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The method of constructing the cavitation characteristics of a screw centrifugal pump using the methods of hydrodynamic modeling

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Abstract. By the example of a centrifugal pump with an upstream screw, the possibilities of using hydrodynamic modeling for constructing a cavitation characteristic of a screw centrifugal pump are shown. An example is given of how the cavitation characteristic of a screw centrifugal pump was obtained on the basis of a simplified model of the Rayleigh–Plesset model. It illustrates and shows how the pump characteristic changes with varying empirical coefficients. According to the results of the study, conclusions were made that in the future will allow to improve the calculation of such pumps and to obtain more accurate calculation results.

1. Introduction

Cavitation refers to the process of disrupting the continuity of flow as a result of the formation of vapor or gas bubbles in a fluid flow in a region of reduced pressure and their subsequent condensation in a region of elevated pressure.

Cavitation is a complex set of the following phenomena:

- vapor and dissolved gases from the liquid in areas where the pressure of the liquid is equal to or less than the pressure of saturated vapors;
- local increase in the velocity of the fluid in the place where the vaporization occurred, and random fluid motion;
- condensation of vapor bubbles entrained by the flow of fluid to the area of high pressure. Condensation of each of the bubbles leads to a sharp decrease in volume and hydraulic shock in microscopic zones; however, the collapse in large quantities on the cavitating surface leads to large areas of destruction. Repeated mechanical effects during condensation of bubbles cause the mechanical process of destruction of the wheel material, which is the most dangerous consequence of cavitation (figure 1).

Cavitation is accompanied by a decrease in the flow, head, power and efficiency of the pump; sound phenomena (noise, crackling, shock) and vibration of the pumping unit; erosion of the material of the channel walls; reduced reliability of the pump.

In centrifugal pumps, cavitation occurs on the back side of the impeller blade near its inlet edge, since here the pressure is much lower than the pressure in the suction inlet pipe due to hydraulic losses in the pump inlet device and local increase in the relative velocity of the fluid.



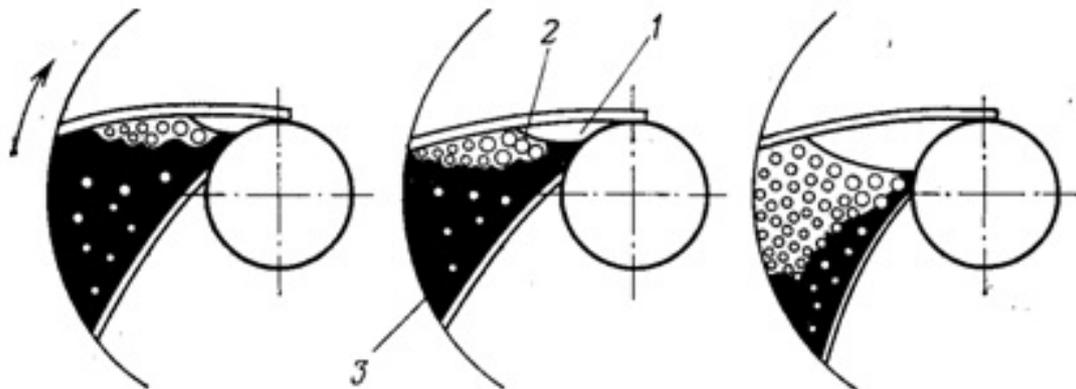


Figure 1. Cavitation in the centrifugal wheel: 1- cavity, 2- hydrodynamic trace, 3 - fluid flow.

The excess of the specific energy of the liquid at the entrance to the pump over the specific energy of the vapor of this liquid, reduced to the center of gravity of the inlet section, is called the cavitation margin Δh , which is determined by

$$\Delta h = \frac{P_{pump}}{\gamma} + \frac{v_0^2}{2g} - \frac{P_{saturated\ stream}}{\gamma}, \quad (1)$$

The evaluation of the cavitation qualities of the pumps is made on the basis of the cavitation characteristics obtained as a result of tests on special stands. Cavitation characteristic — the dependence of the allowable cavitation stock on the pump feed (figure 2).

