Cavitation Detection of Centrifugal Pump Using Vibration Signature Analysis

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Abstract

Cavitation is one of the most common faults in pumps and could lead serious problem such as increasing vibration level, noise and rapid deterioration of the impeller, seal, bearing, shaft and motor. Therefore, condition monitoring of pumps is very important to guarantee the availability and functional of the pumps. In this work, an experimental test rig of centrifugal pump was set up to investigate the cavitation detection using vibration analysis method, and measured parameters including pressure and flow rate for feasibility of cavitation detection. The experimental testing includes four conditions of closing suction valve: 0 , 30 , 45 and 60 . It was shown that the high frequency random vibration in the fast Fourier transform (FFT) spectrum was salient and applicable for cavitation diagnosis. The amplitude of vibration was increased significantly in the spectrum during cavitation existence.

Keywords: Cavitation, centrifugal pump, detection, vibration.

1. Introduction

In modern era, the pumps occupy a very important role for human life and industries such as drinking water industry, oil, petrochemical, power plant and so on. According to a survey in United Kingdom conducted by Sulzer Pump, centrifugal pump involving more than 70% of new pumps markets with a financial total of 16 billion Swiss Francs [1]. This leads to our consent that the research and development in the field of centrifugal pumps has to be improved continuously, regarding the performance and the manufacture of the pumps itself. This condition can be seen in Fig. 1.

However, centrifugal pump often suffers the problem is called cavitation. If cavitation occurs, it will result in noise, increasing vibration level and rapid deterioration of the impeller, seal, bearing, shaft and motor. Cavitation phenomenon has attracted attention of scholars since long time ago. According to Young, Isaac Newton was the first to conduct the observation of cavitation phenomenon in a low pressure area formed between rolling surface [1]. Wislicenus has documented research of cavitation that occurs on ship propeller which has been investigated by Reynolds long before the trial of destroyer 'Daring' in 1894 [2].

Ng and Brennen conducted a study of the dynamic behavior of a pump that had cavitation [3]. Knapp also conducted this study and examined the matrix measurements of dynamic transfer of a normal pump and the one that experiencing cavitation. A transfer function was able to confirm the presence of cavitation, and this can theoretically be explained clearly [4]. Safiah reported a study on the prediction of cavitation in centrifugal pumps based on particular suction specific speed (NSS), which turned out to show a good performance of the pump [5].

2. Cavitation Theory

Thoma suggested that NPSH proportional to H, and cavitation efficiency can be expressed with:

$$\sigma_{TH} = \frac{NPSH(\Delta H)}{H} \quad (1)$$

where H is total head, and H is net positive suction head. But some researchers were raising questions about the above equation that the cavitation typically occurs on the suction side of a pump [6].

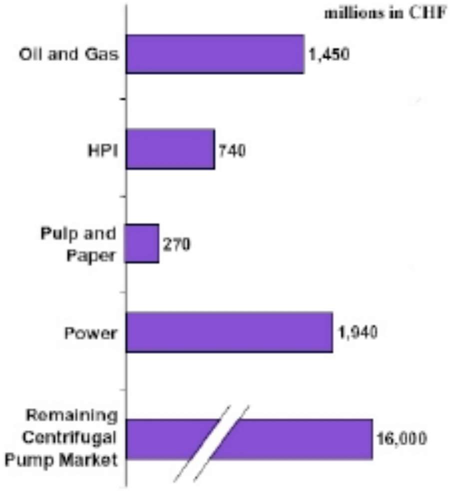


Fig. 1 Estimation of the market of centrifugal pump [1]

Pearsall reported that cavitation occurs when the suction pressure drops too low or when the fluid velocity is too high [7]. Cavitation occurs when the local pressure on the suction side of the blade drop near the vapor pressure of the fluid. This happened on the leading edge of the impeller. Critical net positive suction energy (NPSE) has been defined as decline of 2% of the non-cavitation condition characteristics as shown in Fig. 2.

