torque M_{el}, the pumping unit is accelerated to a steady state. From the point with the difference M_{el}-M_g-M_f=M_{din} creates a dynamic accelerating moment, under the influence of which the pump flow slows down and begins to decrease in the "turbine" mode [5-10, 23].

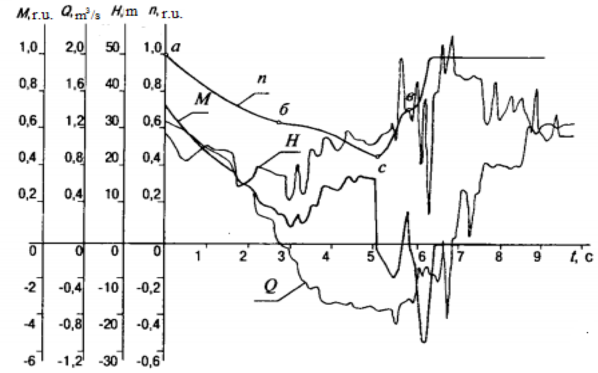

Fig.4. The results of the calculation of self-starting t_{off}=5 s

There is a sharp increase in pressure H, at point c M_g prevails, M_f and M_{din} becomes negative, the acceleration of the pumping unit at this point slows down sharply.Then M_{el} prevails and the speed of the pumping unit reaches the nominal level, while $M_{din}=0$.In the interval *c-b* on the pressure curve, a process of increasing pressure is observed, which has a wave character, which is explained by the action of a direct wave of hydraulic shock in the pressure pipeline.

4 Conclusion

1. The response time of the automatic reclosure of the electrical network for self-starting is determined from the mode run-out of a specific pumping unit, while it is necessary to control the recovering voltage to a value that ensures successful self-start [11-20].

2. The self-starting system of electric motors must take into account technological limitations, the actions of technological protections and automatic restoration of the operation of auxiliary mechanisms. When designing and determining the conditions for their operation, it is necessary to take into account the influence of various types of transients, especially those caused by load shedding and drive shutdown [21-23].

3. An algorithm for calculating the self-starting mode of a pumping unit with an asynchronous electric drive has been compiled.

References

1. K.G.Abidov, O.O.Zaripov, and ofters. AIP Conference Proceedings, 2552, **030023**, (2022), https://doi.org/10.1063/5.0112385
2. K.G.Abidov, O.O.Zaripov, and ofters. AIP Conference Proceedings, 2552, **030022**, (2022), https://doi.org/10.1063/5.0112384
3. K.G.Abidov, O.O.Zaripov, and ofters. E3S Web of Conferences, 289, **07003**, (2021), https://doi.org/10.1051/e3sconf/202128907003
4. K.G.Abidov, and ofters. E3S Web of Conferences, 289, **07004**, (2021), https://doi.org/10.1051/e3sconf/202128907004
5. K.Abidov, N.Khamudkhanova. E3S Web of Conferences, 216, **01111**, (2020), https://doi.org/10.1051/e3sconf/202021601111
6. K.G.Abidov, O.O.Zaripov, and ofters. E3S Web of Conferences, 216, **01110**, (2020), https://doi.org/10.1051/e3sconf/202021601111
7. K.G.Abidov, O.O.Zaripov. E3S Web of Conferences, 139, **01088**, (2019), https://doi.org/10.1051/e3sconf/201913901088
8. K.G.Abidov, A.K.Nuraliev, and ofters. Journal of Advanced Research in Dynamical and Control Systems, **12(7)**, pp. 2167-2171, (2020).
9. R.Karimov. AIP Conference Proceedings, 2552, **030014**, (2022). https://doi.org/10.1063/5.0111533
10. R.Karimov. AIP Conference Proceedings, 2552, **050012**, (2022). https://doi.org/10.1063/5.0111524
11. S.Dzhuraev, R.Karimov, and ofters. ElConRus, (2022), pp. 1166-1169, doi: 10.1109/ElConRus54750.2022.9755782
12. R.Karimov, A. Kuchkarov, and ofters. Journal of Physics: Conference Series 2094, **052050**, (2021). doi:10.1088/1742-6596/2094/5/052050
13. R.Karimov, N.Kurbanova, and ofters. Journal of Physics: Conference Series 2094(5), **052042**, (2021). doi:10.1088/1742-6596/2094/5/052042
14. E.Kh.Abduraimov, D.Kh.Khalmanov. Journal of Physics: Conference Series, 2373(7), **072010,** (2022), DOI 10.1088/1742-6596/2373/7/072010

15. E.Kh.Abduraimov. Journal of Physics: Conference Series, 072009, 2373, (2022), DOI 10.1088/1742-6596/2373/7/072009
16. E.Abduraimov, M.Peysenov, N.Tairova. AIP Conference Proceedings, 2552, **040012**, (2022), https://doi.org/10.1063/5.0116235
17. E.Kh.Abduraimov, D.Kh.Khalmanov. Journal of Physics: Conference Series, 2094(2), **022072**, (2021), DOI 10.1088/1742-6596/2094/2/022072
18. E.Kh.Abduraimov, D.Kh.Khalmanov, and ofters. E3S Web of Conferences, 289, **07026**, (2021), https://doi.org/10.1051/e3sconf/202128907026
19. E.Kh.Abduraimov, D.Kh.Khalmanov. E3S Web of Conferences, 216, **01106**, (2020), https://doi.org/10.1051/e3sconf/202021601106
20. E.Kh.Abduraimov. E3S Web of Conferences, 216, **01105**, (2020), https://doi.org/10.1051/e3sconf/202021601105
21. E.Kh.Abduraimov, D.Kh.Khalmanov. Journal of Physics: Conference Series, 1515(2), **022055**, (2020), DOI 10.1088/1742-6596/1515/2/022055
22. A.K.Nuraliev, and ofters. E3S Web of Conferences, 216, **01108**, (2020), https://doi.org/10.1051/e3sconf/202021601108
23. M.Ibadullaev, A.Nuraliev, A.Esenbekov. IOP Conference Series: Materials Science and Engineering, 862(6), **062031**, (2020), DOI 10.1088/1757-899X/862/6/062031