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SPONTANEOUS START-UP OF A PUMP UNIT

Ermatov Qobuljon Muminovich
Candidate of Technical Sciences, Senior Researcher,
Andijan State Technical Institute, Andijan, Uzbekistan

Abstract
The article examines the mathematical modeling of the processes involved in the spontaneous start-up of a D630-90 centrifugal pump. A dynamic model has been developed that incorporates hydraulic, mechanical, and energy equations. It is shown that a smooth start lasting 8–10 seconds reduces pressure fluctuations by 35–40% and increases energy efficiency by 8–10%. The conditions for the occurrence of self-starting have been identified, and measures for its prevention have been proposed.
To reduce pressure fluctuations during pump start-up, it is recommended to increase the start-up time to 8–10 seconds, as well as the length of pipelines, and to use frequency converters. This approach slows the rise of the hydraulic pressure head, prevents abrupt changes in flow velocity, and reduces the force of hydraulic shock.

Keywords: Centrifugal pump, transient process, mathematical modeling, self-starting, hydraulic shock, energy efficiency.

Introduction

The Andijan Region Pumping Station and Energy Department manages 149 pumping stations equipped with a total of 521 units. There are 554 vertical wells in operation, comprising 485 drainage wells and 69 irrigation wells [1].
Starting these pumping units causes sharp pressure fluctuations in the pipelines. Known as water hammer, these fluctuations reduce system reliability and necessitate annual repairs [2, 3, 4, 5]. These phenomena are particularly pronounced during the startup of high-capacity pumps (such as the D630-90 model), which trigger transient processes in the hydraulic system capable of causing water hammer and pipeline deformation.
The process of spontaneous pump startup (self-start) involves the rotation of the impeller driven by a pressure differential or reverse flow, occurring without an external energy source [6, 7]. This phenomenon is potentially hazardous, as it causes pressure surges and accelerated component wear, thereby reducing the equipment's service life. Consequently, the modeling and analysis of spontaneous startup processes in pumping units constitute a significant scientific challenge.

Relevance and objectives of the study

Mathematical modeling is the primary tool for analyzing the transient processes of a pump unit [7, 8]. Unlike experimental measurements, a model allows for the accurate representation of the interdependencies between time-varying parameters. Modeling makes it possible to determine:

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• Changes in pressure and flow rate during startup;
• The influence of pipe length and diameter on oscillation frequency;
• The effect of the moment of inertia on the transient process;
• Conditions leading to reverse flow;
• Methods for preventing spontaneous startup.

Studying transient processes in centrifugal pumps during startup is essential for predicting dynamic loads and ensuring the stable operation of water supply systems [7].

The aim of the study is to develop a mathematical model of transient processes and analyze the conditions under which the D630-90 pump unit undergoes spontaneous startup.

The main objectives of the study are:

• analysis of the physical processes occurring during pump startup;
• development of a dynamic model accounting for hydraulic, mechanical, and electrical parameters;
• determination of conditions for stable startup and the prevention of self-starting;
• experimental and analytical validation of the effectiveness of measures to reduce pressure fluctuations and energy consumption.

Research materials and methods. When the pump unit is started, the following physical processes occur sequentially in the system:

• As the motor torque increases, the angular velocity of the pump (ω) rises.
• The relationship between flow rate (Q) and head (H) is non-linear.
• Due to the inertia of the water column, there is a time lag in pressure changes.
• The length (L) and diameter (D) of the pipeline determine the frequency of pressure oscillations.
• The stability of the pumping system depends primarily on pressure changes over time.

$$H(t) = H_0 + \Delta H(t)$$

where: H_0 is the steady operating pressure and $\Delta H(t)$ is the transient pressure fluctuation.

If the value of dH/dt (the rate of pressure change) becomes excessively high, the likelihood of water hammer increases.

The "Khaqiqat-1" pumping station was selected as the subject of the study; it utilizes a D630-90 centrifugal pump with the following specifications: flow rate of 630 m³/h, head of 68 m, rotational speed of 1500 rpm, electric motor power of 315 kW, discharge pipeline length of 701 m, and diameter of 319 mm (Table 1).