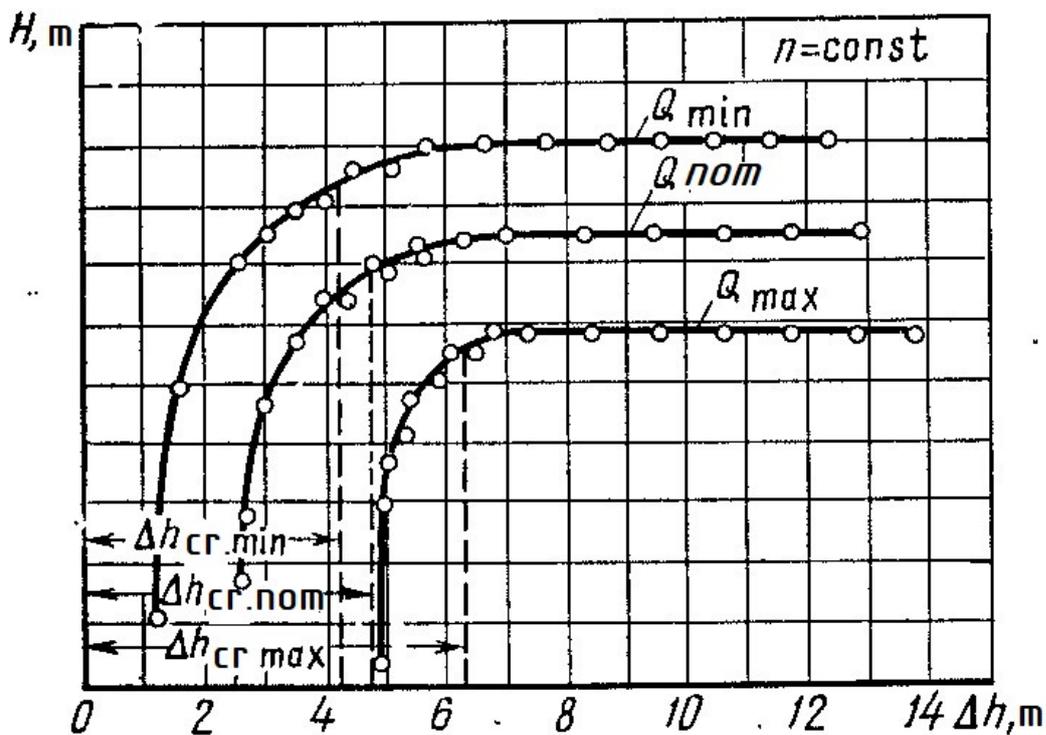


Figure 2. Cavitation characteristics.

In this paper, the calculation and construction of the cavitation characteristic will be performed using hydrodynamic modeling. For this, a simplified Rayleigh–Plesset equation is used, with the establishment of empirical coefficients in it, which make it possible to exclude consideration of complex physical phenomena and a large number of factors in a mathematical model. The cavitation characteristic is constructed for different values of the coefficients, which makes it possible to compare and reveal the dependence of their influence on the cavitation characteristic. In many papers there are materials relating to this topic [1-4], however, the study of the effect of empirical coefficients on the cavitation characteristic of screw centrifugal pumps was not made.

2. Mathematical model

To build the cavitation characteristic, a centrifugal pump with a pre-switched screw was selected. A 3D-model of the flow-through part of such a pump is shown in figure 3.

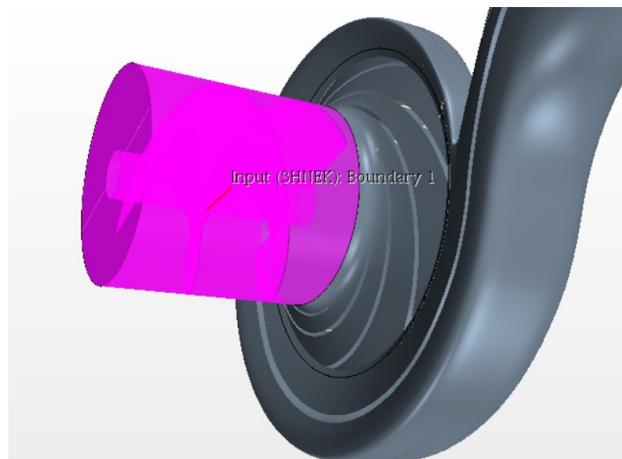


Figure 3. 3D-model of the flow-through part of the centrifugal pump.

