

AN EXPERIMENTAL AND FIELD STUDY OF CAVITATION DETECTION IN
PUMP

TAN CHEK ZIN

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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 $\frac{1}{2}$ 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 $\frac{1}{2}$ 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 stesen jana kuasa elektrik 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 beroperasi 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.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	
	DECLARATION OF ORIGINALITY	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xii
	LIST OF FIGURES	xiii
	LIST OF ABBREVIATIONS	xxiii
	LIST OF APPENDICES	xxiv
1	INTRODUCTION	1
	1.1 Overview	1
	1.2 Problem Formulation	5
	1.3 Objectives of the Study	6
	1.4 Scopes of the Study	6

2	LITERATURE REVIEW	8
2.1	Introduction	8
2.2	Cavitation in Pumps	8
2.3	Cavitation Detection Parameter	12
2.3.1	Pressure	12
2.3.2	Flow Rate	15
2.3.3	Visualization	15
2.3.4	Sound	17
2.3.5	Vibration	19
	2.3.5.1 Fast Fourier Transform	21
	2.3.5.2 Envelope Analysis	23
	2.3.5.3 Wavelet Analysis	25
	2.3.5.4 Joint Time Frequency Analysis	26
2.4	Summary	26
3	OVERVIEW OF VIBRATION SIGNAL ANALYSIS	27
3.1	Introduction	27
3.2	Overview of Envelope Analysis Theories	28
3.3	Selection of Envelope Band Pass Filter	31
3.4	Overview of Fourier Analysis Theories	32
3.5	Comparison of Envelope Analysis and Fourier Analysis	34
4	RESEARCH METHODOLOGY	35
4.1	Overview	35
4.2	Experimental Study	36
4.3	Field Investigation	36

5	EXPERIMENTAL SET-UP AND PROCEDURE	38
5.1	Introduction	38
5.2	Experimental Rig Assembly	40
5.2.1	Pumping System	42
5.2.2	Pressure Variation System	42
5.2.3	Viewing / Observation System	43
5.3	Instrumentation & Calibration	44
5.3.1	Vibration Analyzer	44
5.3.2	Sound Level Meter	47
5.3.3	Pressure Gauge	48
5.3.4	Flow Rate Meter	49
5.4	Experimental Procedures	50
5.5	Repeatability and Confidence Limits of Experiments	51
6	EXPERIMENTAL RESULTS	52
6.1	Overview	52
6.2	Vibration	57
6.2.1	Envelope Spectrum	57
6.2.1.1	Casing (Rear) in Axial Direction	57
6.2.1.2	Casing (Front) in Axial Direction	59
6.2.1.3	Casing in Radial Direction	61
6.2.1.4	Suction Flange	63
6.2.1.5	Discharge Flange	64
6.2.1.6	Bearing in Horizontal Direction	66
6.2.1.7	Bearing in Vertical Direction	68
6.2.2	FFT Spectrum	70
6.2.2.1	Casing (Rear) in Axial Direction	70
6.2.2.2	Casing (Front) in Axial Direction	73
6.2.2.3	Casing in Radial Direction	75
6.2.2.4	Suction Flange	77
6.2.2.5	Discharge Flange	79
6.2.2.6	Bearing in Horizontal Direction	81
6.2.2.7	Bearing in Vertical Direction	83

6.2.3	Time Data	85
6.2.4	Bump Test Results	87
6.3	Sound	90
6.4	Pressure	94
6.5	Flow Rate	103
7	CONSOLIDATED FINDINGS AND DISCUSSION	105
7.1	Overview	105
7.2	Vibration	105
7.2.1	Envelope Analysis	106
7.2.2	Fourier Analysis	109
7.2.3	Time Domain	112
7.2.4	Bump Test	112
7.3	Sound	113
7.4	Pressure	113
7.5	Flow Rate	115
8	FIELD INVESTIGATION IN A POWER PLANT	116
8.1	Overview	116
8.2	Nature and History of the Problem	118
8.3	Field Investigation Philosophy	123
8.4	Vibration Instrumentation	126
8.5	Field Results of 1 st Visit (1 October 2005)	127
8.6	Field Results of 2 nd Visit (18 January 2006)	136
8.7	Field Results of 3 rd Visit (25 March 2006)	148
8.8	Field Results of 4 th Visit (26 May 2006)	160
8.9	Discussion and Consolidated Findings	172
8.10	Concluding Remarks	184

