"Saya akui bahawa saya telah membaca karya ini dan pada pandangan saya karya ini adalah memadai dari segi skop dan kualiti untuk penganugerahan Ijazah Sarjana Muda Kejuruteraan Mekanikal (Termal Bendalir)"

Tandatangan : ....

Nama Penyelia : Mr. Lee Yuk Choi

Tarikh : ....7/05/2007........

FAULT DIAGNOSIS AND FLOW INDUCED VIBRATION IN SUBMERGED VERTICAL PUMPS IN A POWER PLANT

MIRFAIZAL BIN CHUCHU

Laporan ini diserahkan kepada Fakulti Kejuruteraan Mekanikal sebagai memenuhi sebahagian daripada syarat penganugerahan Ijazah Sarjana Muda Kejuruteraan Mekanikal Termal Bendalir)

Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

April 2007

"Saya akui laporan ini adalah hasil kerja saya sendiri kecuali ringkasan dan petikan yang tiap-tiap satunya saya jelaskan sumbernya"

Tandatangan : ....

Nama Penulis : Mirfaizal Bin Chuchu

Tarikh : 07/05/2007

ACKNOWLEDGEMENTS

The deepest gratitude to Allah S.W.T for given the grace and blessing. In preparing this thesis, I was in contact with many people, engineers, researchers, academicians, and practitioners direct and indirectly. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Mr Lee Yuk Choi, for encouragement, guidance, friendship and advice. I am also very thankful to our Dean of Faculty Mechanical Engineering Prof. Madya Dr. Mohd Radzai Bin Said and Mr Md Isa bin Ali without their continued support and interest, this thesis would not have been the same as presented here.

Besides, also not forgetting to the management of the Power Plant, Independent Power Producer In Melaka especially to the Senior Manager (Maintenance Engineer) Mr. Chiew Chin Hing and the Assistance Mechanical Engineer Mr. Arnold Lee Soon Maun for their co-operation and given me a lot valuable experiences, knowledge and information during my analysis there.

I am also indebted to our university library for the facilities provided which was including the references and journals sources that are important in my thesis. My fellow postgraduate students should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Lastly i am also grateful to all my family members for all their sacrifice and supports.

ABSTRACT

Experimental studies were undertaken to investigate the fault diagnosis and flow induced vibration in submerged vertical pumps in the power plant in Melaka. The effect from the failure of the submerged vertical pump would potentially result in a total plant shutdown. It is important to identify the related problems so that the condition monitoring and prediction can be done for machinery fault diagnosis and improvement by using vibration analysis as an indicator. Therefore the problems finding and failure symptoms from the prediction and analysis of this investigation are used to improve and increase the efficiency and make use of the pumps life time as longer as possible. Besides that, the thesis was also carry out a study and applies vibration technology for predictive condition monitoring for most likely faults in industrial environment. The investigation started from undertaken the vibration measurement and analyzed the vibration spectrum. A continuous condition monitoring was develop by detail analysis of monthly statistical overall alarm obviously to obtain a trend of overall vibration characteristic that can warn of impending trouble of the pump in early stages. Based on the vibration measurement, spectrums analysis, statistical overall alarm and the standard of assign vibration monitoring result, the investigation and analysis clearly implied that an impeller design error and high vibration in the CWP1 compare to the CWP2 because of the impeller failure and the existence of cavitation was suspected at CWP1. The pump impeller design that supplied by the pump manufacturer also unmatched the pump needed for the plant.

PENGHARGAAN

Setinggi-tinggi kesyukuran ke atas Allah S.W.T dengan segala nikmat dan rezeki yang dikurniakan. Dalam penghasilan tesis ini saya telah berhubung dengan banyak pihak samaada secara lansung ataupun tidak. Mereka telah banyak menyumbang idea, tenaga, memberi semangat, kerjasama, nasihat, bantuan dalam penghasilan tesis ini dengan jayanya. Dengan rasa penuh berterima kasih saya ingin memberi penghargaan kepada penasihat utama saya iaitu En. Lee Yuk Choi kerana banyak memberi tunjuk ajar, kerjasama, persahabatan dan nasihat.Tidak lupa juga setinggi-tinggi penghargaan saya ucapkan kepada dekan fakulti kejuruteraan mekanikal Prof. Madya Dr. Mohd Radzai Bin Said dan En Md Isa bin Ali kerana tanpa sokongan dan tunjuk ajar mereka tesis ini tidak akan berjalan dengan lancar.

