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Effect of the Profile of Entrance of the Centrifugal Pump Impeller on Cavitation*

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The effect of the impeller entrance profile upon the velocity distribution just before the vane entrance edge was investigated, and experiments were conducted to examine the effect on the cavitation of centrifugal pumps.

The results were as follows.

(1) The velocity distribution just before the vane entrance edge, differed according to the difference of the impeller entrance profile. The flow was considerably one-sided in case of profile A whose cross-sectional area varied suddenly. However, the velocity distribution was uniform in case of profile C whose cross-sectional area varied little.

(2) Irrespective of the velocity distribution, the static pressure distribution at the point just before the vanes was almost the same for all profiles.

(3) In comparison of the cavitation occurrence of profiles A and C, no distinctive difference was observed except that the head drop due to cavitation in the large flow-rate range was smaller in case of profile C.

1. Introduction

There have been many researches carried out heretofore regarding cavitation of centrifugal pumps, but within the writer's scope of knowledge there apparently has been no instance of systematic studies concerning the construction and dimensions of the impeller entrance profile and their effect on cavitation. The writer earlier reported⁽¹⁾ the experimental results on the effect of the impeller vane tip shape at the entrance. Now, this report deals with the results of experiments concerning the impeller entrance profile. This report first discusses the effect that differences of the impeller

entrance profile have upon the flow velocity distribution just before the vane and also what effect they have on cavitation of the pump.

2. Experimental pump

The experimental pump is a vertical type centrifugal pump as shown in Fig. 1. Its impeller is an assembly type with a transparent shroud as shown in Fig. 2. The impeller has an outer diameter of 350 mm, vane inlet diameter of 175 mm, vane inlet angle of 30° , outlet angle of $23^\circ 50'$, and vane width of 15 mm. The vanes are two-dimensional, having a vane thickness of 5 mm, and there are 8 of them. As shown in Fig. 2, the impeller is composed of a hub part (gun metal), vane part (gun metal), and a transparent shroud

Fig. 1 Test pump

Fig. 2 Test impeller

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(acryl resin). The impeller entrance profile is formed by the hub part and suction ring (gun metal). In order to vary this impeller entrance profile, the radius of curvature ρ_0 of the hub and the radius of curvature ρ_i of the entrance ring were changed in various values. The radius r of the hub tip was made as uniform as possible for all hub parts, but it could not be made equal in case of the hub parts having a comparatively large radius ρ_0 due to structural considerations. Therefore, these hub parts had different hub tip radii. Many variations of the entrance profile could be obtained by changing the combination of hub part and suction ring. In this experiment, three kinds of hubs (i.e. $\rho_0=51$ mm, 61 mm and 72 mm) and 4 kinds of suction rings (i.e. $\rho_i=15$ mm, 20 mm, 30 mm and 40 mm) were used in various combinations to form the 6 kinds of profiles listed in Table 1. The profiles were identified by symbols A, B, C, etc. The cross sectional areas of the flow passage of these various entrance profiles are shown in Fig. 3. The cross sectional area was obtained as $2\pi R d$. In this case, d represents the diameter of the circle which touches both walls of the entrance profile and R is the distance from the pump center line to the center of this circle.

When the impeller entrance profile is changed to various forms to study the change of velocity distribution and static pressure just before the vanes, the flow passage profile which produces a uniform distribution for a certain vane profile will not always produce a uniform distribution for other

Table 1 Dimensions of the entrance profile (unit mm)

profile	ρ_i	ρ_0	r
A	15	51	13
B	20	51	13
C	30	51	13
D	40	51	13
E	40	61	10
F	40	72	5

Fig. 3 Sectional areas of flow passage

vane profiles. In order to investigate whether a difference of vane profile affects the flow velocity and static pressure distribution at the point just before the vane, two impellers having the same flow passage profile (identified as profile A) but one with vanes and the other without vanes were tested to examine the difference in flow velocity distribution and static pressure distribution caused by removal of the vanes. Fig. 1 shows the pump having a vaneless impeller. This vaneless impeller has eight bars of 7 mm diameter to connect the side wall of the hub side to the transparent shroud. As these bars were situated in the water passage, their effect was considered. Since they were attached near the outlet, however, their effect on the entrance was judged to be very small.