9	CONCLUSIONS AND FUTURE RECOMMENDATIONS	185
9.1	Conclusion for Experimental Study	185
9.2	Conclusion for Field Investigation	187
9.3	Future Recommendations for Experimental Study	188
9.4	Future Recommendations for Field Investigation	189
	REREFENCES	190
	Appendices A1-A8	196

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 1.1	Centrifugal pump application areas	2
Table 4.1	Band pass filter options	31
Table 6.1	Tabulation of controlled test conditions	53
Table 6.2	Experimental results of testing condition 1	54
Table 6.3	Experimental results of testing condition 2	55
Table 6.4	Experimental results of testing condition 3	56
Table 6.5	Locations of vibration measurements undertaken	57
Table 6.6	Tabulation of the natural frequencies at various locations	87
Table 6.7	Tabulation of SPL difference for testing condition 1	92
Table 6.8	Tabulation of SPL difference for testing condition 2	93
Table 6.9	Tabulation of SPL difference for testing condition 3	94
Table 7.1	Tabulation of suction energy for normal operating condition and cavitation condition under 3 different testing conditions	114
Table 8.1	Summary of recent failures in pump, work done to the impeller (Pump SVP1) and vibration investigations	124

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1.1:	Estimated new pumps market	2
Figure 2.1:	Cavitation characteristic of a pump	13
Figure 2.2:	Submerged vortex cavitation	16
Figure 3.1:	Summary of Envelope Analysis Technique	29
Figure 3.2:	Different signal types	33
Figure 4.1:	Overview of research methodology	37
Figure 5.1:	Schematic drawing of test rig	40
Figure 5.2:	Photograph of the test rig facilities	41
Figure 5.3:	Typical pressure profiles inside a pump	43
Figure 5.4:	Viewing window at pump suction	44
Figure 5.5:	SKF Vibration analyzer calibrated with vibration exciter RION VE-10	46
Figure 5.6:	HP 35670A Vibration Analyzer	46
Figure 5.7:	Sound Level Meter was being calibrated	47
Figure 5.8:	Pressure Indicator	48
Figure 5.9:	Flow rate meter	49
Figure 6.1:	Head vs flow of the centrifugal pump in the test rig	53
Figure 6.2:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Rear) in Axial Direction for Testing Condition 1.	58
Figure 6.3:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Rear) in Axial Direction for Testing Condition 2.	59
Figure 6.4:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Rear) in Axial Direction for Testing Condition 3.	59

Figure 6.5:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Front) in Axial Direction for Testing Condition 1.	60
Figure 6.6:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Front) in Axial Direction for Testing Condition 2.	60
Figure 6.7:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Front) in Axial Direction for Testing Condition 3.	61
Figure 6.8:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing in Radial Direction for Testing Condition 1.	62
Figure 6.9:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing in Radial Direction for Testing Condition 2.	62
Figure 6.10:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Casing in Radial Direction for Testing Condition 3.	62
Figure 6.11:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Suction Flange in Axial Direction for Testing Condition 1.	63
Figure 6.12:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Suction Flange in Axial Direction for Testing Condition 2.	63
Figure 6.13:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Suction Flange in Axial Direction for Testing Condition 3.	64
Figure 6.14:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Discharge Flange in Vertical Direction for Testing Condition 1.	65
Figure 6.15:	Envelope Spectrums of Cavitation and Normal Operating Condition at Pump Discharge Flange in Vertical Direction for Testing Condition 2.	65
Figure 6.16:	Envelope Spectrum of Cavitation and Normal Operating	