Selain itu, tidak dilupakan juga buat pihak pengurusan Power Producer In Melaka terutamanya kepada Senior Manager (Maintenance Engineer) En. Chiew Chin Hing dan Assistance Mechanical Engineer En. Arnold Lee Soon Maun di atas kerjasama yang diberikan dan mendapat pengalaman, pengetahuan, dan maklumat sepanjang analysis saya disana.

Selain itu juga saya ingin berterima kasih kepada pihak perpustakaan Universiti kerana menyediakan kemudahan rujukan dan sumber-sumber jurnal yang penting dalam kandungan tesis ini. Rakan-rakan seperjuangan yang tidak putus-putus memberi sokongan moral dan kerjasama termasuklah individu-individu yang terlibat secara tidak lansung.Akhir sekali saya ingin mengucapkan setinggi penghargaan kepada keluarga saya di atas setiap pengorbanan mereka selama ini.

ABSTRAK

Kajian tentang eksperimen telah dilakukan untuk mengkaji diagnosis kegagalan submerged vertical pump dengan menggunakan kaedah getaran di Stesen Jana Kuasa di Melaka. Hasil daripada kegagalan yang di alami oleh submerged vertical pump boleh menyebabkan keseluruhan 'shutdown' di stesen jana kuasa. Oleh itu adalah penting untuk mengenali permasalahan yang berkaitan agar pengawasan dan jangkaaan dapat dilakukan untuk mengenali masalah kegagalan pam untuk tujuan penambahbaikan dengan menggunakan kaedah getaran sebagai pengesan. Oleh itu segala jawapan dari segala permasalahan dengan simtom kegagalan hasil daripada jangkaan dan analisis daripada kajian dapat digunakan untuk menambahbaik dan mempertigkatkan kecekapan dan jangka hayat pam selama mungkin. Selain itu. Tesis ini juga melibatkan pembelajaran dan mengaplikasikan getaran dan pengawasan yang effektif yang melibatkan kegagalan didalam industri.Kajian bermula daripada pengumpulan segala data getaran dan analisis di dalam spektrum getaran. Pengawasan yang berterusan telah dibuat dengan analisis yang mendalam tentang monthly statistical overall alarm untuk mendapatkan secara keseluruhan sifat getaran yang dapat memberi amaran awal terhadap masalah di dalam pam ketika di tahap awal lagi.Berdasarkan data getaran , analisis spectrum , dan alarm keseluruhan dan jawapan untuk standad untuk pengawasan , kajian dan analisis mendapati bahawa terbukti menunjukan kesalahan didalam rekabentuk bilah kipas pam dan getaran yang tinggi di CWP1 jika dibandingkan dengan CWP2 disebabkan kegagalan pam dan kewujudan cavitation yang ada di CWP1.

CONTENTS

CHAPTERS	TOPICS	PAGES
1	**INTRODUCTION**	1
	1.1 Problem Statement	2
	1.2 Objectives	3
	1.3 Scopes	3
2	**LITERATURE REVIEW**	4
	2.1 Vibration in Submerged Vertical Pump	4
	2.2 Cavitation	6
	2.3 Type of Cavitation in Centrifugal Pumps	8
	2.3.1 Efficiency Alteration	11
	2.4 Vibration Spectrum from Previous Studying	11
3	**THEORY**	14
	3.1 Definition of Important Terms	14
	3.1.1 Capacity	15
	3.1.2 Head	15
	3.2 Net Positive Suction Head	18
	3.2.1 Net Positive Suction Head required, NPSHr	18
	3.2.2 Net Positive Suction Head available, NPSHa	20
	3.3 Pump Performance Curve	21

		3.3.1 Developing a system curve	22
		3.3.2 Developing a Pump performance Curve	22
		3.3.3 Normal Operating Range	22
	3.4	Cavitation	23
		3.4.1 Cavitation Process	24
		3.4.2 The effect of Cavitation	26
	3.5	Vibration	27
		3.5.1 Problem of vibration	27
		3.5.2 Description of basic Vibration terms, concept and equipment	28
		3.5.2.1 Vibration Frequency	29
		3.5.2.2 Vibration Displacement	30
		3.5.2.3 Vibration Velocity	30
		3.5.2.4 Vibration acceleration	31
		3.5.3 Data Types data and formats	31
	3.6	Illustrated Vibration Diagnostic	32
		3.6.1 Hydraulic and Aerodynamic Force	32
		3.6.2 Motor (Belt Drive Problem)	34
4	**METHODOLOGY**		37
	4.1	Project Methodology	37
	4.2	FFT Vibration Analyzer	38
	4.3	Microlog CMVA-60	38
		4.4.1 Machine Analyze Software	39
	4.5	Spectrum Analysis	40
	4.6	Project Methodology Flowchart	41
5	**RESULT AND DISCUSSION**		42
	5.1	Spectrum Analysis	42
		5.1.1 Discharge Base (Vertical)	44
		5.1.2 Mechanical Seal (Vertical-Axial)	46

