Research on Cavitation Experiment of a Centrifugal Pump

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Abstract

Within the working range of a centrifugal pump, cavitation experiment is performed to determine the relationship between $NPSH_{cr}$ and Q. A series of cavitation experimental studies were respectively conducted on the centrifugal pump test platform. Three conditions are guaranteed flow point Q_G, small flow point 0.8 Q_G and large flow point 1.2 Q_G. Under these three flow rates, the values of $NPSH_{cr}$ were obtained respectively. Based on the experimental data, the curve of $NPSH_{cr}=f(Q)$ can be drawn. The results show that $NPSH_{cr}$ increases with increasing of flow. According to the experimental curve, the range of head declined 3% can be regarded as cavitation inception, which used in project is a reasonable criterion. With the help of this principle can be realized cavitation live monitoring of centrifugal pump.

Keywords

Centrifugal pump, cavitation experiment, the critical cavitation margin (NPSHcr), cavitation monitoring.

1. Introduction

Cavitation and cavitation erosion is a physical phenomenon that may occur in the fluid machinery which using liquid as working medium [1-3]. Cavitation will not only lead to a decline of the performance and efficiency of a centrifugal pump, but also produce a series of adverse phenomenon such as vibration, noise and damage to the centrifugal pump flow components [4, 5]. Therefore, it has important theoretical and practical significance to study the cavitation flow phenomenon in the centrifugal pump. In the live or laboratory conditions, monitoring and analysis of cavitation condition of a pump has been an important field of research on cavitation and cavitation erosion [6-10]. In the laboratory condition, the cavitation experiments of a centrifugal pump were conducted at the rated flow condition, small flow condition and large flow condition. Based on the data obtained from the experiment and related research, the rules of $NPSH_{cr}$ changed with flow rate were researched in a centrifugal pump. Finally, using the conclusions obtained from the experiment for cavitation real-time monitoring.

2. Experimental principle

Known by the pump cavitation theory, at a certain rotation speed, flow rate and conveying liquid conditions, the required net positive suction head $NPSH_R$ is a fixed value, but the available net positive suction head $NPSH_A$ changes along with the change of equipment conditions, the relationship between $NPSH_A$ and $NPSH_R$ are as follows

$$NPSHA - NPSHR = \frac{p_k - p_v}{\rho g} \tag{1}$$

where, p_k is the pressure of one point on the back of impeller blade inlet, p_v is the vapor pressure.

When the pressure at the pump inlet p_1 to reduce, make the liquid pressure of one point on the back of impeller blade inlet p_k is equal to the vapor pressure of liquid at the transmission medium temperature

p_v, liquid begins to vaporize and cavitation occurs, then reached a critical state. In the critical state, $NPSH_A$=$NPSH_R$.

$NPSH_A$ refers to the surplus energy of unit weight of liquid at the inlet of a pump over the vapor pressure of liquid [11, 12], the calculation formula of $NPSH_A$ is

$$NPSHA = \frac{P_{abs1}}{\rho g} + \frac{v_1^2}{2g} - \frac{P_v}{\rho g} \tag{2}$$

where, p_{abs1} is the absolute pressure of pump inlet, v is the velocity of pump inlet.

Because of the pressure of pump inlet is lower than atmospheric pressure, therefore

$$\frac{P_{abs1}}{\rho g} = \frac{P_a}{\rho g} - \left|\frac{P_1}{\rho g}\right| \tag{3}$$

where, p_a is the local atmospheric pressure, p_1 is the relative pressure of pump inlet.

By formula (3) into formula (2) can be obtained

$$NPSHA = \frac{P_a}{\rho g} - \frac{P_v}{\rho g} - \left|\frac{P_1}{\rho g}\right| + \frac{V_1^2}{2g} \tag{4}$$

At a certain flow and liquid conditions, by changing the condition of suction device, which can make the pressure of pump inlet p_1 reduced sequentially. For each value of p_1, finding out the corresponding values of H and $NPSH_A$. Then, the values of Q, H and $NPSH_A$ will be converted to the values under the prescribed speed, the curve of $H=f(NPSH_A)$ when the flow is a fixed value can be under the specified speed. On the curve, making the head of the first stage impeller of pump (the head of the initiation of cavitation experiment) fell by 3%, the corresponding value of $NPSH_A$ is defined as the critical net positive suction head which expressed by $NPSH_{cr}$. At this time it can be considered $NPSH_{cr}$ = $NPSH_R$.

