Improving the performance of a centrifugal vane pump by installing vortex generators on the suction surfaces of blades

O Teplov[1] and V Lomakin[1,2]

[1]Bauman Moscow State Technical University

[2]E-mail: lomakin@bmstu.ru

Abstract. The influence of vortex generators mounting in the wet part of a centrifugal pump on its characteristics was investigated. Dependents of efficiency, cavitation characteristic, head and capacity are given. The vortex generators were mounted on the front edges of suction sides of the blades, where stall occurs, and a vortex is formed. The simulation results were compared with the characteristics obtained for the usual optimized flow part of the pump.

Introduction

With the increase of modern computers power, multicriterial CFD optimization[1–4] has become commonplace in the design of centrifugal pumps. The resulting models of wet parts have almost the maximum possible characteristics for their design. Therefore, it is necessary to look for new ways to improve the quality of wet parts, based on the including new elements to the existing design concept.

One of the problem areas in the design of a vane pump is the zone of stalling on the suction surface of the blade. A following the blade vortex is forming there and occurs an energy dissipation [5]. Its negative impaction increases with increasing of angle of attack [6] and leads to a decrease in efficiency when the nominal flow is exceeded. Also, increased vortex formation leads to a deterioration of the cavitation characteristics and a decrease of the pump's suction capacity.
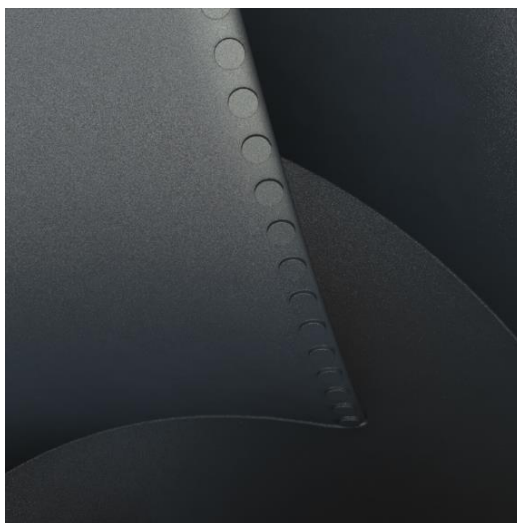

Figure 1. Location of vortex generators on the suction surface of the blade

This problem can be solved by the use of vortex generators, installed on the leading edge of the stall surface (Fig.1). The generators create small eddies, destroying the main stall eddy. It could decrease energy loss due to vortex formation and increase the cavitation characteristics of the flow part by reducing vortex speed.

The existing articles about vortex generators are consider their use on airfoils of helicopter's blades [7], and also on hydrofoils of turbines [8]. There are given detailed description of the nature of processes occurring in the flow after generators. Particular attention should be paid to the article [9], devoted to the influence of vortex generators on the occurrence of cavitation on the hydrofoil NACA0015.

Mathematical model and methods

As an initial model should be chosen the flow part obtained after optimization since it is necessary to exclude the possibility of improving characteristics due to the correction of errors in the construction of geometry. For this role was chosen the model of the wet part of the vane pump with the flow $600\,{}^{m^3}\!/\!_{hr}$ and head $65\,m$ with a tangential dual volute and increased cavitation resistance (Fig.2). Shaft rotation frequency $1450\,rpm.$ Optimization was carried out using LP_τ search on 260 models[10].

Figure 2. Model of optimized pump flow

Modeling was carried out by methods of computational fluid dynamics based on solving the basic hydrodynamic equations discrete analogs. In case of an incompressible fluid model, when the density is constant, these are:

Continuity equation

$$\frac{\partial \tilde{u}_j}{\partial x_j} = 0,$$

where $\tilde{u}_j$ — j axis projection of an averaged value of the fluid velocity (j=1,2,3);

The momentum conservation equation (Reynolds averaged):

$$\rho \left[\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} \right] = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i} \left[T_{ij}^{(v)} - \rho u_i u_j \right];$$

where U, P — averaged velocity and pressure;

$\tilde{T}_{ij}^{(v)} = 2\mu\tilde{s}_{ij}$ —viscous stress tensor for incompressible fluid;

$\tilde{s}_{ij} = \dfrac{1}{2}\left[\dfrac{\partial\tilde{u}_i}{\partial x_j} + \dfrac{\partial\tilde{u}_j}{\partial x_i}\right]$ —instant strain rate tensor;

$\rho u_i u_j$ — Reynolds stresses.