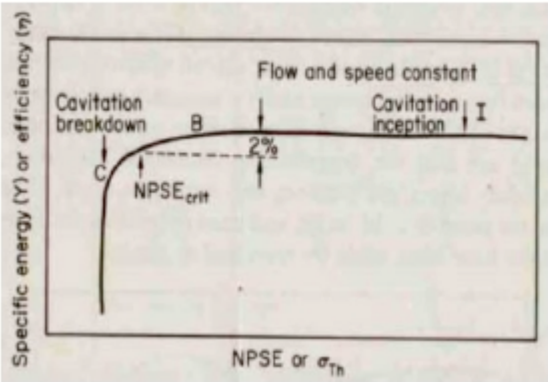


Fig. 2 Characteristic of Pump Cavitation [7]

According to a study conducted by Jensen and Dayton, the flow of the pump declines quickly when cavitation occurs [8]. It is clearly seen that when the cavitation occurs, the pump performance will decrease quickly. The flow rate could be down less than half of that expected. The flow can be a good indicator when the cavitation occurs. Mitchel has conducted a cavitation test using analysis of vibration feature in the field [9]. Cavitation will increase turbulence through impeller which will cause an increase in amplitude of blade frequency. This knowledge becomes very valuable for the field of diagnosis of pump cavitation feature. In addition, analytical techniques such as time averaging, envelope detection, the average peak, and pulse counting proven to show cavitation characteristics based on vibration.

Blade pass frequency (BPF), as shown in Fig. 3, is a characteristic of pump and vane. This frequency sticks to the pump, causing a very high noise level. But a large amplitude on BPF (harmonic) can be generated if the pump having a speed difference in vane rotation and diffuser. BPF can sometimes arise when the natural frequency of the system causing a high vibration.

$$BPF = \frac{\#Blades}{60} xRPM \qquad (2)$$

Cavitation as shown in Fig. 4 usually occurs randomly at high frequencies which indicated by harmonic BPF. If the fluid pressure drops below the saturated vapour pressure, bubbles will appear in the fluid. Cavitation can cause failure to the pump and reduce pump performance. Each of these bubbles produces some sort of impact that tends to generate random vibration at high frequencies.

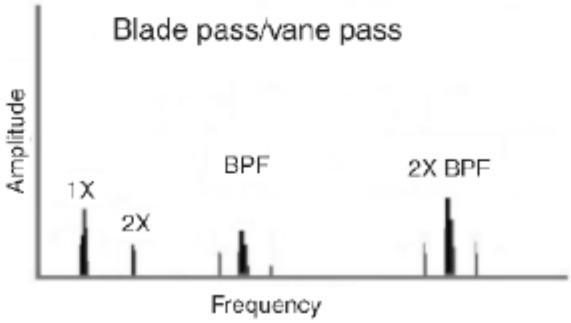


Fig. 3 Blade Pass Frequency [10].

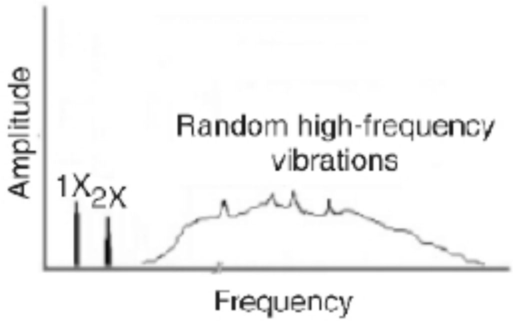


Fig. 4 Cavitation presented by vibration signal in frequency domain [10]

3. Experimental work

In this study, data acquisition was conducted by using a test rig facilities called machine fault simulator (MFS) which is able to conduct experiments for rotating machineries, including centrifugal pumps. Vibration, pressure and flow rate data are acquired by accelerometer sensor, pressure gauge, and flow meter, respectively. Vibration data was acquired through VibraQuest software on a laptop that was connected to the machine fault simulator (MFS) to display and analyze time domain signals and frequency domain signals. Fig. 5 shows the pressure data measurements in centrifugal pumps.