The calculation for cavitation implies the flow of the working fluid in the flow part of the pump, which consists of two phases: the liquid phase + the gas phase (vapors) [5,6].

This fact greatly complicates the mathematical model necessary for the calculation.

Such models as Euler multiphase, multiphase equations of state, VOF-model were used.

The growth of the cavitation bubble was calculated from the simplified Rayleigh-Plesset equation with the introduction of the coefficients k_1 and k_2 to compensate for the simplifications introduced into the model, where the first coefficient measures the growth rate of the cavitation bubble, and the second – the collapse rate:

$$\left(\frac{dR}{dt}\right) = k_1 \sqrt{\frac{2}{3} \left(\frac{p_{pump} - p}{\rho}\right)} \quad \text{if } p_{pump} > p, \quad (2)$$

$$\left(\frac{dR}{dt}\right) = -k_2 \sqrt{\frac{2}{3} \left(\frac{p_{pump} - p}{\rho}\right)} \quad \text{if } p_{pump} < p, \quad (3)$$

Construction of cavitation characteristics was carried out by varying the reference pressure (Total Pressure). The Total Pressure function returns the static pressure and velocity pressure values:

$$T_p = p + \frac{\rho V^2}{2}. \quad (4)$$

The computational grid consists of 480,000 computational cells (figure 4), it is structured at solid walls (prismatic boundary layer) and is not structured in the flow core (polyhedra) [7, 8].



Figure 4. Calculated grid of screw centrifugal pump.

3. Simulation results

Calculation of the cavitation characteristic was made by gradually lowering the reference pressure, because this method allows to reduce the pressure level in the entire flow section simultaneously, the working fluid is water at a temperature of 25 °C.

The construction of the cavitation characteristic and the calculation of the values of pressure were made for different values of empirical coefficients: 1) 1 and 1; 2) 2 and 0.5; 3) 5 and 0.2; 4) 10 and 0.1.

Based on the obtained numerical values, the cavitation characteristic of the pump was obtained at coefficients 1 and 1 (figure 5). As can be seen from this characteristic, the pump does not have a pressure drop even at values of the cavitation margin close to zero, which cannot be [9-12].

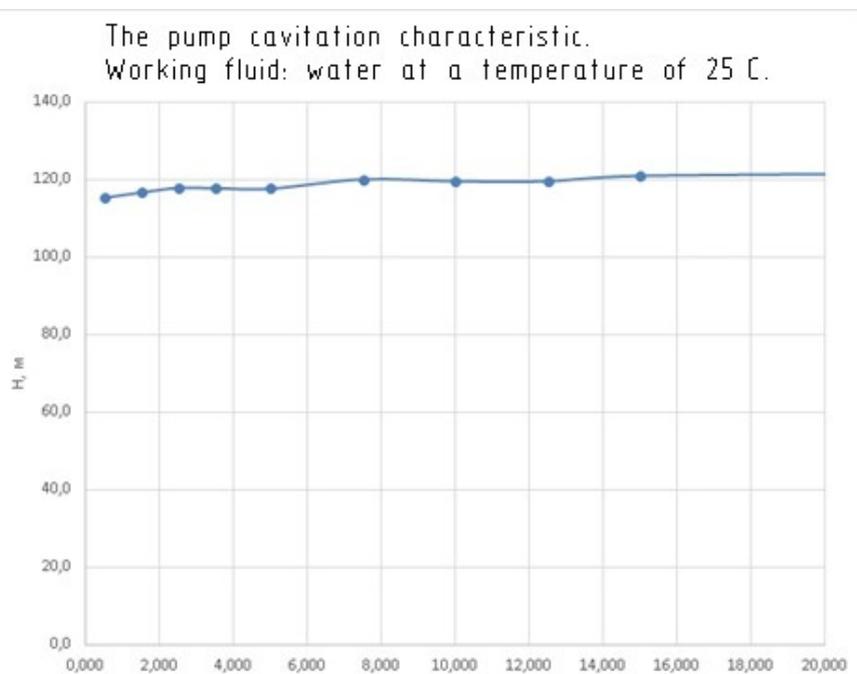


Figure 5. Cavitation characteristic of a centrifugal pump with empirical coefficients 1 and 1.