		5.1.3 Motor (Axial)	48
		5.1.4 Motor (Horizontal)	49
		5.1.5 Pump Casing (Horizontal)	50
	5.2	Bump Test at Pump Component	51
		5.2.1 Pump Casing	52
		5.2.2 Mechanical Seal	55
	5.3	Bar Chart for Overall Velocity and Acceleration	57
		5.3.1 Bar Chart for CWP1	58
		5.3.2 Bar Chart for Overall CWP2	61
	5.4	Monthly Statistical Overall Alarm	64
		5.4.1 Monthly graph for Statistical Overall Alarm	65
		5.4.2 Sample Calculation Statistical Overall Alarm	67
	5.5	Standard for Assessing the Pumps Condition	68
6	**CONCLUSION**		71
	6.1	Recommendation	72
	REFERENCES		74
	APPENDIXES		77

LIST OF TABLES

NO OF TABLES	TOPICS	PAGES
1	History of failure in the submerged vertical pump 1 and 2	2
2	Pump Specification	3
5.5 a	Criteria for overall condition rating	68
5.5 b	Monthly statistical overall vibration level criteria for Pump Y-axis	69

LIST OF FIGURES

NO OF FIGURES	TOPICS	PAGES
2.3 a	Influence of the discharge value on the flow velocity triangle at the impeller inlet	8
2.3 b	Computation of pressure distribution along the mid span streamline of a storage pump impeller	9
2.3 c	Traveling bubble development in a storage pump impeller.	9
2.3 d	Leading edge cavity development in a storage pump impeller.	10
2.3 e	Influence of the discharge value on a storage pump NPSE.	10
2.3.1	Cavitation curves for a centrifugal pump for different discharge coefficient value.	11
2.4 a	Radial Vibration (20 KHz)	12
2.4 b	Axial Vibration (20 KHz)	12
2.4 c	Radial Vibration (1 KHz)	13
2.4 d	Axial Vibration (1 KHz)	13
3.3.3	Typical System and Pump Performance Curves	23
3.4.1 a	Impeller cavitation regions	24
3.4.1 b	Collapse of a Vapor Bubble	26
3.5.2.3	Velocity from Displacement Curve	30
3.5.2.4	Acceleration from the Displacement Curve	31
3.6.1 a	Blade Pass Frequency	32
3.6.1 b	Flow Turbulences	33
3.6.1 c	Cavitation	33

3.6.2 a	Worn, Loose or Mismatched Belt	34
3.6.2 b	Belt/Sheave Misalignment	35
3.6.2 c	Eccentric Sheaves	35
3.6.2 d	Belt Resonance	36
4.6	Flowchart of Project Methodology	41
5.1.1 a	Velocity Spectrum (0- 500Hz) for Discharge Base	44
5.1.1 b	Velocity Spectrum (0- 100Hz) for Discharge Base	44
5.1.1 c	Acceleration Spectrum (3500-5000 Hz) for Discharge Base	45
5.1.2 d	Velocity Spectrum (0- 500Hz) for Mechanical Seal	46
5.1.2 e	Velocity Spectrum (0- 100Hz) for Mechanical Seal	47
5.1.3 f	Acceleration Spectrum (0-4000 Hz) for Motor (Axial)	48
5.1.4 g	Velocity Spectrum (0- 200Hz) for Motor (Horizontal)	49
5.1.5 h	Acceleration Spectrum (0-1000 Hz) for Pump Casing	50
5.1.5 i	Acceleration Spectrum (0-100 Hz) for Pump Casing	50
5.2.1 a	Natural frequency for Pump Casing	52
5.2.1 b	CWP1 Pump Casing	53
5.2.1 c	CWP2 Pump Casing	54
5.2.2 d	Natural frequency for Mechanical Seal	55
5.2.2 e	CWP1 Mechanical Seal	55
5.2 f	CWP2 Mechanical Seal	56
5.3.1 a	Overall Pump Casing (CWP1)	58
5.3.1 b	Overall Mechanical Seal (CWP1)	58
5.3.1 c	Overall Discharge Base (CWP1)	59
5.3.1 d	Overall Motor (CWP1)	59
5.3.2 a	Overall Pump Casing (CWP2)	61
5.3.2 b	Overall Mechanical Seal (CWP2)	61
5.3.2 c	Overall Discharge Base (CWP2)	62
5.3.2 d	Overall Motor (CWP2)	62
5.4.1 a	Pump Y- axis	65
5.4.1 b	Motor X-axis	66
5.4.1 c	Motor Y- axis	66