3. Experimental equipment

The required suction head was supplied to the experimental pump by an auxiliary feed pump via a tank. The experimental pump was driven by a horizontal type electric dynamometer (40 kW capacity). The pump speed of rotation was measured by a Hasler tachometer. The flow rate of the pump was measured by a rectangular weir having 0.44 m width provided in the channel. The measuring point of the suction pressure was set at a point 302.5 mm upstream (pipe diameter 105 mm) from the vane width center line as shown in Fig. 4. A 3-tap cylinder type pitot tube was used to measure the flow velocity distribution. A piezometer tap was provided at I, II, III and IV as shown in Fig. 4, but measurement of the velocity distribution was taken only at I and III. As seen in Fig. 4, measuring point I is in a suction pipe of 90 mm diameter, while measuring point III is 10 mm upstream from the vane tip.

In this experiment, the total head H was

Fig. 4 Velocity and pressure measurement

obtained from the total pressure difference between measuring points I and IV.

In the comparative test of the vaneless impeller and the impeller with vanes, measurement was taken of the static pressure distribution on the side walls which formed the impeller entrance profile. Eleven static-pressure piezometer taps were provided perpendicular to the side wall of the hub part as shown in Fig. 2. The diameter of these taps was 0.5 mm. As seen in Fig. 1, these piezometer taps pass through the side wall and are led to the outside of the impeller from where they go through the pump's hollow shaft and are connected to the mercury pressure gauge which is attached at the bottom of the pump and rotates with the pump shaft. Eleven static pressure piezometer taps are also provided in the suction ring. As shown in Fig. 1, the static pressure on this side wall was led outside through a vinyl tube and measured by a U type mercury pressure gauge.

The cavitation occurrence on the vane was observed by taking readings under the light of a stroboscope and, at the same time, data were taken on the length of comet-like cavitation and its location.

4. Results of experiment

4.1 Difference of static pressure distribution on flow-walls between the vaneless impeller and the impeller with vanes

The vaneless impeller and the impeller with vanes were operated at $N=600$ r.p.m. to compare

Fig. 5 The velocity and static pressure at measuring point I

the difference of static pressure distribution on the side walls.

The results confirmed that there was hardly any difference of static pressure distribution.

4.2 Difference of flow velocity distribution between the vaneless impeller and the impeller with vanes

The velocity and static pressure at velocity measurement point I are plotted on a graph in Fig. 5. The axis of abscissa (x_I) indicates the distance from the pipe wall, while the vertical axis represents static pressure (gauge pressure) p_I/γ absolute velocity v_I and flow angle θ_I (angle between pipe axis and flow). The test was made at the two flow rates $Q=0.99$ m³/min and 1.69 m³/min, and $N=600$ r.p.m. This graph shows that, regardless of whether vanes are attached or not, the velocity and static pressure are almost the same.

Next, the velocity and static pressure at measuring point III are plotted on a graph in Fig. 6. As the graph indicates, the impeller with vanes obtains higher speed at the hub side than one without vanes at the opposite side wall. The static pressure distribution shows the same value regardless of whether vanes are provided or not. Therefore, it can be said that, since there is a slight change in velocity distribution whether vanes are provided or not, there is no effect on the static pressure.

According to the results of this experiment,

Fig. 6 The velocity and static pressure at measuring point III

the velocity distribution just before the vane shows a slight change but the static pressure is not affected in any way by this difference of velocity and no local pressure drop can be observed. From

Fig. 7 The velocity and static pressure at measuring point I (Comparison of each profile A, B, C, D)

Fig. 8 The velocity and static pressure at measuring point III (Comparison of each profile A, B, C, D)

these results, it is decided that there is no need to repeat the same experiment with 2 or 3 different vane profiles in such an experiment where the impeller entrance profile is changed to various shapes to study whether the cavitation is affected by changes of the velocity distribution just before the vane and the static pressure distribution. Therefore, the experiment was conducted by changing the impeller entrance profile to various shapes for one kind of vane profile.

