Movement of Location of Tip Vortex Cavitation along Blade Edge due to Reduction of Flow Rate in an Axial Pump

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***Abstract*—**Tip vortex cavitation is one of well known patterns of cavitation phenomenon which occurs in axial pumps. This pattern of cavitation occurs due to pressure difference between the pressure and suction sides of blades of an axial pump. Since the pressure in the pressure side of the blade is higher than the pressure in its suction side, thus a very small portion of liquid flow flows back from pressure side to the suction side. This fact is cause of tip vortex cavitation and gap cavitation that may occur in axial pumps. In this paper the results of our experimental investigation about movement of tip vortex cavitation along blade edge due to reduction of pump flow rate in an axial pump is reported. Results show that reduction of pump flow rate in conjunction with increasing of outlet pressure causes movement of tip vortex cavitation along blade edge towards the blade tip. Results also show that by approaching tip vortex cavitation to the blade tip, vortex tip pattern of cavitation replaces with a cavitation phenomenon on the blade tip. Furthermore by further reduction of pump flow rate and increasing of outlet pressure, an unstable cavitation phenomenon occurs between each blade leading edge and the next blade trailing edge.

***Keywords*—**Axial Flow Pump, Cavitation, Gap Cavitation, Tip Vortex Cavitation.

I. Introduction

CAVITATION phenomenon may occur in hydraulic machineries. Vapor bubbles are produced in anywhere which liquid flow is subjected to a pressure less than the liquid saturated vapor pressure. These bubbles move with liquid flow and collapse in high pressure regions where pressure is above the liquid saturation vapor pressure. Production and collapse of vapor bubbles is called cavitation which is an important phenomenon in industry, science and medicine. Cavitation is an undesirable phenomenon in pumps and turbines because it causes vibration, noise, efficiency drop and mechanical damage. Cavitation is well recognized as a phenomenon that may cause serious pump malfunction due to improper pump inlet conditions [1].

The development of high speed and high performance pumps for liquids and their inclusion in increasingly complex hydraulic systems have created a need for improvement in our understanding of these flows [2].

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Mitchell, in his novel work has classified cavitation patterns in an axial flow pump into two main types [3]; the first type is blade surface cavitation which is affected by the secondary flows, and the second type is the cavitation that occurs in the clearance between the rotor blade tip and the pump casing. This type of cavitation is because of the flow from the high pressure surface of the rotor blade to the low pressure surface.

Improvements in hydraulic machines design have led to much better control of cavitation effects. Consequently, different kinds of cavitation phenomena which were not much considered in the past are attracting more attention. Among these, tip clearance and tip vortex cavitation are becoming prominent topics. Delaying or eliminating these two types of cavitation (entirely or partially) is a major goal in design of axial flow pumps, due to their undesirable consequences such as noise, vibrations, mechanical damage and power loss [4].

Shervani-Tabar and Poursharifi in their experimental work concluded that tip vortex cavitation can directly lead to losses in efficiency, especially for flow rates inside the cavitation zone [5]. They also stated that tip vortex cavitation occurs at maximum flow point and by approaching the cavitation zone, the effect of cavitation on decreasing of pump head is revealed more significantly. Finally they concluded that by adjusting the flow rate out of the critical region, tip vortex cavitation is avoidable to a great extent.

Tsujimoto in his brilliant paper classified flow instabilities in a pump into two cavitating and non cavitating instabilities. He expressed that a certain quantity of air trapped in a pipeline serves as a capacitance and a surge may occur even if the pipeline does not include external capacitance [6]. He also mentioned that cavitation instabilities called rotating cavitation and cavitation surge may occur even at the design flow rate.

