AN EXPERIMENTAL AND FIELD STUDY OF CAVITATION DETECTION IN PUMP

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To Pa, late-Mum, and family for
their love and support.

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ABSTRACT

Cavitation represents one of the most common faults in pumps and could potentially lead to a series of failures in mechanical seal, impeller, bearing, shaft, motor, etc. In this work, an experimental rig was setup to investigate cavitation detection using vibration analysis method, and measured parameters including sound, pressure and flow rate for feasibility of cavitation detection. The experimental testing includes 3 operating points of the centrifugal pump (Best Efficiency Point, 90% of Best Efficiency Point and 80% of Best Efficiency Point). It was shown that the high frequencies random vibration in the fast fourier transform (FFT) spectrum was vital and applicable for cavitation diagnosis. Cavitation was found to have easily excited natural frequencies of the pump components. There was a significant vibration amplitude increase at the frequency of ½ of blade passing frequency (BPF) in the envelope spectrum during cavitation existence. High impulsive spikes were clearly evident in the vibration time signal of cavitation. A grinding sound synonymous with cavitation was clearly audible during cavitation. Margin ratio of net positive suction head (NPSH), suction energy, cavitation number and flow rate were proven to be a good indicator for detecting cavitation. The findings of the experimental results were consistent for all test conditions. The field investigation of two submerged vertical pumps with suspected cavitation and flow induced vibrations in a power plant are presented. Such pumps do not have an adequate pressure and flow instrumentation that could detect abnormal hydraulic operating conditions. These pumps had a history of catastrophic impeller failures and the failure modes showed cavitation erosion and a sheared impeller blade. High frequencies random vibration was a good indicator for flow excitation and cavitation in the field investigation. Evidence of an excessive clearance and/or sleeve bearing wear were also noted in the pump of concern. The field investigations confirmed concern relating to operations during low tide and combined pumps operated in parallel where inadequate submergence were identified as the likely causes to the impeller failures. The impeller of concern was identified as not being the root cause of the problem. The investigations implied a system design problem and pump operating conditions compounding the system design error that had resulted in frequent failures of the pumps.

ABSTRAK

Kavitasi merupakan salah satu masalah yang kerap berlaku dalam pam dan boleh mengakibatkan kegagalan pada pengadang mekanikal, bilah, aci, bering, motor dan sebagainya. Dalam tesis ini, ujikaji telah disediakan untuk mengkaji teknik mengesan kavitasi dengan kaedah analisis getaran, serta parameter-parameter bunyi, tekanan dan kadar aliran. Kajian ini melibatkan 3 titik operasi pam empar (Titik operasi paling efisien, 90% daripada titik operasi paling efisien and 80% daripada titik operasi paling efisien). Hasil ujikaji menunjukkan getaran rambang yang berfrekuensi tinggi dalam spektrum FFT adalah penting serta sesuai untuk mengesan kavitasi. Kavitasi boleh merangsang frekuensi asli komponen pam dengan mudah. Semasa berlakunya kavitasi, diperhatikan terdapat peningkatan amplitud getaran yang nyata pada ½ daripada frekuensi bilah memusing dalam spektrum sepadan. Hentakan bertubi dapat dikesan dan jelas terbukti dalam isyarat masa getaran semasa kavitasi. Terdapat juga bunyi kisaran yang jelas kedengaran semasa kavitasi. Nisbah margin tekanan sedutan, tenaga sedutan, nombor kavitasi dan kadar aliran telah terbukti sebagai petunjuk yang baik untuk mengesan kavitasi. Penemuan keputusan ujikaji konsisten untuk semua keadaan yang telah diuji. Ujikaji dijalankan ke atas dua buah pam tegak terbenam di stesan jana kuasa eletrik yang bermasalah. Pam-pam tersebut tidak dilengkapi dengan instrumentasi tekanan dan kadar aliran yang dapat mengesan keadaan operasi hidraulik yang tidak normal. Pam-pam tersebut juga mempunyai latar belakang kegagalan bilah yang teruk di mana corak kegagalannya mencadangkan kavitasi kakisan dan bilah yang pecah dengan cendung. Getaran rambang yang berfrekuensi tinggi merupakan petunjuk yang baik untuk gangguan aliran dan kavitasi dalam ujikaji ini. Bering didapati mempunyai kelonggaran yang berlebihan pada pam yang bermasalah. Hasil ujikaji ini telah membuktikan bahawa punca sebenar kegagalan bilah adalah berasaskan keadaan operasi pam seperti laut surut dan kekurangan redaman bagi pam-pam yang beropreasi secara selari dan bukannya masalah bilah itu sendiri sahaja. Ujikaji ini juga menunjukkan masalah reka bentuk sistem telah menyebabkan kegagalan pam yang kerap, dan keadaan operasi pam telah memburukkan lagi kesilapan rekabentuk sistem tersebut.

