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Development of the pump protection system against cavitation on the basis of the stator current signature analysis of drive electric motor

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Development of the pump protection system against cavitation on the basis of the stator current signature analysis of drive electric motor

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Abstract. In the present paper a new registration method of such inadmissible phenomenon as cavitation in the operating mode of centrifugal pump is offered. Influence of cavitation and extent of its development on the value of mechanical power consumed by the pump from the electric motor is studied. On the basis of design formulas the joint mathematical model of centrifugal pumping unit with the synchronous motor is created. In the model the phenomena accompanying the work of a pumping installation in the cavitation mode are considered. Mathematical modeling of the pump operation in the considered emergency operation is carried out. The chart of stator current of the electric motor, depending on the degree of cavitation development of is received. On the basis of the analysis of the obtained data the conclusion on the possibility of registration of cavitation by the current of drive electric motor is made and the functional diagram of the developed protection system is offered, its operation principle is described.

1. Introduction

Centrifugal pumping installations are the most often used units at the enterprises of different technology orientation [1]. Such pumping installations are widely used in different brunches of industry and life support: in water disposal systems of mines, open-pit mines, pits, in urban pumping stations (also cold water supply, the sewerage), at combined heat and power plant, state district power plant, the NPP (circulating, feeding, condensate, etc. pumps), at the plants of petrochemical, metallurgical, food industry for pumping of different liquids.

In some cases centrifugal pumps are especially responsible units. These include pumps for urban water supply systems, circulating pumps for nuclear power plants, drainage of mining enterprises, pumps for cooling systems for blast furnaces. High requirements to reliability and uninterrupted operation of work cause need of development and designing of protection systems of pumping installations against abnormal and emergency operation of work.

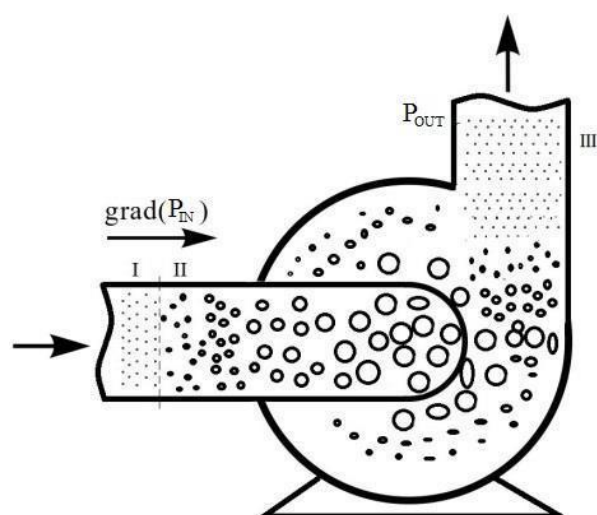
It is reasonable that the system of protection includes the minimum quantity of elements, in particular – sensors. In the existing schemes of control and protection sensors are the most vulnerable elements of the system from the point of view of failure.

The requirement to minimize the number of elements can be met by a system created on the basis of the method of indirect diagnostics of the equipment operation – stator current control of the drive motor. Such a system in its composition will have only the protection device itself (based on a microprocessor terminal or some other electronic device) and a measuring transducer.

One of the most dangerous for centrifugal pumping units is the mode of cavitation. Cavitation is a violation of the continuity of the fluid that occurs in sections of the stream where the pressure, falling, reaches a certain critical value [2]. When the pump sucks liquid from the reservoir, the pressure in the suction pipeline of the P_{IN} drops below atmospheric pressure [3].

In figure 1 emergence of cavitation in the pump is shown. In the pipeline the pressure gradient takes place. At the beginning of the pipeline pressure is close to atmospheric, and the closer to the pump – the discharge is greater. In process of advance of liquid in the pump its pressure can become less than the pressure of the liquid saturated steam under existing conditions.

In this case there is a cold boiling up of liquid. Along with it there is an emission of the dissolved gas from the liquid. The bubbles filled with saturated steam are formed. The lower the pressure drops, the more bubbles increase in volume, turning into large bubble-caverns. Further, the bubbles are carried away into the zone of high pressure (forcing pressure) of P_{OUT} beginning at the exit from a pump wheel where instantly disappear due to condensation of the vapors filling them. Thus, in the flow there is a fairly narrowly limited cavitation zone. This phenomenon is characterized by vibrations and noises. With a strong development of cavitation, flow disruption and pump shutdown can occur [1, 2].



I - a zone of reduced pressure without cavitation;

II - a zone of reduced pressure with cavitation; III
- a pressure zone

Figure 1. Process of liquid cavitation in the pump.