In this paper experimental investigations are carried out by using a closed circuit axial pump setup for investigating dynamic behavior of tip vortex cavitation under different circumstances. A stroboscopic light is employed for high speed photography from the cavitation phenomenon in an axial pump. Three series of experimental investigations are carried out in three different blade angle of the pump. In each series of experimental investigation a manual valve is used for reduction of pump flow rate. Since a closed circuit has been used in the experimental setup, therefore reduction of pump flow rate is in conjunction with increasing of outlet pressure. Experimental visualization of the liquid flow by using a stroboscopic light reveals that by reduction of flow rate and increasing of outlet pressure, tip vortex cavitation moves along bade edge towards the blade tip and finally an unstable cavitation occurs between leading edge of each blade and trailing edge of the next blade.

II. EXPERIMENTAL SETUP

In order to study dynamic behavior of the tip vortex cavitation in an axial flow pump, a closed loop system including an axial flow pump, a Kaplan turbine and a surge tank is used. The blades of the pump are adjustable and can be set at several different angles. For these series of experiments, the blade angles are set at different angles of 15, 22 and 29 degrees respectively. The pump is driven by a D. C. electromotor and it has nominal speed of 1440 rpm. But the rotational speed can be set at 980 rpm too. For all steps of these experimental tests, the rotational speed of the rotor is chosen to be 980 rpm. Pump's casing is made of plexi-glass and this makes it possible to observe the patterns of cavitation around the pump blades. A manual valve is utilized to control the flow rate.

III. RESULTS AND DISCUSSION

Experimental tests have been carried out in three series with different blade angle of 15, 22 and 29 degrees respectively. In each series of experiments the flow rate of the axial pump is reduced gradually by using a manual valve. Since the experimental setup is a closed circuit, then the reducing of the pump flow rate by closing a manual valve is together with increasing of outlet pressure. Operating conditions of the axial flow pump have been given in tables 1-3.

TABLE I
AXIAL FLOW PUMP OPERATING CONDITIONS IN THE FIRST SERIES OF EXPERIMENTS

Experiment No.	Inlet pressure (gage pressure) (Pa)	Outlet pressure (gage pressure) (Pa)	Flow rate (Cumecs)	Blade angle (Degree)	Pump speed (RPM)	Input power (W)	Output power (W)
1-1	1765.8	9319.5	0.1325	15	980	2918	1001
1-2	1765.8	11772	0.1275	15	980	3059	1276
1-3	2060.1	20601	0.105	15	980	3703	1947
1-4	3139.2	35806.5	0.052	15	980	4528	1699
1-5	2158.2	47088	0.02	15	980	5594	899

[a]Units are: Pa = pascal, CUMECS = cubic meter per second, RPM = revolutions per minute, W = watt.

TABLE II
AXIAL FLOW PUMP OPERATING CONDITIONS IN THE SECOND SERIES OF EXPERIMENTS

Experiment No.	Inlet pressure (gage pressure) (Pa)	Outlet pressure (gage pressure) (Pa)	Flow rate (Cumecs)	Blade angle (Degree)	Pump speed (RPM)	Input power (Watt)	Output power (Watt)
2-1	196.2	16677	0.177	22	980	5131	2917
2-2	588.6	20601	0.167	22	980	5474	3342
2-3	1962	31882.5	0.117	22	980	6339	4997
2-4	2158.2	33354	0.056	22	980	6118	1747
2-5	1471.5	47088	0.025	22	980	8150	1140

[a]Units are: Pa = pascal, CUMECS = cubic meter per second, RPM = revolutions per minute, W = watt.

TABLE III
AXIAL FLOW PUMP OPERATING CONDITIONS IN THE THIRD SERIES OF EXPERIMENTS

Experiment No.	Inlet pressure (gage pressure) (Pa)	Outlet pressure (gage pressure) (Pa)	Flow rate (Cumecs)	Blade angle (Degree)	Pump speed (RPM)	Input power (Watt)	Output power (Watt)
3-1	-981	23053.5	0.205	29	980	7788	4927
3-2	294.3	------	0.177	29	980	8372	------
3-3	2648.7	28939.5	0.087	29	980	6842	2287
3-4	1863.9	36297	0.050	29	980	8372	1722
3-5	981	46597.5	0.023	29	980	10062	1049

[a]Units are: Pa = pascal, CUMECS = cubic meter per second, RPM = revolutions per minute, W = watt.