Fig. 5 Installation of centrifugal pump experiment

Condition taken at the time of testing is by varying the pump rotating speed and opening suction valve. Several different conditions of pump rotating speed are intended to determine whether or not the phenomenon of cavitation occurred on low, medium, or high rotation.

The several numbers of opening suction valve at the tank were made for simulating the cavitations at certain pressure condition in accordance with the value when the suction valve opened. The rotating speed was increasing between 1400 rpm, 2400 rpm, 3000 rpm and 3600 rpm while the cover degrees of valve in outer tank are 0°, 30°, 45° and 60°. When the valves mathematically in the outer tank 0° means it is opened as much as one full rotating, 30° means the suction valve is rotated 30° for closing direction, 45° means the suction valve is rotated 45° for closing direction too and that way is also applied for 60°.

4. Results and Discussion

The results of measurements of vibration with various rotating speed of centrifugal pump were conditionally presented with suction valve at 0°, 30°, 45° and 60°. Table 1 shows the example of measurement data of such pump with suction valve 45°. Data of measurements on the tank of suction valve with condition 0° and 30° indicate that it is almost same where cavitations does not exist at all of the rotational. This happened because the pressure changing is relatively small in the suction valve so there is no turn into saturated vapour.

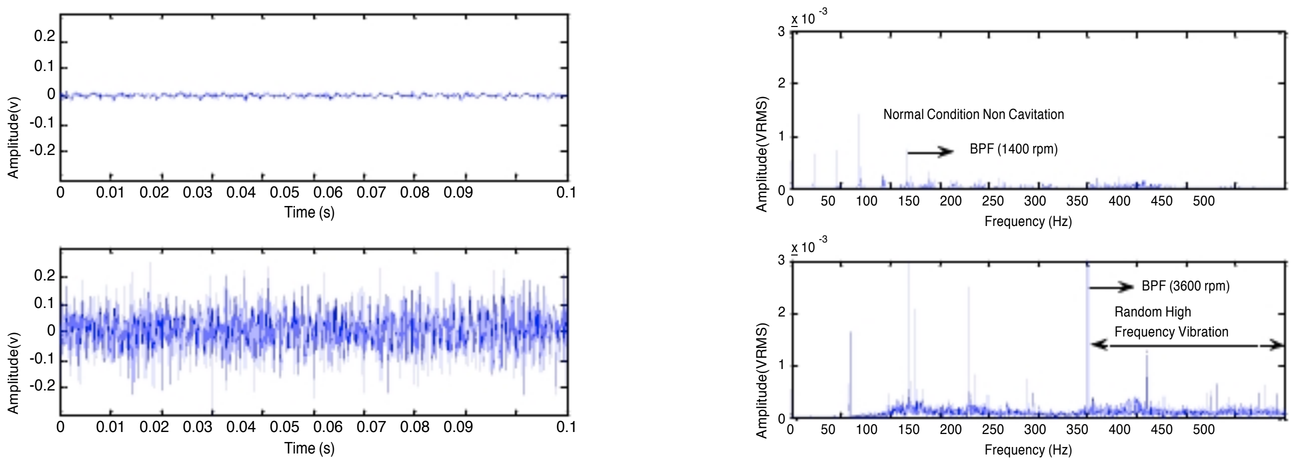
While the condition of the suction valve 45° and 60°, the pressure would be changing on the suction turned out to be relatively large so it becomes to water saturated vapor pressure especially in the conditions of 3000 rpm and 3600 rpm. Visually, it can also be seen through the cover setrifugal pump that looks a bubble of air around the impeller pump.