The introduction of the Reynolds averaged Navier-Stokes equation makes the equations system not closed, as additional unknowns, Reynolds stresses, appear.

To solve this system of equation, the k-ω SST turbulence model was used. It introduces the necessary additional equations: the transport equations for the turbulent kinetic energy and the relative dissipation rate of this energy:

$$\frac{\partial k}{\partial t} + U_j\frac{\partial k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_j}\left[\left(\nu + \sigma_k\nu_T\right)\cdot\frac{\partial k}{\partial x_j}\right]$$

$$\frac{\partial\omega}{\partial t} + U_j\frac{\partial\omega}{\partial x_j} = \alpha\cdot S^2 - \beta\cdot\omega^2 + \frac{\partial}{\partial x_j}\left[\left(\nu + \sigma_\omega\nu_T\right)\cdot\frac{\partial\omega}{\partial x_j}\right] + 2\cdot\left(1 - F_1\right)\cdot\sigma_{\omega 2}\cdot\frac{1}{\omega}\cdot\frac{\partial k}{\partial x_i}\cdot\frac{\partial\omega}{\partial x_i}$$

Boundary conditions are pressure value on the inlet and speed value on the output. The resulting best model was additionally edited manually.

Comparison of the characteristics of the wet parts was made according to the efficiency (η_1,η_2), head (H_1, H_2) and capacity (N_1, N_2) in the value range from $300\,{}^{m^3}\!/_{hr}$ to $900\,{}^{m^3}\!/_{hr}$ in increments of $100\,{}^{m^3}\!/_{hr}$. To determine the cavitation values dependencies of heads on the net positive suction heads which characterize the suction capacity of the pump were obtained. Schnerr-Sauer Cavitation Model was used which is based on a reduced Rayleigh-Plesset equation and neglects the influence of bubble growth acceleration, viscous effects, and surface tension effects[11, 12].

Discussion and results

Table 1. Results obtained during CFD modeling (*1* — model without vortex generators, *2* — model with vortex generators)

Q, ${}^{m^3}\!/_{hr}$	η_1, %	η_2, %	H_1, м	H_2,м	N_1,kW	N_2,kW
300	77,5	76,3	81	81,2	85,6	87,42
400	83	82,3	79,6	79,4	104,11	105,48
500	87,1	86,2	77,13	76,6	119,29	120,05
600	88,8	88,8	73,8	73	132,63	132,95
700	88,2	88,6	67,5	67,6	143,87	143,87
800	84,5	85	60,5	60,9	152,98	152,68
900	79,6	80,8	52,8	53,3	160,27	159,96