Then the cavitation characteristic of the pump was obtained with coefficients 2 and 0.5 (figure 6). As can be seen from this characteristic, the pump also does not have a pressure drop even at values of the cavitation margin close to zero, as well as at values 1 and 1, which cannot correspond to reality [13-15].

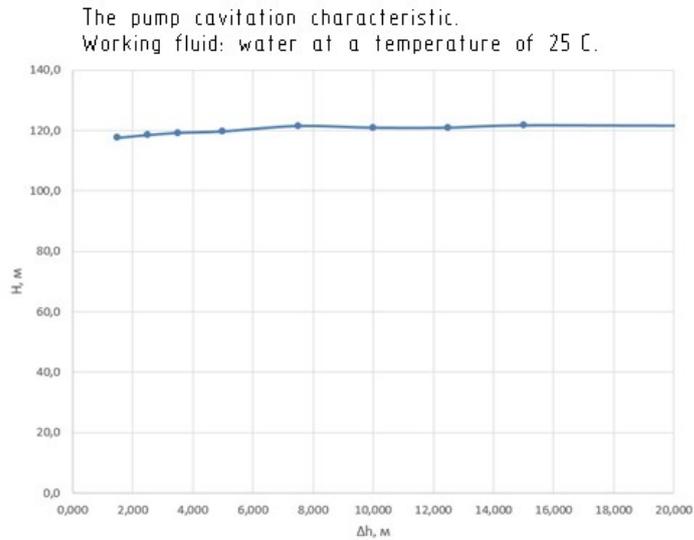


Figure 6. Cavitation characteristics of a screw centrifugal pump with empirical coefficients of 2 and 0.5.

Further calculations were performed for the coefficients 5 and 0.2, as well as 10 and 0.1, respectively. Figure 7 shows a comparison of the cavitation characteristics of the pump at different coefficients. As we see from the graphs, the disruption of the pump begins when the values 5 and 0.2 are chosen. At coefficients of 10 and 0.1, the disruption of work occurs at a higher pressure, that is, at a higher value of the safety factor.

According to the calculations, the cavitation reserve in the pump calculated by the formula (4) is equal to 2 m. Thus, the coefficients 5 and 0.2, as well as 10 and 0.1, reflect more closely the reality of the cavitation process occurring in the hydromachine [16, 17].

$$\Delta h_c = \frac{v_0^2}{2g} + \lambda_{cr} \frac{W_0^2}{2g}.$$

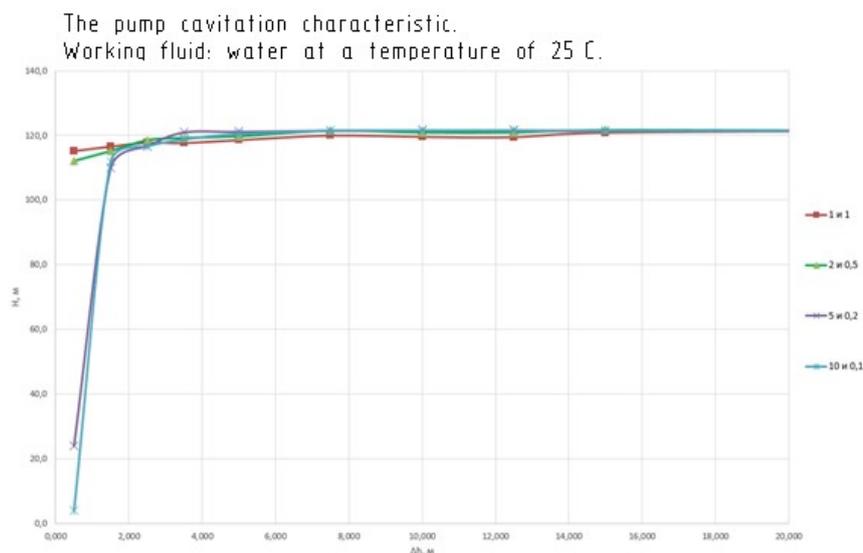


Figure 7. Comparison of the cavitation characteristics of the pump with different empirical coefficients.