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LIST OF ABBREVIATIONS

B.E.P	-	Best Efficiency Point
BPF	-	Blade Passing Frequency
BPFI	-	Inner Ball Passing Frequency
BPFO	-	Outer Ball Passing Frequency
CFD	-	Computational Fluid Dynamics
CHF	-	In currencies, this is the abbreviation for the Swiss Franc.
FFT	-	Fast Fourier Transform
GVF	-	Guide Vane Frequency
HPI	-	Hydrocarbon Processing Industry
NPSH	-	Net Positive Suction Head
NPSHa	-	Available Net Positive Suction Head
NPSHr	-	Required Net Positive Suction Head
SPL	-	Sound Pressure Level
SVP1	-	Submerged Vertical Pump 1
SVP2	-	Submerged Vertical Pump 2
TDH	-	Total Delivery Head
VDMA	-	German Engineering Federation (*Verband Deutscher Maschinen- und Anlagenbau*)

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CHAPTER 1

INTRODUCTION

1.1 Overview

Imagine a world without pumps. It is hard as pumps are everywhere. Modernization had changed the life style, of the human mankind where mechanical equipments such as pumps plays a vital role in various industries. These industries include water, oil and gas, petrochemical, power generation, etc. The common usage and application area of centrifugal pump are tabulated in Table 1.1. This work was undertaken to investigate a problem that often affect the reliabilities of a pump.

From the estimation of new pump market done by Sulzer Pumps (2006) as shown in Figure 1.1, centrifugal pump consists more than 70% of the estimated new pump market with a financial cost of 16 billions CHF. It is therefore not surprising that continuous extensive research & development for pump manufacturers and operators had been undertaken.

Centrifugal Pump Application Areas	
Energy	• Feedwater Circuit • Condensate Circuit • Cooling Water Circuit • Auxiliary Circuits
Oil	• Water Injection • Oil Pipeline Pumps • Petrochemicals
Water	• Seawater Transport • Drinking Water Supplies • Irrigation • Drainage • Sewage
Industry	• Mine Drainage • Sugar Refining • Paper Production • Marine Duties • Hydraulic Conveyance of Solids • Flue-gas desulphurization • Seawater desalination • Energy Recovery

Table 1.1 Centrifugal pump application areas

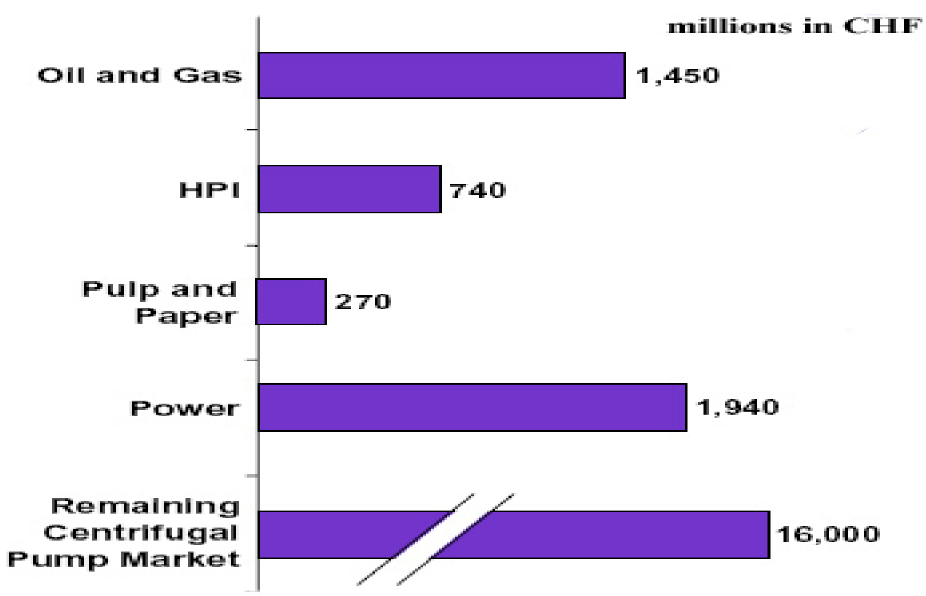

Figure 1.1: Estimated new pumps market (extracted from Sulzer Pumps)

A study done by Yates (1996) showed that pumps consume approximately 25% of the national electricity of United Kingdom. This was consistent with finding of Bloch and Budris (2005) that centrifugal pumps represent the most frequently utilized machine on the earth. It has estimated that over 100,000,000,000 of them are in use worldwide, consuming approximately 20% of the world's energy demand. Various research and studies have shown that improvements to pumping plant performance would save 12.5% and improvements in pumping systems and operation could save a further 37.5% (Yates). To conserve energy, pumps need to operate at high efficiency. An efficiency drop would imply more power input for the same flow. Selection and design do affect the efficiency and reliability of a pumping system. Although an appropriate selection may be done, the operating parameters in real industry do vary over the time. The plant maintenance personnel strive to enhance the reliability of machinery.