LIST OF SYMBOLS

SYMBOLS	DEFINITIONS
m	Meter
mm	Millimeter
Sec	Seconds
t	Time
Q	Capacity
V	Velocity
A	Area
H	Total head
g	Acceleration due to gravity
hS	Static Suction Head
hd	Static Discharge Head
hf	Friction Head
hvp	Vapor Pressure Head
hp	Pressure Head
hv	Velocity Head
Hs	Total Suction Head
Hd	Total Discharge Head
HT	Total Differential Head
NPSH	Net Positive Suction Head
NPSHr	Net Positive Suction Head Required
NPSHa	Net Positive Suction Head available

RPM	Revolution per minute
CPM	Cycle per Minutes
CPS	Cycles per Second
RMS	Root Mean Square
T	Time Period
Hz	Hertz
G's	Acceleration
S	Standard Deviation
SOA	Statistical Overall Alarm
BPF	Blades Pass Frequency
BEP	Best Efficiency Point
CWP1	Submerged Vertical Pump 1
CWP2	Submerged Vertical Pump 2

GREEK WORDS

$\sum$	Summation
$^{\circ}$	Degree
π	Pi

SUBSCRIPTS

AVE	Averages
S	Static Suction
d	Static Discharge
f	Friction
vp	Vapor Pressure
p	Pressure
v	Velocity
T	Total Differential

LIST OF APPENDIXES

APPENDIXES	TOPICS	PAGES
A	Gantt Chart For PSM 1	77
B	Gantt Chart For PSM 2	78
C	Overall Velocity (mm/sec) and Acceleration (G's) for CWP1	79
D	Overall Velocity (mm/sec) and Acceleration (G's) for CWP2	80
E	Tables for Average Overall Level	81
F	Tables for Standard Deviation	82
G	Tables for Statistical Overall Alarm	83
H	Tables for Monthly CWP1 Overall Vibration Level Category	84
I	Tables for Monthly CWP2 Overall Vibration Level Category	86
J	Pictures	88

CHAPTER 1

INTRODUCTION

Pumping sets are important and critical operation in the power generation and petrochemical industry. The Investigation has been done at one of the power generation at Melaka to collect vibrations data and make observation due to the submerged vertical pump situation. The pump is used for pumping of cooling water to the condenser. The pump also had a mechanical problem history several time. Failure of the submerged vertical pump would potentially result in the total plant shutdown. Analyzer software is used in the vibrations data analysis and investigation of the two pumps which are submerged vertical pump 1 and submerged vertical pump 2.

Cavitations are the main problem that exists due to the high random vibration in the submerged vertical pump. Vibration and knocking sound will be heard if the cavitation occurs when the pump is operating. This happens when the bubbles explode in the flow of fluids in the pump that can damage the pump impeller. If the pump keep on operation there will cost many damages and mechanical problem in the submerged vertical pump. By knowing the characteristic, the problems and doing a vibration analysis, condition monitoring and earlier predictive can be made to reduce the mechanical problem in the submerged vertical pump.

1.1 Problem Statement

The problem occurs when there was a high vibration at the submerged vertical pump 1 (CWP1) compared to the submerged vertical pump 2 (CWP2) cause by the impeller failure. Besides that, the lack of measurement equipment in the submerged vertical pump was one of the factors that influence the diagnosis due to the submerged vertical pump problem. There were currently no flow measurement devices on the pumps, and came fitted with analogue pressure indicator on the common discharge pipe only. The pump impeller design that supplied by the pump manufacturer also unmatched the pump specification needed for the plant. Condition monitoring and prediction also need to be improve because of the critically failure situation of pump. The CWP1 had the history of impeller failure with the broken impeller blade for last 5 years. The power plant had welded back the broken impeller every time the pump fails and changed the impeller designs for several times. There had been unscheduled breakdown failures a few times during the operation of the critical CWP1.The similar failure with the same pattern occurred on the impeller every times it fail. The plant management obviously requires edification on the root cause to the pump failures and whether there was a system design problem with the pumping system such that a long term solution for improved pump reliability could be identified.