Figure 1 illustrates the cavitation pattern around the pump blades under operating condition of No. 1-1. As it is seen in this figure tip vortex cavitation occurs under this condition. Tip vortex cavitation occurs because of the fact that a very small portion of the liquid flows back from the pressure side of the blade to its suction side due to the pressure difference between the pressure and suction sides of the blade. It can be seen from fugures 2-5 that by grdually reducing the flow rate of the pump and cosequently increasing the outlet pressure, at the first step the tip vortex cavitation disappears. Then the cavitation phenomenon moves along the blade edge towards the blade tip. Disappearance of the tip vortex cavitation in figure 2 and appearance of a weak tip vortex cavitation in figure 3 may be because of the fact that intensity of the tip vortex cavitation phenomenon during its movement towards the blade tip reduces at the first stages and then by further movement of the tip vortex cavitation towards the blade tip the cavitation intensity increases again. By further reducing of the pump flow rate and increasing of the outlet pressure an unstable cavitation phenomenon occurs between the leading edge of each blade and the trailing edge of the next blade.

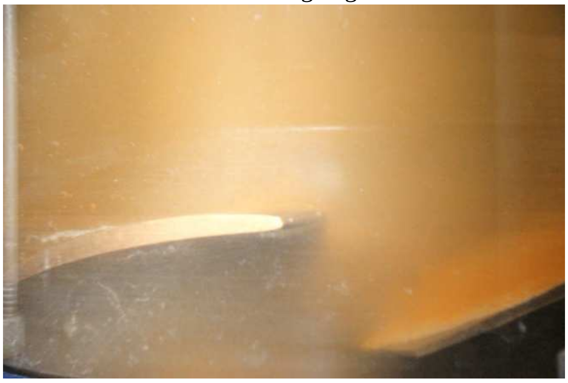

Fig. 1 Cavitation pattern under operating condition of No. 1-1

Fig. 2 Disappearance of cavitation under operating condition of No. 1-2

Fig. 3 Cavitation pattern under operating condition of No. 1-3

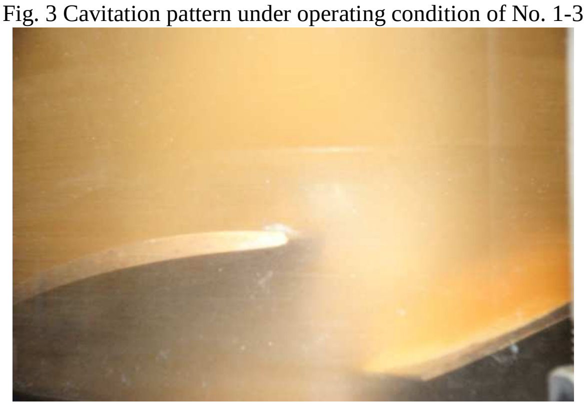

Fig. 4 Cavitation pattern under operating condition of No. 1-4

Fig. 5 Cavitation pattern under operating condition of No. 1-5

Figure 6 illustrates the cavitation pattern around the axial flow pump blades under operating condition of No. 2-1. As it is seen in figure 6 the cavitation pattern under this condition is a tip vortex cavitation phenomenon. Figures 7-8 show that by reducing the pump flow rate and consequently by increasing the outlet pressure, the tip vortex cavitation moves along the blade edge towards the blade tip. As it is seen in figure 8, under condition of this figure, gap cavitation occurs together with tip vortex cavitation. Gap cavitation occurs in the clearance between the blade and the pump casing. Figure 9 shows that by further reducing of the pump flow rate and increasing of the outlet pressure, tip vortex cavitation transforms to a cavitation phenomenon on the tip of the blade which is followed by occurrence of an unstable cavitation between the leading edge of each blade tip and the trailing edge of the next blade. This kind of unstable cavitation can be seen in figure 10. A comparison between figures 6, 7 and 8 shows that under these conditions the intensity of the tip vortex cavitation by its movement towards the blade tip decreases at the first stages and then by further movement of the tip vortex cavitation towards the blade tip the cavitation intensity increases again.. This fact is previously observed under the conditions of figures 1-3.