As expected the obtained results show an increase in efficiency in the area of increased flow, however with a decrease of the flow below optimal point the inverse effect of a decrease in efficiency is manifested. Values of pressure and capacity practically did not change.
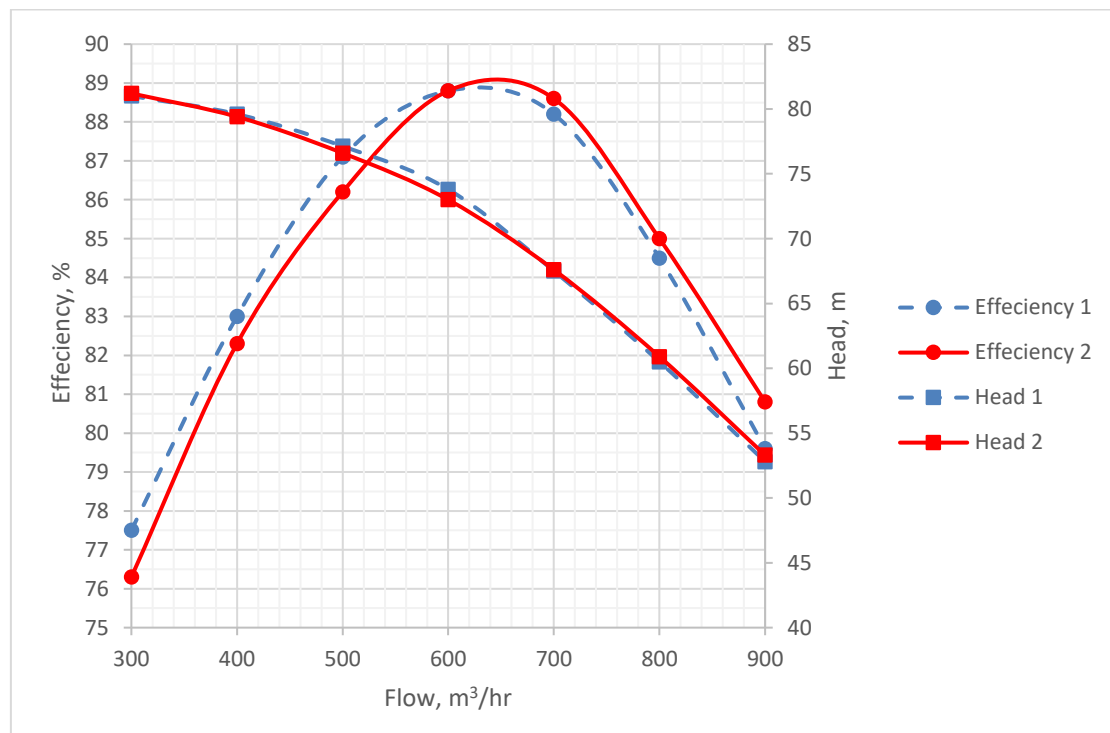
Figure 3. Graphs of efficiency and pressure (*1* — model without vortex generators, *2* — model with vortex generators)
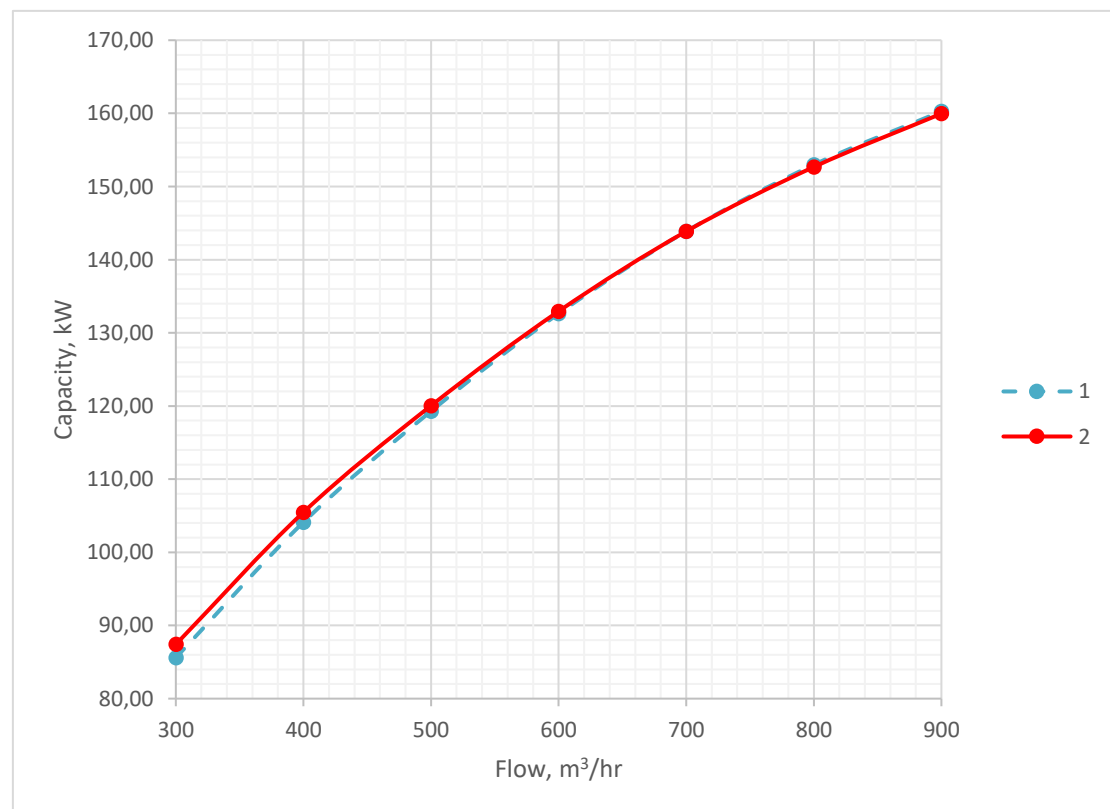