Figure 8 illustrates the process of cavitation development when the coefficients in the Rayleigh–Plesset equation change [18-20].

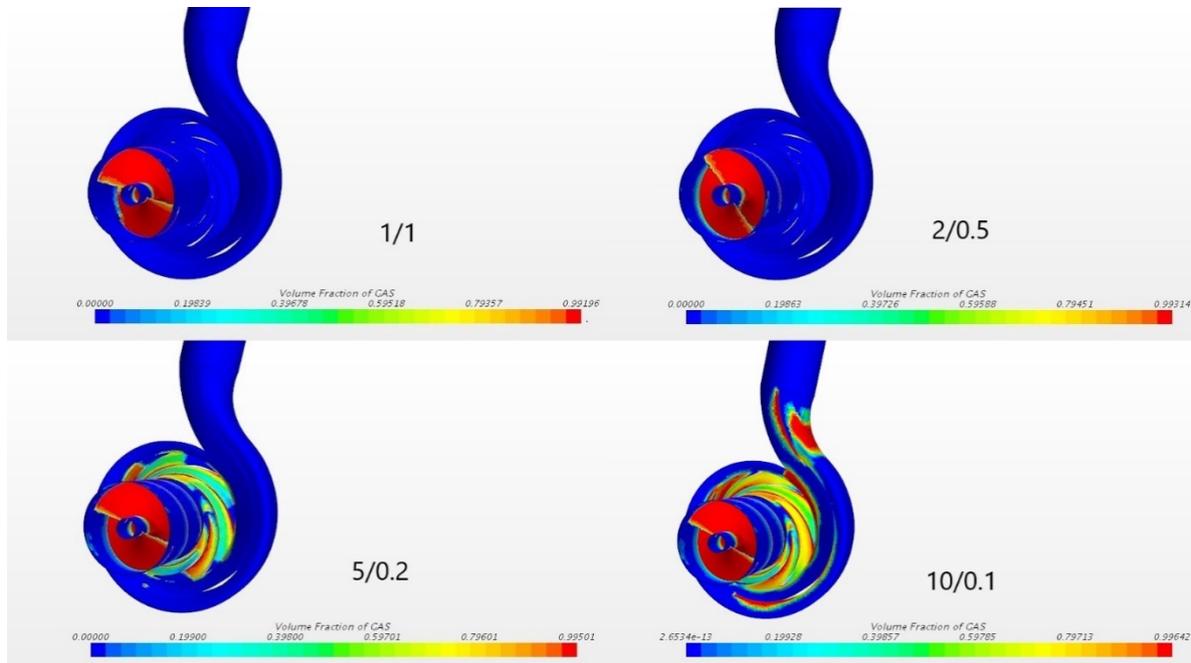


Figure 8. Volume fraction of gas with a cavitation reserve of 2.5 m with various empirical coefficients.

4. Findings

The dependence between the coefficients in the Rayleigh-Plesset equation and the cavitation characteristic of a centrifugal pump is revealed. With the mutual increase of the first coefficient and decrease of the second, a change in the cavitation characteristic and the cavitation reserve of the screw-centrifugal pump is observed.

It is necessary to take into account the coefficients in the Rayleigh-Plesset equation, since simplifying the calculation model negatively affects the final result of the study.

Due to mathematical modeling, it is possible to predict the operation of the pump without preliminary full-scale testing, which will allow pre-identification of possible shortcomings in the work. Thus, the percentage of tests that meet the requirements of developers will be increased, which means that the cost of the finished product can be reduced.

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