3. The cavitation experimental system of centrifugal pump

3.1 Experimental method

Two methods commonly used to change $NPSH_A$: One is changing the valve opening degree on the pump suction pipeline which is essentially changing the resistance of the suction pipeline. In order to remain the constant flow, when changing the valve opening degree on the pump suction pipeline, and at the same time, adjusting the regulating valve which on the export pipeline at any time. The other is on the closed test bench, using vacuum pump for pumping to continuously increase the vacuum value of the free surface of cavitation tank, that is, the method of vacuum. By making the pressure of pump inlet for change while maintaining the flow is constant, we can achieve the purpose of changing $NPSH_A$.

Experimental device

The pump used for the experiment is a single stage centrifugal pump IS150-125-250 with number of blades is 6. The pump is driven by an AC motor which rated power is 18.5kW and the rotational speed is 1450, the rated flow is 200m^3/h, the head is 20m and the $NPSH_R$ is 3m. Experimental device is shown in Fig. 1.

3.2 Experimental steps

1. Cavitation experiment should be performed under 3 flow rate conditions at least, which are the guaranteed flow point Q_G, the small flow point 0.8 Q_G and the large flow point 1.2 Q_G. Under every flow, the $NPSH_A$ should be measured not less than 15 points, and required the points in the interval from cavitation began to the curve of $H=f(NPSH_A)$ began to fracture not less 8 points. That is, taking intensive points in the interval that cavitation will occur.

2. Cleaning the water storage tank and injecting water into it. In an experiment process, the need of basic guarantee is that the temperature of water does not change.

3. Starting the vacuum pump and making the degree of vacuum of pump inlet gradually increases, which can make the $NPSH_A$ progressive decreases in turn. When reach a predetermined value (a predetermined value refers to the reading interval of the vacuum gauge, it given by the participants in advance. Generally, choosing the larger interval within the range from the start to cavitation will occur, and choosing the smaller interval within the range from pump cavitation occurred to the curve of $H=f(NPSH_A)$ began to fracture.), Turn off the vacuum pump and record at the same time. So go ahead experiment until full cavitation (that is, observed a serious decline of flow and outlet pressure).

4. In order to maintain a constant flow during experiment process, changing the vacuum value of pump inlet, at the same time, adjusting the outlet regulating valve at any time.

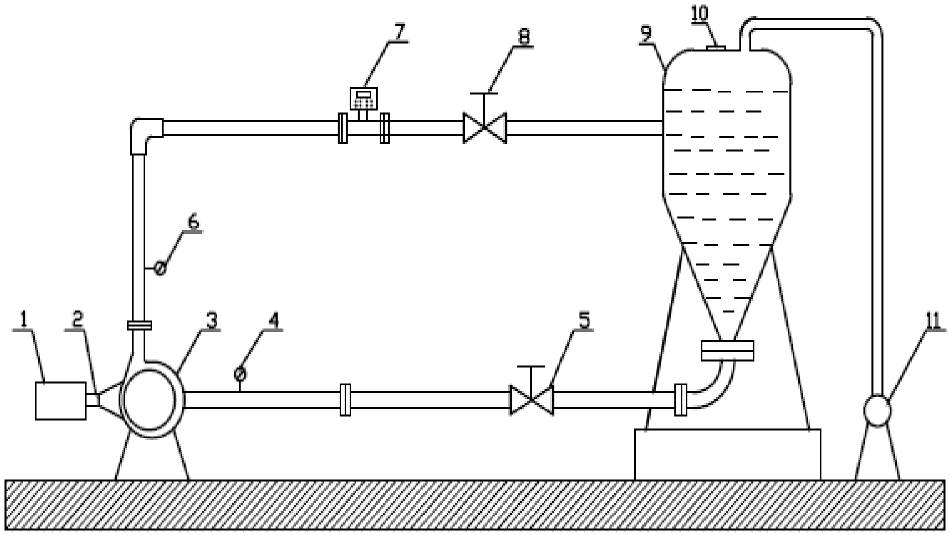

Fig. 1 the closed experimental device of a centrifugal pump
1-electric motor 2-speed and torque sensor 3-the test pump 4-pressure sensor of inlet
5-seal valve 6-pressure sensor of outlet 7-flow sensor 8-regulating valve
9-water storage tank 10-packing mouth 11-vacuum pump