	Condition at Pump Discharge Flange in Vertical Direction for Testing Condition 3.	65
Figure 6.17:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Horizontal Direction for Testing Condition 1.	67
Figure 6.18:	Envelope Spectrums of Cavitation and Normal Operating Condition at Pump Bearing in Horizontal Direction for Testing Condition 2.	67
Figure 6.19:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Horizontal Direction for Testing Condition 3.	67
Figure 6.20:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Vertical Direction for Testing Condition 1.	69
Figure 6.21:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Vertical Direction for Testing Condition 2.	70
Figure 6.22:	Envelope Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Vertical Direction for Testing Condition 3.	70
Figure 6.23:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing (rear) in Axial Direction for Testing Condition 1.	72
Figure 6.24:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing (rear) in Axial Direction for Testing Condition 2.	72
Figure 6.25:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing (rear) in Axial Direction for Testing Condition 3.	72
Figure 6.26:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Front) in Axial Direction for Testing Condition 1.	74
Figure 6.27:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Front) in Axial Direction for Testing Condition 2.	74
Figure 6.28:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing (Front) in Axial Direction for Testing Condition 3.	74
Figure 6.29:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing in Radial Direction for Testing Condition 1.	76

Figure 6.30:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing in Radial Direction for Testing Condition 2.	76
Figure 6.31:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Casing in Radial Direction for Testing Condition 3.	76
Figure 6.32:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Suction Flange in Axial Direction for Testing Condition 1.	78
Figure 6.33:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Suction Flange in Axial Direction for Testing Condition 2.	78
Figure 6.34:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Suction Flange in Axial Direction for Testing Condition 3.	78
Figure 6.35:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Discharge Flange in Vertical Direction for Testing Condition 1.	80
Figure 6.36:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Discharge Flange in Vertical Direction for Testing Condition 2.	80
Figure 6.37:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Discharge Flange in Vertical Direction for Testing Condition 3.	80
Figure 6.38:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Horizontal Direction for Testing Condition 1.	82
Figure 6.39:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Horizontal Direction for Testing Condition 2.	82
Figure 6.40:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Horizontal Direction for Testing Condition 3.	82
Figure 6.41:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Vertical Direction for Testing Condition 1.	84
Figure 6.42:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Vertical Direction for Testing Condition 2.	84
Figure 6.43:	FFT Spectrum of Cavitation and Normal Operating Condition at Pump Bearing in Vertical Condition for Testing Condition 3.	84
Figure 6.44:	Comparison between normal and cavitation condition in time domain for Testing Condition 1	85
Figure 6.45:	Comparison between normal and cavitation condition in time	

	domain for Testing Condition 2	86
Figure 6.46:	Comparison between normal and cavitation condition in time domain for Testing Condition 3	86
Figure 6.47:	Bump test at rear side of centrifugal pump casing (axial direction)	87
Figure 6.48:	Bump test at front side of centrifugal pump casing (axial direction)	88
Figure 6.49:	Bump test at centrifugal pump casing (radial direction)	88
Figure 6.50:	Bump test at suction flange (axial direction)	88
Figure 6.51:	Bump test at discharge flange (vertical direction)	89
Figure 6.52:	Bump test at bearing (horizontal direction)	89
Figure 6.53:	Bump test at bearing (vertical direction)	89
Figure 6.54:	Comparison in Sound Pressure Level for Cavitation and Normal Operating Condition for Testing Condition 1.	91
Figure 6.55:	Comparison in Sound Pressure Level for Cavitation and Normal Operating Condition for Testing Condition 2.	91
Figure 6.56:	Comparison in Sound Pressure Level for Cavitation and Normal Operating Condition for Testing Condition 3.	92
Figure 6.57:	TDH vs Suction Pressure for Testing Condition 1	96
Figure 6.58:	TDH vs Suction Pressure for Testing Condition 2	96
Figure 6.59:	TDH vs Suction Pressure for Testing Condition 3	96
Figure 6.60:	TDH vs NPSHa for Testing Condition 1	98
Figure 6.61:	TDH vs NPSHa for Testing Condition 2	98
Figure 6.62:	TDH vs NPSHa for Testing Condition 3	98
Figure 6.63:	TDH vs Cavitation Number for Testing Condition 1	100
Figure 6.64:	TDH vs Cavitation Number for Testing Condition 2	100
Figure 6.65:	TDH vs Cavitation Number for Testing Condition 3	100
Figure 6.66:	Suction Energy vs Cavitation Number for Testing Condition 1	102
Figure 6.67:	Suction Energy vs Cavitation Number for Testing Condition 2	102
Figure 6.68:	Suction Energy vs Cavitation Number for Testing Condition 3	102
Figure 6.69:	TDH vs Flow Rate for Testing Condition 1	104
Figure 6.70:	TDH vs Flow Rate for Testing Condition 2	104
Figure 6.71:	TDH vs Flow Rate for Testing Condition 3	104
Figure 7.1:	Cascade of FFT spectrum undertaken at the pump casing while the suction pressure being decreased (Point A1 – A7)	111
Figure 8.1(a):	SVP1 (in green color) & SVP2 (in blue color) located adjacent	