Table 1 Results of measurements at discharge valve 45°

RPM	Pressure at suction (Psi)	Pressure at discharge (Psi)	F (Hz)	Condition
1393	-1	1	23,41	No cavitation
1400	-1	1	23,48	No cavitation
1401	-1	1	23,42	No cavitation
2394	-6	7	40,05	No cavitation
2400	-6	7	40,09	No cavitation
2401	-6	7	40,08	No cavitation
2999	-10	8	50,04	No cavitation
3001	-10	8	50,06	No cavitation
3006	-10	8	50,01	No cavitation
3594	-14	13	60,11	Cavitation
3598	-14	13	60,12	Cavitation
3600	-14	13	60,14	Cavitation

At 1400 rpm the amplitude of vibration signal is small enough, that is equal to $3.5x10^{-3}$ in/det^2. This amplitude was increased as $4x10^{-3}$ in/det^2 for the rotating speed of 3000. At this speed, the condition is prior cavitation. When the rotating speed is increased until 3600 rpm, vibration amplitude increases as much as $49{,}73x10^{-3}$ in/det^2. It means, cavitation occurs which is indicated by maximum amplitude at BPF and it has been already started in high frequency area.

The comparison of vibration signal acquired from centrifugal pump in normal condition and cavitation condition are presented in Fig. 6. This figure show a significant difference of vibration signal amplitude in time domain and frequency domain for normal and cavitation conditions.



(a) (b)

Fig. 6 Time waveform and FFT of vibration signal: a) at 1400 rpm (normal); and b) at 3600 rpm (cavitation)

Another experimental data is presented as plot of Head (m) versus NPSH and flow rate Q (m^3/s) with variation of valve conditions at 1400 rpm, when the pump was operated in normal condition. These conditions are depicted in Figs. 7 and 8. Obeserving Fig. 7, the head is reduced as increasing NPSH with the closing conditions of valve are 60°, 45°, 30° and 0°. This situation also increases the flow rate of centrifugal pump with varying of closing conditions of valve as shown in Fig. 8.

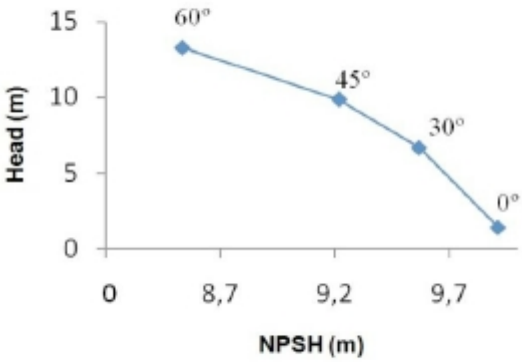


Fig. 7 Plot of Head v.s. NPSH at normal condition (1400 rpm)

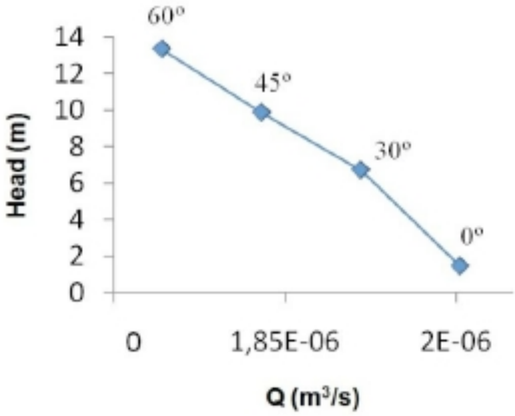


Fig. 8 Plot of head (H) v.s. flow rate (Q) at normal condition (1400 rpm)

When the cavitation occurs at 3600 rpm, the situation was changed. The maximum head of centrifugal pump was reduced till remain 10 m. The NPSH was also reduced till only maximum of 8.5 m, but the flow rate Q was not significantly changed. However, for the closing condition of valve is 45°, the head was suddenly increased, because increasing of friction in the suction pipe. When the valve was closed further (60^0), then there is cavitations in the pump. The cavitations are indicated from figure 9 and figure 8 that of decreasing of Head and pump capacity. The phenomenon agree with the time waveform and FFT of vibration signal in figure 6.