4. Results and analysis

4.1 The conversion of the results of experiment

If the flow is in the 50% to 120% range of the highest efficiency point flow under the corresponding experiment speed, and the experiment speed is in the 80% to 120% range of the specified speed. All the date should be converted to the prescribed speed as the benchmark, conversion formulae are as follows

$$Q_T = Q\left(\frac{n_{sp}}{n}\right) \tag{5}$$

$$H_T = H\left(\frac{n_{sp}}{n}\right)^2 \tag{6}$$

$$NPSHA_T = NPSHA\left(\frac{n_{sp}}{n}\right)^2 \tag{7}$$

where, Q_T, H_T, $NPSHA_T$ are the value under the prescribed speed n_{sp}, Q, H, $NPSH_A$ are the value under the measured speed n.

Records of the results of experiment

According to the experiment device known, when calculating the total head H, the position difference of import and export pressure points is 0.62m. Because of the diameter of import and export pipeline is equal, so the velocity difference of import and export is zero. Only change is the inlet velocity head varies according to the change of experimental flow. The experimental data are shown in table 1 to table 3.

Table 1 the test data of the rated flow condition

In table 1, the inlet velocity head is 0.031m.

S/N	Flow	Import vacuum gauge	Reduced import head	Outlet pressure gauge	Reduced export head	Total head	Speed	NPSHa	Conversion to the rated speed		
									Flow	Head	NPSHa
	Q	$\frac{H_v}{M_s}$	$\frac{P_1}{\rho g}$	M_d	$\frac{P_2}{\rho g}$	H	n	$(NPSH)_a$	Q^O	H^O	$(NPSH)_a^0$
	m^3/h	MP_a	m	MP_a	m	m	r/min	m	m^3/h	m	m
1	198.51	-0.009	-0.918	0.200	20.12	21.66	1487	7.415	193.531	20.585	7.048
2	198.51	-0.012	-1.224	0.197	19.814	21.66	1487	7.109	193.518	20.583	6.757
3	198.51	-0.016	-1.632	0.195	19.610	21.86	1488	6.701	193.479	20.768	6.366
4	198.51	-0.020	-2.040	0.190	19.100	21.76	1487	6.293	193.544	20.685	5.982
5	198.51	-0.022	-2.224	0.187	18.794	21.66	1487	6.089	193.622	20.605	5.793
6	198.51	-0.024	-2.448	0.185	18.590	21.66	1488	5.885	193.492	20.577	5.591
7	198.51	-0.026	-2.652	0.183	18.386	21.66	1487	5.681	193.518	20.583	5.399
8	198.51	-0.028	-2.856	0.179	17.978	21.45	1486	5.477	193.687	20.424	5.214
9	198.51	-0.032	-3.264	0.175	17.570	21.45	1486	5.069	193.661	20.419	4.824
10	198.51	-0.034	-3.468	0.173	17.366	21.45	1488	4.865	193.479	20.380	4.622
11	198.51	-0.036	-3.673	0.170	17.060	21.35	1488	4.661	193.492	20.286	4.428
12	198.51	-0.038	-3.876	0.168	16.856	21.35	1488	4.457	193.479	20.284	4.234
13	198.51	-0.042	-4.284	0.160	16.040	20.94	1486	4.049	193.753	19.952	3.857
14	198.51	-0.043	-4.386	0.158	15.836	20.84	1487	3.947	193.544	19.812	3.752
15	198.51	-0.044	-4.488	0.152	15.224	20.33	1488	3.845	193.440	19.307	3.651
16	198.51	-0.048	-4.896	0.140	14.000	19.52	1487	3.437	193.622	18.567	3.269
17	198.51	-0.052	-5.304	0.118	11.756	17.68	1487	3.092	193.596	16.816	2.881
18	198.51	-0.054	-5.508	0.100	9.920	16.05	1481	2.825	194.315	15.377	2.707

Table 2 the test data of the small flow condition

In table 2, the inlet velocity head is 0.021m.