each other	117
Figure 8.1(b): Schematic drawing of pumping installation	118
Figure 8.2: Damaged impeller	121
Figure 8.3: Timeline showing history of SVP1 impeller and field investigations	122
Figure 8.4: A new impeller with revised design from the pump OEM was then installed in September 2005	122
Figure 8.5(a): Accelerometer mounted on pump discharge base and casing	125
Figure 8.5(b): Accelerometer mounted on pump mounted on mechanical seal (axial direction)	125
Figure 8.5(c): Accelerometer mounted on the motor (axial direction)	125
Figure 8.6: Comparison of vibration for SVP 1 and SVP 2 (Casing Pump Discharge in horizontal direction undertaken on 1 October 2005)	
(a) Velocity Spectra (0 Hz to 500 Hz)	127
(b) Zoom Spectra (0 Hz to 100 Hz)	128
Figure 8.7: Bump test results on several pump components.	
(a) Pump Discharge Casing (0Hz to 100Hz)	128
(b) Casing pump discharge (100 Hz to 500 Hz)	129
(c) Pump Discharge Base	129
(d) Inner tube of the riser casing	129
(e) Mechanical Seal	130
(f) Shaft	130
(g) Impeller	130
Figure 8.8: Comparison of vibration for SVP1 & SVP2 (Pump Discharge Base in axial direction undertaken on 1 October 2005)	
(a) Acceleration Spectra (0 Hz to 3000 Hz)	131
(b) Velocity Spectra (0 Hz to 500 Hz)	131
Figure 8.9: Comparison of vibration for SVP1 and SVP 2 (Mechanical Seal in axial direction undertaken on 1 October 2005)	
(a) Velocity Spectra (0 Hz to 500 Hz)	132
(b) Acceleration Spectra (0 Hz to 1000 Hz)	132
(c) Acceleration Spectra (1000 Hz to 3000 Hz)	133
Figure 8.10: Comparison of vibration for SVP1 and SVP2 (Motor Casing in axial direction undertaken on 1 October 2005).	134