4.3 Difference of velocity and static pressure distribution just before the vane caused by change of entrance profile

The velocity and static pressure distribution were measured at points I and III for impellers having the impeller entrance profiles listed in Table 1. The pump was operated at 600 r.p.m. with Q set at $1.0 \text{ m}^3/\text{min}$ and $1.7 \text{ m}^3/\text{min}$.

The velocity and static pressure distribution at measuring point I are compared for profiles A, B, C and D in Fig. 7. Regardless of the difference of profile, the velocity distribution is almost the same in

Fig. 9 The velocity and static pressure at measuring point III (Comparison of each profile D, E, F)

each case. In case of profile D, the v_I value was slightly lower, probably because Q was smaller than that of the other profiles. The static pressure distribution, too, was almost the same for all profiles except D. The higher static pressure of D was assumed to be due to the velocity decrease caused by smaller Q . From the above results, it can be said that, the conditions just before the bend of the flow passage are practically the same in every case and the effect of the bend does not extend upstream.

Fig.8 shows a graph of the experimental results of the velocity and static pressure distribution at velocity measuring point III for profiles A, B, C and D. Fig. 9 shows a graph of the results for profiles D, E and F. The velocity distribution differed according to the profile. The velocity distribution of profiles A and B differs definitely from those of C, D, E and F. A and B indicate a rather one-sided distribution, i. e. the velocity is much lower on the inside of the bend. This one-sided velocity distribution of A and B is assumed to be due to the effect of the sudden reduction of flow areas at the bend (refer to Fig. 3). Although D, E and F have a rather large ρ_i and ρ_o and larger flow area than C, their velocity distribution is almost the same as C. The uniform distribution at C can be attributed to the absence of any sudden change of the flow area.

The average value of inflow angle along the cross section differs according to the profile. This

Table 2 Capacities for incipient cavitation

Profile	Capacities for incipient cavitation m ³ /min			
	$H_s=10\text{m}$	$H_s=5\text{m}$	$H_s=1\text{m}$	$H_s=-2\text{m}$
A	2.40	2.22	2.00	1.80
C	2.62	2.32	1.98	1.80

Fig. 10 The modes of cavitation occurrence for entrance profile A

valve was near 90° for profiles A and B, but was about 97° for the other profiles.

The static pressure distribution was almost the same in value, irrespective of the profile, and was not affected by the variation of the velocity distribution. And no pressure drop due to velocity increase was observed.

4.4 Difference of cavitation occurrence due to difference of entrance profile

Owing to a nonuniformity of velocity distribution just before the vane inlet, the relative inflow angle to the vane inlet becomes dissimilar along a vane edge. Since the vane inlet angle is constant over the entire length of the vane tip, shockless entry will not be obtained over the entire vane tip due to the difference of the inflow angle. In regard to this point, it can also be assumed the nonuniformity of the velocity distribution will affect the cavitation. Therefore, cavitation experiments were conducted for profiles A and C. The experiments were carried out for both the inception cavitation and the cavitation which drops in head-capacity curve.