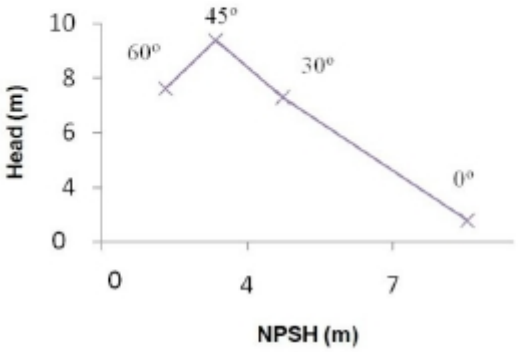


Fig. 9 Plot of head (H) v.s. NPSH at cavitation condition (3600 rpm)

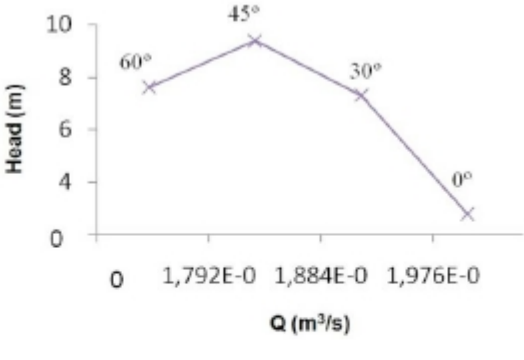


Fig. 8 Plot of head (H) v.s. flow rate (Q) at cavitation condition (3600 rpm)

5. Conclusion

Vibration signature can inform the cavitation condition on centrifugal pump. The characteristic of vibration of centrifugal pump under cavitation is presented in high-frequency range after blade pass frequency (BPF). BPF can be a reference frequency for cavitation detection in centrifugal pump. In this work, the frequency of 300 Hz is detected as BPF of tested centrifugal pump and the frequency range after 300 Hz shows random vibration that represents cavitation in the pump. The amplitude of vibration was also increased significantly after cavitation occured from 3.5×10^{-3} in/det^2 to $49{,}73 \times 10^{-3}$ in/det^2. The difference of pressure between suction and discharge confirms that cavitation was started 3594 rpm. Cavitation produces decreasing the total head and NPSH of the pump, but the flow rate (Q) was not significantly changed based on the experimental work.

Acknowledgments

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Nomenclature

σ_{TH}	Cavitation efficiency	H	Total head [m]
H	Net positive suction head (*NPSH*) [m]	*NPSE*	Net positive suction energy
BPF	Blade pass frequency [Hz]	Q	Flow rate (m^3/s)

References

[1] Young, R.F., 1999, Cavitations, 2nd Ed., Imperial College, London.
[2] Wislicenus, G.F., 1969, "Remarks on the History of Cavitations as an Engineering Problem", Proceeding of the ASME Fluids Engineering and Applied Mechanics Conference, Illinois, June 16-18, New York, 10-14.
[3] Ng, S.L. and Brennen, C., 1978, "Experiments on the Dynamic Behavior of Cavitating Pumps", Journal of Fluid Engineering, ASME, Vol. 100, pp. 166-176.
[4] Knapp, R.T., Daily, J.W. and Hammit, F.G., 1970, Cavitation, McGraw Hill, New York.
[5] Safiah, O., 2002, "Cavitation Prediction in Centrifugal Pumps", M. Eng. Thesis, University Technology Malaysia.
[6] Thoma, D., 1926, Die Kavitation bei Wasser-Turbinen, VDI Verlag, Berlin.
[7] Pearsall, I.S., 1972, Cavitation, Miils and Boon, London.
[8] Jensen, J. and Dayton, K., 2000, "Detecting Cavitation in Centrifugal Pumps – Experimental Results of the Pump Laboratory, Orbit Second Quarter, 26-30.
[9] Mitchell, J.S., 1975, "Examination of Pump Cavitation, Gear Mesh and Blade Performance Using External Vibration Charactericties", Proceeding of the 4th Turbomachinery Symposium, Texaz A&M University, Oct. 14-16, 39-45.
[10] Paresh, G., 2004, Practical Machinery Vibration Analysis and Predictive Maintenance, Newnes An imprint of Elsevier Linacre House, Jordan Hill, Oxford OX2 8DP 200 Wheeler Road, Burlington, MA 01803.