Figure 4. Capacity graphs (*1* — model without vortex generators, *2* — model with vortex generators)

Table 2. Results of cavitation calculation (*1* — model without vortex generators,
2 — model with vortex generators)

Δh_1, m	H_1, m	Δh_2, m	H_2, m
1	8	1	15,3
1,5	19,49	1,25	31,89
2	32,83	1,5	47,6
2,5	47,12	1,75	61,49
2,75	53,29	2	72,13
3,5	72	2,15	73

Cavitation characteristic shows significant reduction of required net positive suction head more than 1.5 meters.
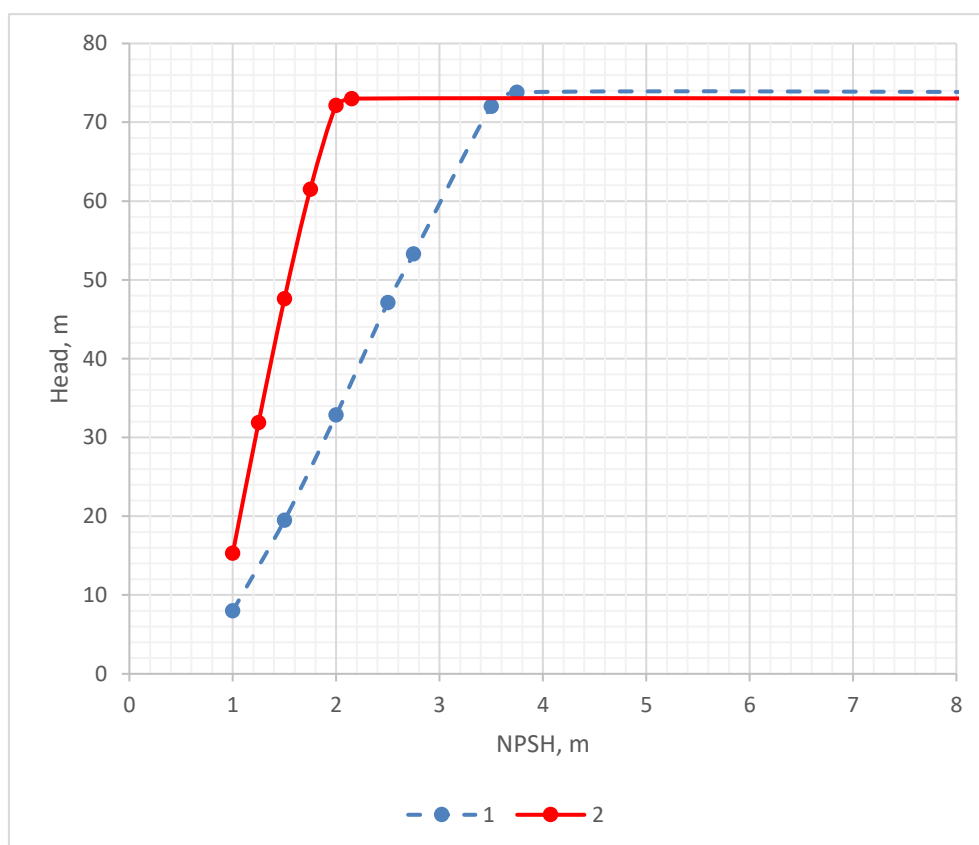