When the caverns are collapsed on the surface of the impeller and the pump volute, a force attack – a hydroblow occurs. In this case, a pressure develops, the value of which has values exceeding the yield strength of the wheel and pump volute materials. The prolonged impact of cavitation leads to the destruction of the pump.

2. Modeling of behavior of stator current of the electric motor at cavitation

It is known that resistance moment on the shaft of the engine which is created by the pump can be determined by the following formula [2, 4]:

$$M_c = \frac{30 Q \rho g H}{\pi n \eta}, \quad (1)$$

where Q – pump flow, m^3/h ; ρ – liquid density, kg/m^3 ; H – pump pressure, m ; η – efficiency of the pump, n – rotating speed of the pump, RPM .

Also, it is known that when the positive suction head of the pump decreases, its head drops and its efficiency decreases, which is confirmed by the kink of the experimental curve given in [1, 3] (zone II).

As it can be seen from the graph, as the positive suction head decreases, the power consumed by the pump first increases and then falls sharply to the values close to the ones of the dry run, since with fully developed cavitation the flow breaks down and the pump stops pumping the liquid [1, 3].

On the basis of the above it is possible to draw a conclusion that current of the drive electric motor of the pump will change according to the change in the loading on its shaft [5, 6].

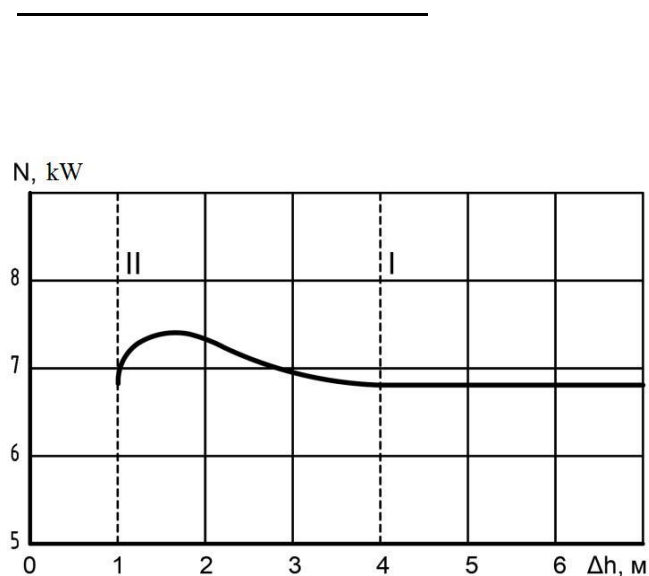


Figure 2. Dependence of the mechanical power consumed by the pump depending on a positive suction head.

For confirmation of this assumption in the software MatLAB Simulink modeling of work of pumping installation in the cavitation mode was carried out.

As a model of pumping installation the unit as a part of the pump AD4000-95-2S was used (pump flow – 4000 m³/h, pressure – 95 m) and synchronous motor SND 2-16-59-6U3 (1600 kW, 1000 RPM, 6 kV). The model of the engine is implemented on a two-phase system of the Park-Gorev' equations [7].

$$\begin{aligned}
 & \begin{cases} i_a = i_d \cos \gamma - i_q \sin \gamma \\ i_b = i_d \cos \left(\gamma - \frac{2\pi}{3} \right) - i_q \sin \left(\gamma - \frac{2\pi}{3} \right) \\ i_c = i_d \cos \left(\gamma + \frac{2\pi}{3} \right) - i_q \sin \left(\gamma + \frac{2\pi}{3} \right) \end{cases} \\
 & \begin{cases} \frac{d\psi_d}{dt} = \overline{U_d} - \omega \psi_q + r_1 i_d \\ \frac{d\psi_q}{dt} = \overline{U_q} - \omega \psi_d + r_1 i_q \end{cases} \\
 & \begin{cases} \frac{d\psi_f}{dt} = \overline{U_f} + r_f i_f \\ \frac{d\psi}{dt} = \overline{U_0} + r_{yd} i_{yd} + r_{yq} i_{yq} \end{cases} \\
 & \frac{d\omega}{dt} = \dots
 \end{aligned} \tag{2}$$

where i_a, i_b, i_c – phase currents of the stator, A; U_d, U_q – voltage on stator winding clips on longitudinal and cross axes; Ψ_d, Ψ_q, i_d, i_q – according to flux linkage and currents of windings of phases of the

stator on longitudinal and cross axes; r_1 – the active resistance of phase winding of the stator; U_f – voltage on field winding clips; Ψ_f, i_f – flux linkage and current of field winding; r_f – the active resistance of field winding; $\Psi_{yd}, \Psi_{yq}, i_{yd}, i_{yq}$ – according to flux linkage and currents of damper winding on longitudinal and cross axes respectively; r_{yd}, r_{yq} – active resistance of damper winding on longitudinal and cross axes; M – the electromagnetic moment, M_s – the moment of loading resistance, J – inertia moment of rotating masses, γ – the angular position of a rotor.