Table 1: History of failure in the submerged vertical pump 1 and 2 (CWP1, CWP2)

Date	2005-2005	1 October 2005	18 January 2006	25 March 2006	26 May 2006
CWP1	Used original impeller. Catastrophic failure in Dec2003. Broken blade welded back in 2003.Failure to impeller in Sept 2004 and Nov 2004	New Impeller of different design(different shape compared to the original impeller)	Refurbished (original) Impeller	Refurbished (original) Impeller	New impeller (original design)
CWP2	New pump replacement in 2002 (with original impeller design)				

Table2: Pump Specification

Capacity	Speed	Total Dynamic Head(TDH)	Specific Speed (Ns)
13800 m^3/hour	585 rpm	16.2 m	8500

1.2 Objectives

The objectives of this thesis were defined as follows:

1. To study and investigate the characteristic of common fault experience in a submerged vertical pump experimentally.

2. To investigate parameters that could be used to predict the main fault in a submerged vertical pump.

1.3 Scopes

To achieve the above objective, the scope of this work generally involved the following:

1. To study and investigate the characteristic of common fault experience in a submerged vertical pump experimentally.

2. To conduct vibration measurement at the power plant.

3. To analyze and determine the most likely cause of vibration and identifying characteristic of each.

CHAPTER 2

LITERATURE REVIEW

2.1 Vibration in Submerged Vertical Pumps

Failures of submerged vertical pumps often occur without due to the warning from the installed sensors and monitors [5]. The reason is the lack of transducers mounted where they can reliably sense the condition of the pump, down in the hole. Since there are no industrial standards that require sensors at the bottom of the pump, regardless of the power rating, the sensors are most often mounted on the motor, some distance from the pump. In the past, reduced efficiency and pump failure have not proven to be enough incentive for operators to properly instrument the system. In today's economic climate, industries are pressured to operate their equipment longer and at improved efficiencies, while maintaining safe and reliable operation. This can be achieved in part by monitoring and trending of parameters such as vibration, lube oil condition, performance, exhaust gas analysis, etc. Vibration monitoring is probably the most important tool in these programs and has become accepted and proven worldwide in various industries [5].

There are certain conditions and configurations where the pump vibration data can be picked up at the top of the motor. However, this "tail-wagging-the-dog" [5] methodology has limitations; the signal will be attenuated by the different machine components between the pump and the motor and will be overlaid with the signal of the motor. For example, the detection of cavitation can only be carried out in the impeller/pump bowl region. Farther up the riser tube, flow-generated noise coming from the intermediate bearings adds to the cavitation signal and confuses the diagnosis. Since higher frequency signals attenuate faster than lower frequency signals, the data may not even reach the transducers Results from several installations have shown that bearing and impeller condition data is readily available to transducers installed under water, close to the source of the data.

In order for a pump to be maintained at its optimum performance, regular inspection is recommended. There may well be indicators downstream of the pump that can show if the pressure or flow is below the required norm; these, if trended, will give an indication that the pump should be withdrawn from service before unacceptable performance or failure occurs. The vibration data can be used to indicate the mechanical condition of the submerged bearings, what parts might need to be replaced, and an appropriate maintenance schedule that would minimize the cost of downtime.

The areas surrounding the pump bowl and intake are subject to high turbulence [5], with significant force being generated by the swirling water. The transducer and the conduit must be securely attached to the surface, and the conduit attached to the pump body at frequent intervals. If the components that are torn off the pump by the turbulence are ingested, they will damage the impeller. Any conduit passing across the intake of the bearing will cause a wake. This wake will give rise to cavitation at the impeller, increasing the risk of erosion. Keep the conduit in line with struts or webs to prevent turbulence.

In a centrifugal pump, a rotating element called an impeller is enclosed in a case [3]. The fluid to be pumped enters into the case through the suction piping into the impeller and is forced out the discharge side of the pump by means of centrifugal force pushing the fluid out radially through the impeller. The fluid is discharged at a higher pressure and a higher velocity. The major portion of the velocity energy is then converted into pressure energy by means of a volute or by a set of stationary diffusion vanes surrounding the impeller periphery [3]. In a pump, vibration is caused by the interaction between the moving pump impeller and the stationary parts of the pump such as the volute and the diffuser vanes. Also, vibration is caused by the interaction between the impeller blades and the fluid being pumped.