Figure 5. Cavitational characteristics (*1* — model without vortex generators, *2* — model with vortex generators)

Conclusions

1. Application of vortex generators increases efficiency of the pump for exceeding the optimum flow (in the presented model to 0.8%) but decreases for values of flow less then optimum.

2. This solution reduces required net positive suction head (in the considered model it was possible to reduce the $NPSH_R$ almost twice), which in creases pump resistance to cavitation.

3. Vortex generators can be easily implemented technologically, which economically fully justifies the expediency of their widespread use in industry.

References
[1]   Lomakin, V.O., Chaburko, P.S., Kuleshova, M.S. Multi-criteria Optimization of the Flow of a Centrifugal Pump on Energy and Vibroacoustic Characteristics (2017) Procedia Engineering, 176, pp. 476–482.
[2]   Gouskov, A., Lomakin, V., Banin, E., Kuleshova, M., Chaburko, P. Investigation of the influence of centrifugal pump wet part geometry on hemolysis index (2019) IOP Conference Series: Materials Science and Engineering, 492 (1), № 012013
[3]   Gouskov, A.M., Lomakin, V.O., Banin, E.P., Kuleshova, M.S. Minimization of Hemolysis and Improvement of the Hydrodynamic Efficiency of a Circulatory Support Pump by Optimizing the Pump Flowpath (2017) Biomedical Engineering, 51 (4), pp. 229–233.
[4]   Chaburko, P., Kossova, Z. Wet part hybrid optimization method of hermetic pump (2019) IOP Conference Series: Materials Science and Engineering, 492 (1), № 012011.
[5]   Tao, R., Zhao, X., Wang, Z. Evaluating the transient energy dissipation in a centrifugal impeller under rotor-stator interaction (2019) Entropy, 21 (3), № 271.
[6]   V. B. Maleev, V. A. Prishchenko The influence of the angle of attack in the impeller of the pump for drainage on its suction capacity (2004) Scientific works of Donetsk national technical University ("Mining and electromechanical" series), 83 pp. 208–214.
[7]   Mai, H., Dietz, G., Geißler, W., Richter, K., Bosbach, J., Richard, H., de Groot, K. Dynamic stall control by leading edge vortex generators (2008) Journal of the American Helicopter Society, 53 (1), pp. 26–36.
[8]   Kundu, P., Sarkar, A., Nagarajan, V. Improvement of performance of S1210 hydrofoil with vortex generators and modified trailing edge (2019) Renewable Energy, 142, pp. 643–657.
[9]   Che, B., Chu, N., Schmidt, S.J., Cao, L., Likhachev, D., Wu, D. Control effect of micro vortex generators on leading edge of attached cavitation (2019) Physics of Fluids, 31 (4), № 044102.
[10] Sobol I.M. Numerical Monte Carlo methods. M. Nauka, 1973. — 311p.
[11] Sauer, J., InstationaerkavitierendeStroemungen—Einneues Modell, basierend auf Front Capturing VOF und Blasendynamik, Dissertation, UniversitaetKalrsruhe, 2000.
[12] Lomakin, V., Bibik, O. Numerical prediction of the gas content effect on the cavitation characteristics of the pump using the simplified Rayleigh-Plesset equation (2019) IOP Conference Series: Materials Science and Engineering, 492 (1), № 012037.