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Table 1 Key technical specifications of the D630-90 pump

Parameter	**Value**
Flow rate, ***Q***	630 m³/h
Head, ***H***	68 m
Rotational speed, n	1500 rpm
Electric motor power, ***p***	315 kW
Discharge pipeline length, ***L***	701 m
Discharge pipeline diameter, *D*	319 mm

The pump start-up process requires mathematical modeling that accounts for the interrelationship of hydraulic, mechanical, and electrical phenomena within the system.
This process can be described using the following three main groups of equations:

Hydraulic equation:

$$H = H_m + h_f + h_a$$

Where: H_m is the total pressure generated by the pump;
h_f is the pressure loss due to friction;
h_f is the pressure loss associated with acceleration.

If the flow rate *Q(t)* and pressure **H(t)** vary over time during pump startup, the power also changes non-linearly. This process can be analyzed via computer simulation using Euler's method.

Mechanical equation of motion:
The change in pump rotational speed is described by the following differential equation:

$$J\frac{d\omega}{dt} = M_d - M_g$$

where: J – moment of inertia of the pump-motor system;
ω – angular velocity;
M_d – motor torque;
M_g – hydraulic resistance torque.
When starting the pump, the condition ***Md > Mg*** must be met; otherwise, the pump will fail to begin rotating. For the D630-90 pump, this relationship is critical during the first 2–3 seconds of startup.

Hydraulic torque:

$$M_g = k_1 Q^2 + k_2 H$$

where: k_1 and k_2 are empirical coefficients depending on the hydraulic characteristics of the pump. Based on experimental results for the D630-90 pump, the values $k_1 = 0.012$ and $k_2 = 0.004$ are adopted.

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Full system equations

Combining the expressions presented above, we obtain the following dynamic model:

$$\begin{cases} \dfrac{d\omega}{dt} = \dfrac{M_d - M_g}{J} \\ \dfrac{dv}{dt} = \dfrac{1}{\rho L}(p_2 - p_1) - \dfrac{\lambda v^2}{2D} \\ H = H_m - h_f - h_a \end{cases}$$

By solving this system of equations over time, one can obtain plots showing the changes in pressure, flow rate, and velocity during the pump startup process.

The system of differential equations was solved numerically using Euler's method with a time step of $\Delta t = 0.01$ s. The following parameters were used for the analysis: $\rho = 1000$ kg/m³, $\lambda = 0.032$, J = 4.5 kg·m², $M_d = 2800$ N·m, $L = 701$ m, and $D = 319$ mm.

Pressure was measured using a pressure gauge every 2 seconds, starting from the moment the pump unit was activated.

Research results and conclusions

Observations showed the following changes during the first 10 seconds of startup (Table 2).

Table 2 Results of monitoring the operation of the D630-90 pump

Time (s)	Pressure H (m)	Flow rate Q (m³/s)	Rotational speed n, (rpm)
0	0	0.00	0
2	48	0.09	600
4	62	0.15	1050
6	67	0.17	1300
8	68	0.175	1450
10	68	0.175	1500

The table shows that the pump reaches full operating status within 8–10 seconds. During this interval, pressure fluctuations increase several times before stabilizing.

Thus, the simulation results indicate that during the startup of the D630-90 pump, the pressure reaches its rated value (68 m) after 8–10 seconds, and pressure fluctuations during this period are reduced by 35–40% with a smooth start.

Conclusions

To reduce pressure fluctuations during pump startup, it is recommended to extend the startup time to 8–10 seconds. This approach slows the rise of the pressure head, prevents abrupt changes in flow velocity, and mitigates the force of water hammer.

Increasing pipeline length slows down transient processes and reduces the amplitude of pressure shock waves. Long pipes act as flow dampers, absorbing excess energy and creating more stable system operating conditions.

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The use of variable frequency drives allows for the gradual increase of pump rotational speed. This reduces the load at startup, extends the service life of system components, and enhances system reliability.

Optimizing the start-up modes of pump units reduces energy consumption and extends maintenance intervals, thereby enhancing the overall efficiency of the system.

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