S/N	Flow	Import vacuum gauge	Reduced import head	Outlet pressure gauge	Reduced export head	Total head	Speed	NPSHa	Conversion to the rated speed		
									Flow	Head	NPSHa
	Q	$\frac{H_v}{M_s}$	$\frac{P_1}{\rho g}$	M_d	$\frac{P_2}{\rho g}$	H	n	$(NPSH)_a$	Q^O	H^O	$(NPSH)_a^0$
	m^3/h	MP_a	m	MP_a	m	m	r/min	m	m^3/h	m	m
1	163.57	-0.012	-1.224	0.212	21.344	23.19	1485	7.099	159.693	22.102	6,768
2	163.57	-0.016	-1.632	0.206	20.732	22.98	1485	6.691	159.715	21.913	6.379
3	163.57	-0.022	-2.244	0.200	20.120	22.98	1485	6.079	159.672	21.902	5.793
4	163.57	-0.028	-2.856	0.193	19.406	22.88	1486	5.467	159.661	21.801	5.209
5	163.57	-0.032	-3.264	0.189	18.998	22.88	1486	5.059	159.640	21.796	4.819

6	163.57	-0.036	-3.672	0.183	18.386	22.68	1486	4.651	159.607	21.593	4.428
7	163.57	-0.039	-3.978	0.179	17.978	22.58	1485	4.345	159.736	21.530	4.144
8	163.57	-0.042	-4.284	0.174	17.468	22.37	1485	4.039	159.747	21.338	3.852
9	163.57	-0.044	-4.488	0.168	16.856	21.96	1484	3.835	159.779	20.958	3.659
10	163.57	-0.046	-4.692	0.166	16.652	21.96	1486	3.631	159.661	20.927	3.459
11	163.57	-0.048	-4.896	0.162	16.244	21.76	1486	3.427	159.607	20.718	3.263
12	163.57	-0.050	-5.100	0.151	15.122	20.84	1488	3.223	159.393	19.791	3.061
13	163.57	-0.052	-5.304	0.137	13.694	19.62	1487	3.019	159.522	18.659	2.871

Table 3 the test data of the large flow condition

In table 3, the inlet velocity head is 0.0446m.

S / N	Flow	Import vacuum gauge	Reduced import head	Outlet pressure gauge	Reduced export head	Total head	Speed	$NPSH_a$	Conversion to the rated speed		
									Flow	Head	$NPSH_a$
	Q	$\frac{H_v}{M_s}$	$\frac{P_1}{\rho g}$	M_d	$\frac{P_2}{\rho g}$	H	n	$(NPSH)_a$	Q^O	H^O	$(NPSH)_a^0$
	m^3/h	MP_a	m	MP_a	m	m	r/min	m	m^3/h	m	m
1	237.92	-0.018	-1.8360	0.168	16.856	19.31	1486	6.511	232.125	18.383	6.197
2	237.92	-0.0208	-2.1216	0.165	16.550	19.29	1486	6.225	232.156	18.368	5.927
3	237.92	-0.0244	-2.4888	0.161	16.142	19.25	1486	5.858	232.219	18.339	5.580
4	237.92	-0.0268	-2.7336	0.159	15.938	19.29	1483	5.613	232.266	18.386	5.349
5	237.92	-0.0300	-3.0600	0.155	15.530	19.21	1486	5.287	232.109	18.283	5.032
6	237.92	-0.0340	-3.4680	0.152	15.224	19.31	1484	4.879	232.516	18.445	4.660
7	237.92	-0.0360	-3.6720	0.147	14.714	19.01	1485	4.675	232.313	18.121	4.457
8	237.92	-0.040	-4.0800	0.139	13.898	18.6	1484	4.267	232.406	17.746	4.071
9	237.92	-0.0422	-4.3044	0.133	13.286	18.21	1485	4.042	232.344	17.367	3.855
10	237.92	-0.0448	-4.5696	0.127	12.674	17.86	1486	3.777	232.125	17.004	3.595
11	237.92	-0.0480	-4.8960	0.120	11.960	17.48	1486	3.451	232.172	16.642	3.286
12	237.92	-0.0502	-5.1204	0.114	11.348	17.09	1485	3.226	232.250	16.284	3.074
13	237.92	-0.0538	-5.4876	0.098	9.7160	15.82	1486	2.859	232.156	15.066	2.722
14	237.92	-0.0540	-5.5080	0.082	8.084	14.21	1486	2.839	232.234	13.541	2.705

4.2 The experimental curve

According to the data in table 1 to table 3 and taking $NPSH_A$ as the abscissa and H as the ordinate. According to a certain scale and drawing the curve of $H=f(NPSH_A)$ under the prescribed speed, as shown in fig. 2.