The system of the equations (4) accurately describes operation of the synchronous motor at a symmetric mode, is applicable to the considered case and is implemented in the form of the standard block from Simulink/Simscape/SimPowerSystems library.

The functional diagram of the model of pumping unit in the mode of cavitation is provided on the figure 3.

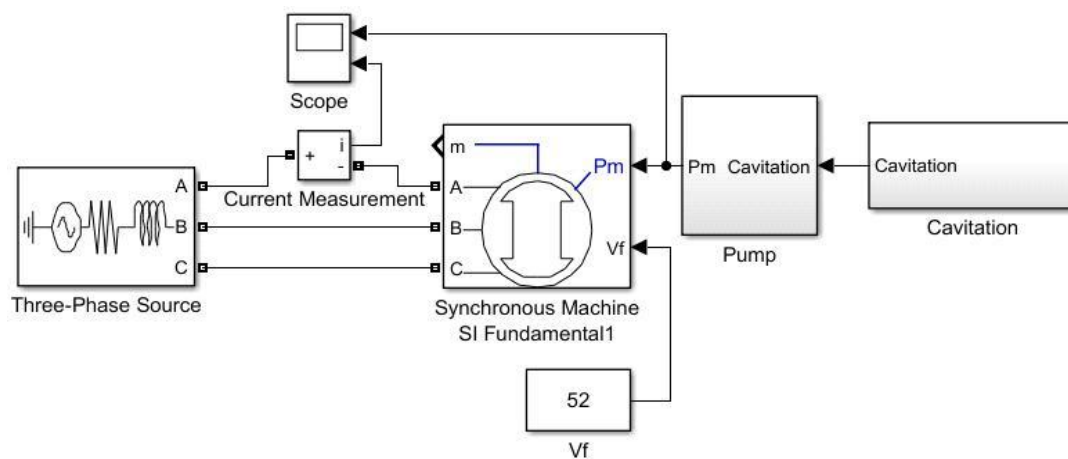


Figure 3. The functional diagram of the model of pumping unit in the mode of cavitation.

3. Results of modeling

The results of modeling of pump unit performance during the occurrence of the phenomenon of cavitation are given in the figure 4.