4.4.1 Inception cavitation With $N=1000$ r.p.m., the experiments were conducted for 4 different suction head H_s values ($H_s = p_s/\gamma + v_s^2/2g$; p_s/γ is the static pressure in suction pipe and v_s is the average velocity in suction pipe), i. e. approximately 10 m, 5 m, 1 m and -2 m. Measurements were taken of Q , total head H , and λ (length of comet-like cavitation). In A and C, the velocity distribution at the point just before the vane is different but the cavitation occurred at about the same point in the vane width direction. In both cases, the inception cavitation occurred on the hub side. This is only natural since the hub side of both A and C is of high velocity. The relation between λ and Q for profile A is shown in Fig. 10. Fig. 11 shows the relation of λ and Q for profile C. The inception cavitation for Q at each H_s value was read from these graphs and listed in Table 2. According to

Fig. 11 The modes of cavitation occurrence for entrance profile C

Table 2, the Q value which produces inceptional cavitation in profile C is slightly larger when H_s is 10 m and 5 m. However, at H_s values of 1 m and -2 m, inceptional cavitation occurs at almost the same values of Q in profiles A and C and there is no distinctive difference caused by difference of profile.

4.4.2 Cavitation which drops in head capacity curve When the cavitation progresses beyond the incipient stage and grows rather long to a magnitude which affects the total head H , it will become as follows according to the flow passage profile.

The H - Q curves for various H_s values are shown in Figs. 12 and 13 for profiles A and C. The head drop in the H - Q curves due to cavitation was read from these graphs for $Q=2.6 \text{ m}^3/\text{min}$ and $2.9 \text{ m}^3/\text{min}$. The head drop in the H - Q curves is

$\Delta H = H_0 - H$ as indicated in Fig. 14. The relation between ΔH and cavitation coefficient σ will be as shown in Fig. 15. Here, σ can be expressed by the following equation,

$$\sigma = \frac{H_{sv}}{H_0}$$

H_0 is the head when there is no cavitation. H_{sv} is the net positive suction head which can be expressed as $H_{sv} = H_a - H_v + H_s$, where let H_a be atmospheric pressure, H_v be the vapour pressure at the prevailing water temperature.

Fig. 15 (b) shows the head drop for the case of $Q=2.6 \text{ m}^3/\text{min}$. H is about the same for both A and C and becomes rather large from the vicinity of $\sigma=1$. Also, the λ value at this time does not differ according to the profile.

Next, when $Q=2.9 \text{ m}^3/\text{min}$, ΔH differs

Fig. 12 Head-capacity characteristic for entrance profile A

Fig. 13 Head-capacity characteristic for entrance profile C

Fig. 14 Definition of ΔH

Profile A ΔH λ
C $\otimes$ $\circ$

Fig. 15 Drop in head due to cavitation

considerably according to profiles A and C. H starts to drop from $\sigma=2.7$ in case of profile A, but H does not drop unless $\sigma=2.4$ in case of profile C. In case of the same σ value, for example, $\sigma=2$, $\Delta H \approx 3$ m for A but $\Delta H=0.4$ m for profile C. Thus the head drop for profile C at the same σ value is much smaller. $Q=2.6$ m³/min is approximately the condition at shockless entry of the impeller. Therefore, near the shockless entry, there is no difference of head drop due to cavitation. When Q becomes larger than 2.6 m³/min, the head drop will differ according to the profile while profile C having a more uniform velocity distribution will have less head drop.

The overall results of these experiments indicate that, although profiles A and C have considerably different velocity distribution at the point just before the vane, there is no great difference between A and C at inception of cavitation and at the cavitation occurrence which has progressed beyond the incipient stage where head drop starts. Consequently, even when there is dissimilarity of the velocity distribution at the point just before the vane, the cavitation characteristics will differ very little as long as the static pressure distribution does not change.

5. Conclusion

The results of these experiments can be summarized as follows.

(1) The velocity distribution just before the vane, differed according to the difference of the impeller entrance profile. The flow was considerably one-sided in case of profile A whose cross-sectional area varied suddenly. However, the velocity distribution was uniform in case of profile C having very little variation of the cross-sectional area.

(2) Irrespective of the velocity distribution, the static pressure distribution just before the vanes was almost the same for all profiles.

(3) In comparison of the cavitation occurrences of profiles A and C, no distinctive difference was observed except that head drop due to cavitation in the large flow-rate range was smaller in case of profile C.

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Reference

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