In the curve of $H=f(NPSH_A)$ shown in figure, for each given flow, when the head of the pump fell by 3%, the corresponding value of $NPSH_A$ is defined as the value of $NPSH_{cr}$ which under the condition of given flow. At this time $NPSH_{cr}$ = $NPSH_R$. It can be seen from figure 2, under the rated flow condition, $NPSH_{cr}$=3.752m; under the small flow condition, $NPSH_{cr}$=3.459m; and under the large flow condition, $NPSH_{cr}$=4.211m. Tracing above corresponding points of the value of Q and $NPSH_{cr}$ in $NPSH_{cr}$-Q coordinate diagram and connecting each point into a smooth curve. That is the relationship curve of $NPSH_{cr}$-Q, as shown in fig. 3.

As can be seen from the figure 2 and figure 3, in the premise of guaranteeing the flow of experimental condition remains the same, the head of the pump fell by 3% can be used as the basis for judging the cavitation inception inside the pump. The value of $NPSH_{cr}$ of centrifugal pump increases along with increasing of flow.

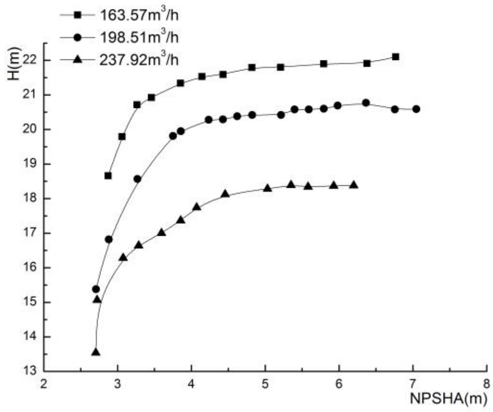

Fig. 2 the curve of $H=f(NPSH_A)$ under different flow

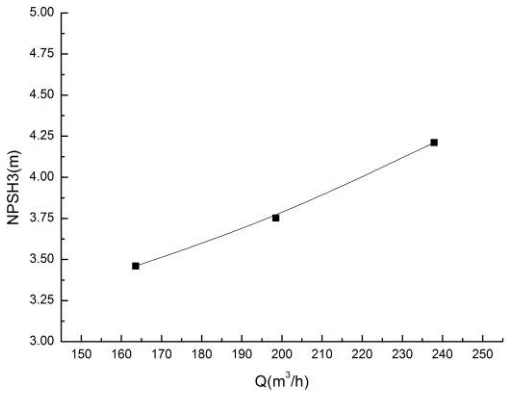

Fig. 3 the relationship curve of $NPSH_{cr}$-Q

5. Conclusion

In the process of experiment, judgment the point which cavitation occurs is the key. Therefore, when the flow rate and outlet pressure of pump dropped significantly, special attention should be paid to observe and listen carefully to the noise of pump and measuring points should also be encrypted appropriate to judge the occurrence of cavitation. When cavitation occurs, the outlet pressure of pump will decline rapidly and noise and vibration will increase obviously. In order to the accuracy of experiment, it is best to drawing the curve of $H=f(NPSH_A)$ while testing.

According to the experimental data and the resulting curves, the value of $NPSH_{cr}$ of centrifugal pump increases along with increasing of the flow of experimental condition.

In the premise of guaranteeing the flow of experimental condition remains the same, the head of the first stage impeller of pump fell by 3% can be considered the cavitation inception inside the pump. This basis can be used not only to instruct the engineering practice, but also to conduct the cavitation live monitoring of centrifugal pump, which is conducive to judge the occurrence of cavitation timely and reduce the damage caused by cavitation.

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