Various faults can occur in the centrifugal pump that results in low efficiency operation of centrifugal pump. The survey carried out on behalf of the VDMA showed that 80% of the pump failures in the chemical and process industries were from cavitation, dry run, gas containing liquids, externally excited vibrations, imbalance, wear of bearing and blockage (pressure side and/or suction side gate valve closed). It was found that cavitation is however the most common faults.

Cavitation-related phenomena include such diverse occurrence such as erosion of ship propellers, ultrasonic cleaning, detection of high energy particles, fragmentation of biological cells, etc (Young, 1999). Cavitation also occurs in the body of a human-being. While flying, a rapid drop in the cabin pressure at high altitude will cause cavitation in the blood. When a diver comes to the surface too fast after a deep dive, cavitation also will occur. Cavitation may cause damage to heart valves, and at the junction of arteries may cause to heart valves. Artificial mechanical pump could be damaged due to cavitation. A useful medical application of cavitation is however ultrasound. The cavitation induced at the tip of this probe creates the desired effect when it is placed close to the tissue or solid material. One of the earliest uses of an ultrasonic probe was in dentistry, where ultrasonic probes are now commonly used to clean teeth. Another interesting use of cavitation in blood systems is the removal of a thrombus consisting of a quantity of coagulated blood that blocks the blood vessel, by inserting a hollow ultra sonic waveguide of small diameter into the blood vessel.

While cavitation can have useful application, cavitations in the industry are often with serious consequence. On 15 November 1999, H-II Flight #8 was officially launched from Tanegashima Space Center, Japan (which is appended in Appendix). The first stage engine suddenly failed after 3 minutes and 59 seconds upon launching. Investigation showed that cavitation in the turbo pump was the root cause. The blade in the turbo pump and inlet of the liquid hydrogen turbo pump broke, resulting in a stoppage of the supply of the propellant. This resulted in a sudden failure of the engine.

A more common occurrence covering the entire industry is relates to cavitation in pumps and hydraulic machines in general. In this work, cavitation detection study focused primarily on pumps. Experimental studies were carried out to detect cavitation in a centrifugal pump using vibration analysis. Background studies were undertaken and an experimental test rig was fabricated for cavitation induced investigations. Sound, pressure, flow rate were measured for both cavitation and normal operating conditions. Field investigation was undertaken, with vibration measurements on vertical submerged pumps in a power generation plant with suspected cavitation failures. Cavitation and flow excited vibration on the pump was successfully detected with vibration diagnosis.

1.2 Problem Formulation

In the Malaysian industry, pumps have often been blamed as the source of the problem when cavitation related damages occur even though the source of a problem may be in the work process or system design. Some end-users are reluctant to accept the fact that changes in their process has indeed upset the pumping condition and causing the cavitation to be more severe. The detection of cavitation in centrifugal pump is then an important task in the industry.

It is often possible that changes in the process have been evolving which may result in conditions conducive to cavitation. Pump performance such as efficiency, flow rate or head (pressure) deteriorate over the time. Another common cause of cavitation in pump relates to the system design error. If the cavitation detection is not carried out, remedial work may not be initiated. The failure of pump could potential repeat. Unscheduled downtime will inevitably result in production loss and disruptions to the entire plant. Having the ability to detect the fault could reduce downtime and prevents catastrophic failure.

While cavitation can often be detected with pressure measurements, it had been noted that many pumps in the industry do not come adequately installed with pressure or flow sensors. Even if such sensors are installed, it is common that such measurement devices are not functional over time. As a result, pressure or flow drop during cavitation could not be detected even though the net positive suction head available (NPSHa) is lower than net positive suction head required (NPSHr), where cavitation would be expected to occur. Vibration analysis is hereby investigated as an indicator and detector of cavitation over and above its conventional use in mechanical severity assessment.

Cavitation often results in failure of the impellers, which is often preceded by premature failures of the mechanical seals. Failure of the impeller has serious consequential damage to the pump. Cavitation occurrence in the pump also results performance degradation of the pumps and this is usually not desirable. The detection of cavitation is obviously necessary, and a simple and robust technique using vibration analysis warrants the work reported herein.

1.3 Objectives of the Study

The objective of this work was to investigate vibration analysis in the detection of cavitation in centrifugal pumps using a laboratory test rig where cavitation would be induced under controlled condition. The vibration analysis technique shall then be used in a case study of actual pumps in an industrial facility.

1.4 Scopes of the Study

The scope of work involved the following.

1. A test facility involving a centrifugal pump where cavitation could be induced had to be fabricated. Suitable pressure and flow measurement devices were installed such that parameters affecting cavitation could be correlated. Both vibration and sound were measured.

2. Characteristic of cavitation experienced in the centrifugal pump under different operating points was studied. Comparison of cavitation and normal running condition are made. Fourier Analysis and Envelope Analysis have been carried out for vibration data. Analysis on sound pressure level, pressure and flow have been done

3. Field measurements were undertaken at an Independent Power Producer (power generation plant) to investigate a suspected cavitation and flow excited vibrations failure in the submerged vertical pumps.