2.2 Cavitation

Cavitation is a phenomenon in which liquid evaporates and vapor bubble occurs in the region where the pressure of the liquid falls off under vapor pressure. Cavitation is usually observed in areas of the high-speed fluid machinery such as propellers and pumps, where the flow accelerates and the pressure decreases. Sheet cavitation, which includes strong unsteady phenomena such as cyclic cloud cavity shedding under a certain cavitation condition, causes a large-scale oscillation in fluid machinery, reduces the performance, and becomes a cause of damage [3]. Furthermore, phenomena called cavitation instabilities are caused by mutual interference between the cavitation and the fluid machine systems, where the original unsteadiness of cavitation increases. Actually, these become a cause of serious accidents involving fluid machinery.

Cavitation usually occurs in a flowing liquid where the local pressure drops below the saturation vapor pressure of the liquid at the given local temperature, causing liquid evaporation and generation of vapor bubbles in the low pressure region. Fluid machinery is a common application where low pressures are routinely generate by hydraulic actions. For example on the blade surface, with a consequent possibility of cavitations [1], the existence of cavitation is undesirable as it result in deterioration of the hydraulic performance, lead to physical damage effecting the equipment or component structural integrity and higher noise. Onset of cavitation is defined by ISO 3555 as a 3% drop in the pump pressure head without inlet or discharge throttling at the given flowrate [1]. A characteristic audible sound (rumbling stones or marbles sound) would be emitted from the pump when cavitation is occurring.

Detection of cavitation in pump has been by a subject of interest. Jeremy Jensen (2000) reported that the dynamic pressure was a direct indicator of cavitation, whereas Net Positive Suction Head Available (NPSHA) monitoring was an indirect indicator. Jorge L.Porrondo(1998) reported that pressure at the oulet pump is sensitive to changes when the cavitation occurs [1]. The sensibility of pressure at the inlet of the pump was also regarded as a satisfactory indicator. Experiment have shown that there is a discrete frequency tone with the audible noise spectra, typically at half of blade passing frequency(BPF),which is strongly dependent on the cavitation process and its development (M.Cudina 2002) [1]. The discrete frequency tone at the half of the BPF could therefore be used to detect the incipient of cavitation and its development. T Uchiyama (1998) investigated a fault diagnostic method for centrifugal pump using the network approach.

There are three common causes of vapor formation in a liquid [3]:

1. Flow separation of a viscous fluid from its guiding surface due to a surface discontinuity.

2. The addition of heat to the fluid, raising its vapor pressure (boiling point).

3. Reducing the pressure of the fluid to below its vapor pressure.

One important terminology in pump theory is net positive suction head (NPSH). NPSH is a measure of the difference between the total suction head and the fluid vapor pressure. The concept of NPSH is related with cavitation closely. For a specific pump, there are the required NPSH and available NPSH. The required NPSH is the factory suggested value which must be maintained to prevent the happening of cavitation. The available NPSH is the real pressure difference between the suction head and the fluid vapor pressure.

Cavitation might excite high frequency structural resonance. It may also reduce the impeller vane pass frequency vibration. Although cavitation is less likely to happen on a slow speed pump, it will develop very fast if it happens.

2.3 Type of Cavitation in Centrifugal Pumps

Cavity development in a centrifugal pump is fully controlled by the discharge coefficient according to the relative flow velocity incidence angle at the impeller inlet [7], Figure 2.3(a), which strongly affects the pressure distribution on the blades at the inlet, taken from 9, Figure 2.3(b)

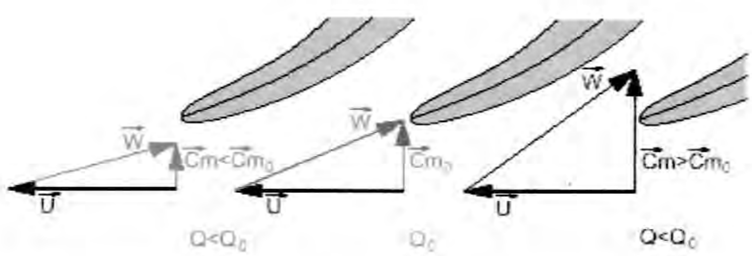

Figure 2.3(a) Influence of the discharge value on the flow velocity triangle at the impeller inlet.