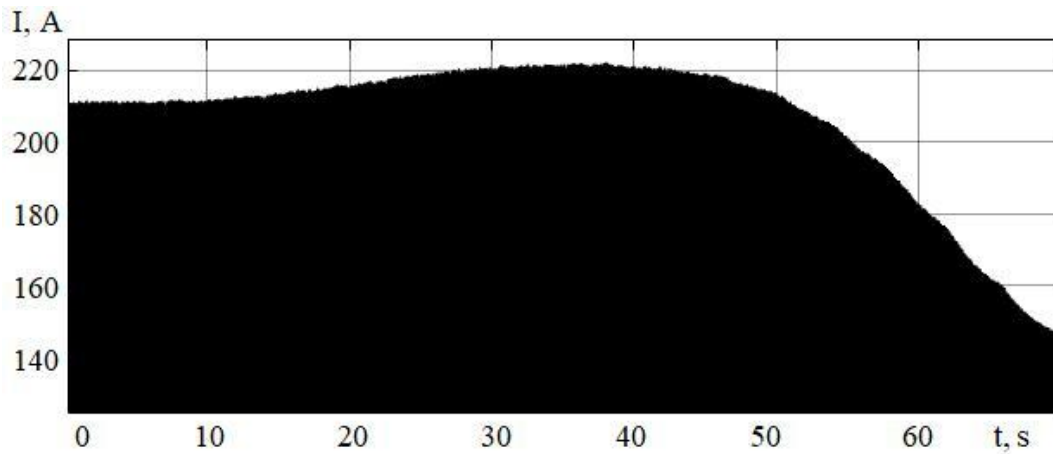


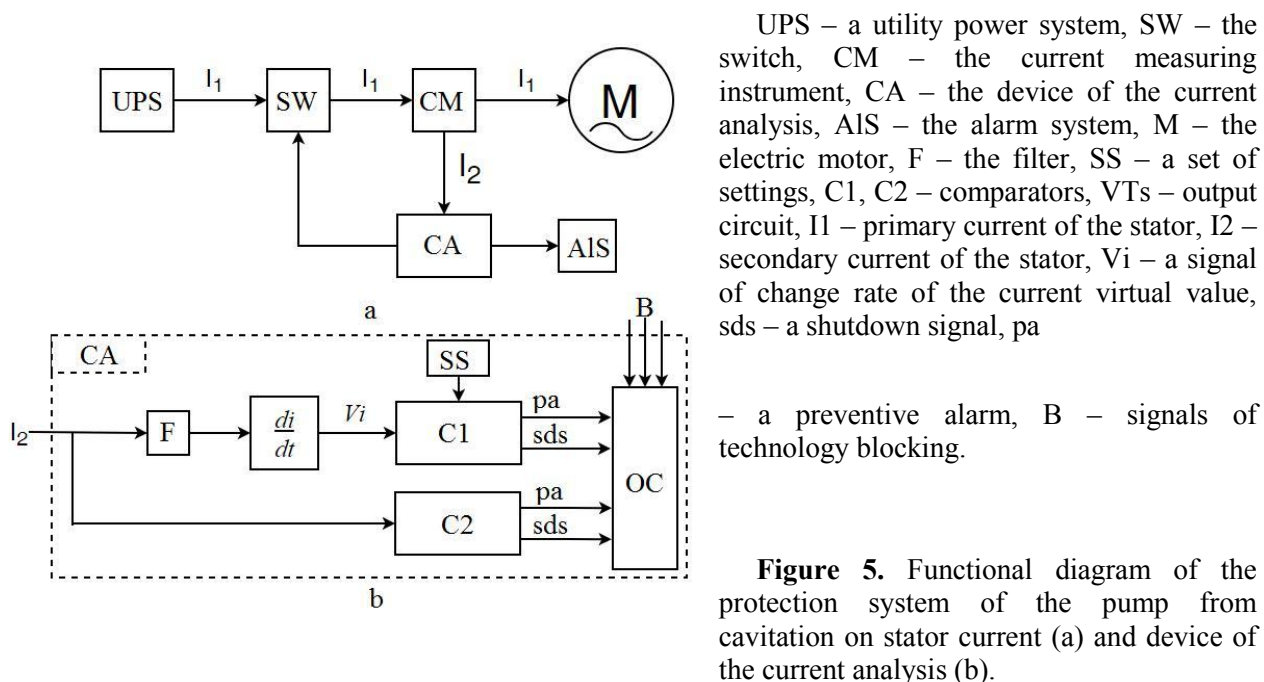
Figure 4. Diagram of the stator phase current of pump drive engine working during cavitation.

The diagram of the stator current, as expected, repeats with its own form the load curve on the motor shaft during cavitation.

Cavitation, which has just begun to develop, is technically difficult to detect with respect to the stator current, since some increase in the stator current in the initial section of zone II of figure 3 will be virtually indistinguishable from the increase in current caused by the increase of the torque on the shaft due to technological overload. However, the most dangerous developed cavitation can be identified by this method. Rapidly developing cavitation causes a drop in the load power on the motor shaft, and hence the phase current of the stator. In this case, cavitation can be identified by the rate of change of the current value of the stator current. The faster the cavitation develops, the faster the stator current falls. Cavitation, which develops slowly, can be detected by comparing the stator current in the normal mode of the pump with current in cavitation mode.

4. Development of the functional diagram of system of protection

The offered functional diagram of the protection system of pumping equipment against cavitation is presented in figure 5.



The principle of system operation is the following: the measuring instrument of current will transform primary strengths of stator current to a virtual value and gives it to the device of the current analysis.

The analysis device has in its composition two comparison channels. One channel compares the current stator current with the current value in the normal mode (set in the setting block when adjusting

the equipment). If the difference between the specified stator current and the measured current is not large, a warning signal is given to the duty personnel on the abnormal operating mode of the pumping unit. If the difference is significant, then the second stage of protection is triggered – shutdown of the pump, if this is not prohibited by technological interlocks. The second channel calculates the derivative of the current value of the stator current in time, that is, determines the rate of change in the stator current. The filter cuts off the high-frequency part of the current oscillations caused by noise, jolts of the current due to any processes in the mains or any other phenomena, since they can cause a false protection trigger. The obtained rate of current change is compared with a set of preset settings that determine the further operation of the device. If the rate of change is small, a warning signal is given to the duty personnel on the abnormal operating mode. If the rate of change is high and the stator current falls rapidly, a signal is sent to turn off the pump.

5. Conclusion

The offered system, thanks to a small number of structural elements will exceed other existing protection systems in terms of reliability. Besides, owing to the use of the stator current of the drive engine as a control parameter, the high-speed performance will also be greater, than at the existing systems.

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