Fig. 6 Cavitation pattern under operating condition of No. 2-1

Fig. 7 Cavitation pattern under operating condition of No. 2-2

Fig. 8 Cavitation pattern under operating condition of No. 2-3

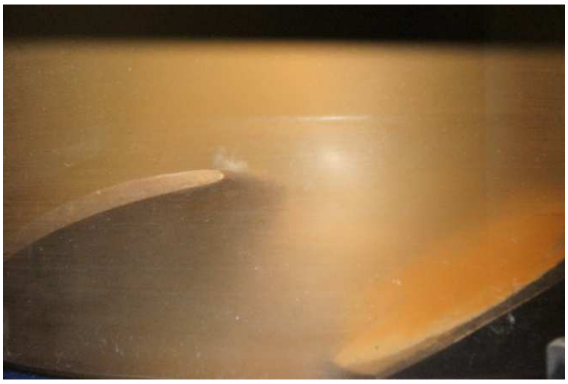

Fig. 9 Cavitation pattern under operating condition of No. 2-4

Fig. 10 Cavitation pattern under operating condition of No. 2-5

Figure 11 illustrates the cavitation pattern around the blades of the axial flow pump under operating condition of No. 3-1. A comparison between this figure and figure 6 shows that by increasing angle of the pump blade, the intensity of the tip vortex cavitation increases and the tip vortex cavitation occurs close to the blade tip. Figure 12 shows that by reducing the flow rate of the pump and consequently by increasing the outlet pressure, the tip vortex cavitation moves towards the blade tip. This figure also shows that under this condition the gap cavitation occurs in the clearance between the blade and the pump casing together with the tip vortex cavitation.

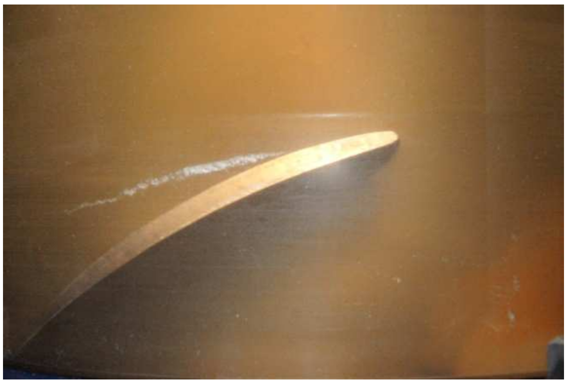

Fig. 11 Cavitation pattern under operating condition of No. 3-1

Fig. 12 Cavitation pattern under operating condition of No. 3-2

Figures 13-15 show that by further reducing of the pump flow rate and consequently by further increasing of the outlet pressure the tip vortex cavitation transforms to a cavitation phenomenon on the blade tip which is followed by occurrence of an unstable cavitation between the leading edge of each blade and the trailing edge of the next blade.

Fig. 13 Cavitation pattern under operating condition of No. 3-3

Fig. 14 Cavitation pattern under operating condition of No. 3-4

Fig. 15 Cavitation pattern under operating condition of No. 3-5

IV. CONCLUDING REMARKS

In this paper an experimental investigation has been carried out for better understanding of dynamic behavior of the tip vortex cavitation in an axial flow pump.

The experimental setup consists of a closed circuit with an axial pump, a Kaplan turbine and a surge tank. Therefore reduction of pump flow rate by closing a manual valve causes increasing of the outlet pressure.

Results show that by reducing the pump flow rate and consequently increasing the outlet pressure, the tip vortex cavitation moves along the blade edge towards the blade tip.

Results also show that by further reducing of the pump flow rate and consequently by further increasing of the outlet pressure, the tip vortex cavitation transforms to a cavitation phenomenon on the tip of the pump blades which is followed by occurrence of an unstable cavitation between the leading edge of each blade and the trailing edge of the next blade.

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