Figure 8.11:	Comparison of vibration for SVP1 and SVP2 (Motor Casing in transverse direction undertaken on 1 October 2005).	134
Figure 8.12:	Comparison of vibration for SVP1 and SVP2 (Motor Casing in horizontal direction undertaken on 1 October 2005).	134
Figure 8.13:	Comparison of vibration for SVP 1 and SVP 2 in time domain (Motor Casing in axial direction)	135
Figure 8.14:	Comparison of vibration for SVP 1 and SVP 2 in time domain (Motor Casing in transverse direction)	135
Figure 8.15:	Comparison of vibration for SVP 1 and SVP 2 in time domain (Motor Casing in horizontal direction)	135
Figure 8.16:	Water Level Indicator	137
Figure 8.17:	Comparison of vibration for SVP 1 and SVP 2 (Casing Pump Discharge in horizontal direction undertaken on 18 January 2006)	138
Figure 8.18:	Comparison of vibration for SVP1 operating in combined mode and single mode (Casing Pump Discharge in horizontal direction)	139
Figure 8.19:	Comparison of vibration for SVP2 operating in combined mode and single mode (Casing Pump Discharge in horizontal direction)	139
Figure 8.20:	Comparison of vibration for SVP 1 and SVP 2 (Pump Discharge Base in axial direction undertaken on 18 January 2006).	
	(a) Velocity Spectra (0 Hz to 500 Hz)	141
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	141
Figure 8.21:	Comparison of vibration for SVP1 operating in combined mode and single mode (Pump Discharge Base in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	142
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	142
Figure 8.22:	Comparison of vibration for SVP2 operating in combined mode and single mode (Pump Discharge Base in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	143
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	143
Figure 8.23:	Comparison of vibration for SVP 1 and SVP 2 (Mechanical Seal in axial direction undertaken on 18 January 2006).	
	(a) Velocity Spectra (0 Hz to 500 Hz)	145
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	145
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	145

Figure 8.24:	Comparison of vibration for SVP1 operating in combined mode and single mode (Mechanical Seal in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	146
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	146
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	146
Figure 8.25:	Comparison of vibration for SVP 2 operating in combined mode and single mode (Mechanical Seal in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	147
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	147
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	147
Figure 8.26:	Comparison of vibration for SVP1 and SVP2 (Casing Pump Discharge in horizontal direction undertaken on 25 March 2006).	149
Figure 8.27:	Comparison of vibration for SVP1 fitted with new impeller of revised design and refurbished impeller (Casing Pump Discharge in horizontal direction)	150
Figure 8.28:	Comparison of vibration for SVP2 fitted with original impeller undertaken on 1 st visit and 3 rd visit (Casing Pump Discharge in horizontal direction)	150
Figure 8.29:	Comparison of vibration for SVP1 and SVP2 (Pump Discharge Base in axial direction undertaken on 25 March 2006)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	152
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	152
Figure 8.30:	Comparison of vibration for SVP1 fitted with new impeller of revised design and refurbished impeller of original design (Pump Discharge Base in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	153
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	153
Figure 8.31:	Comparison of vibration for SVP2 fitted with original impeller undertaken on 1 st visit and 3 rd visit (Pump Discharge Base in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	154
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	154
Figure 8.32:	Comparison of vibration for SVP1 and SVP2 (Mechanical Seal in axial direction undertaken on 25 March 2006)	

	(a) Velocity Spectra (0 Hz to 500 Hz)	157
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	157
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	157
Figure 8.33:	Comparison of vibration for SVP1 fitted with new impeller of revised design and refurbished impeller (Mechanical Seal in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	158
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	158
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	158
Figure 8.34:	Comparison of vibration for SVP2 fitted with original impeller undertaken on 1 st visit and 3 rd visit (Mechanical Seal in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	159
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	159
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	159
Figure 8.35:	Comparison of vibration of SVP1 and SVP2 (Casing Pump Discharge in horizontal direction undertaken on 26 May 2006)	161
Figure 8.36:	Comparison of vibration for SVP1 fitted with new impeller of revised design and new impeller of original design (Casing Pump Discharge in horizontal direction)	162
Figure 8.37:	Comparison of vibration for SVP2 fitted with original impeller undertaken on 1 st visit and 4 th visit (Casing Pump Discharge in horizontal direction)	162
Figure 8.38:	Comparison of vibration of SVP1 and SVP2 (Pump Discharge Base in axial direction undertaken on 26 May 2006)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	164
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	164
Figure 8.39:	Comparison of vibration of SVP1 fitted with new impeller of revised design and new impeller of original design (Pump Discharge Base in horizontal direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	165
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	165
Figure 8.40:	Comparison of vibration for SVP2 fitted with original impeller undertaken on 1 st visit and 4 th visit (Pump Discharge Base in	

	axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	166
	(b) Acceleration Spectra (0 Hz to 3000 Hz)	166
Figure 8.41:	Comparison of vibration for SVP1 and SVP2 (Mechanical Seal in axial direction undertaken on 26 May 2006)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	169
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	169
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	169
Figure 8.42:	Comparison of vibration for SVP1 fitted with new impeller of revised design and new impeller of original design (Mechanical seal in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	170
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	170
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	170
Figure 8.43:	Comparison of vibration for SVP2 fitted with original impeller undertaken on 1 st visit and 4 th visit (Mechanical Seal in axial direction)	
	(a) Velocity Spectra (0 Hz to 500 Hz)	171
	(b) Acceleration Spectra (0 Hz to 1000 Hz)	171
	(c) Acceleration Spectra (1000 Hz to 3000 Hz)	171
Figure 8.44 (a):	Impellers (new) of the SVP1 after 3 Weeks Operations	173
Figure 8.44 (b):	Shaft	173
Figure 8.45:	Pitting Found on The Blade After 3 Weeks Operations.	174
Figure 8.46:	Minimum submergence required	176
Figure 8.47:	Design performance curve for SVP1 & SVP2	178
Figure 8.48:	Typical performance curves fro individual and pumps operating in parallel	178
Figure 8.49:	Pitting on the Impeller of SVP2 during March 2006	179

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 (<i>Verband Deutscher Maschinen- und Anlagenbau</i>)

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A1	H-II Launch Vehicle Flight #8	196
A2	Theoretical Background	198
A3	Envelope Analysis Theories	206
A4	Application Note: Envelope Analysis	207
A5	Example Calculation for Testing Condition 1	215
A6	Photographs of Vibration Measurement Location	218
A7	Pump Curve of the Centrifugal Pump	222
A8	Bearing Frequency Calculator	223

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	<ul style="list-style-type: none"> • Feedwater Circuit • Condensate Circuit • Cooling Water Circuit • Auxiliary Circuits
Oil	<ul style="list-style-type: none"> • Water Injection • Oil Pipeline Pumps • Petrochemicals
Water	<ul style="list-style-type: none"> • Seawater Transport • Drinking Water Supplies • Irrigation • Drainage • Sewage
Industry	<ul style="list-style-type: none"> • 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

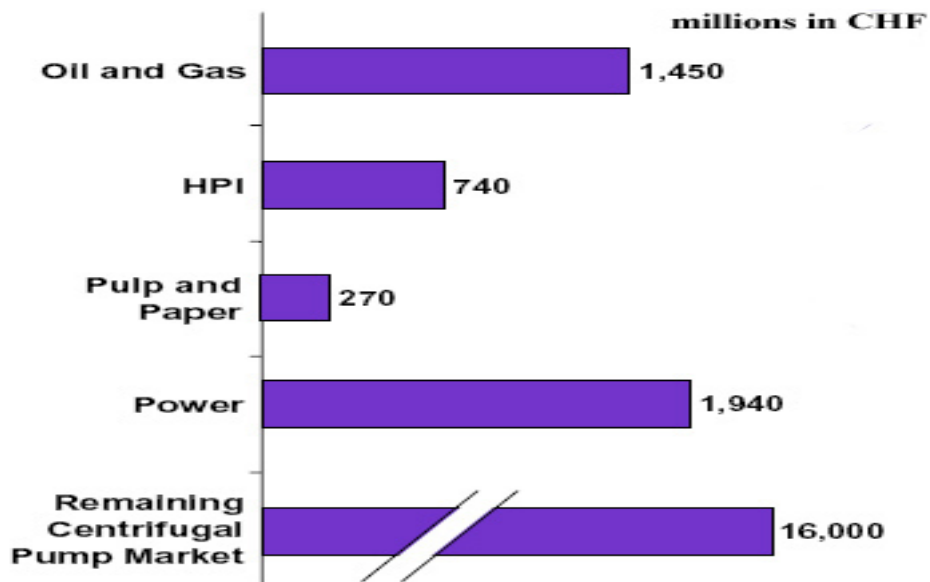


Figure 1.1: Estimated new pumps market (extracted from Sulzer Pumps)

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 ultrasonic 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.