"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor Mechanical Engineering (Structure & Material)"

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Date : 8/5/2008

MODELING AND SIMULATION OF AN IMPELLER IN CIRCULATING WATER PUMP IN A POWER GENERATION INDUSTRY

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A project report submitted in partial
fulfillment of the requirements for the award of
the Degree of Bachelor Mechanical Engineering (Structure & Material)

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MAY 2008

"I hereby declared that this thesis is my own work except the ideas and summaries which I have clarified their sources"

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ABSTRACT

Pumping sets are common but often critical operating assets in the industry. Common pump failure modes showed cavitations erosion and a sheared at the impeller blade. This thesis is concerned about the geometrical and material study of an impeller in vertical submersible circulating water pumps in a power generation industry. Within the industry today, companies save significant amounts of money through computer simulations. Mathematics through numerical methods becomes more important and therefore the investigation is done with the Finite Element Method (FEM). The objectives of this thesis are to determine the best condition impeller blades diameter for 700 mm, 850 mm and 1000 mm and also to identify the best standard material of impeller by using the simulation software. This study revealed that the smallest diameter of impeller is the optimum blade profile which can sustain high pressure, force and stress under operating condition based on the evaluation of simulation investigations. It is advisable that the industries using the smaller impeller's diameter in impeller design because it is more stiffness structure in configuration and provide higher factor of safety. Beside that, this works verified that Stainless Steel AISI 2205(Duplex) provide the highest factor of safety, Young's Modulus and stiffness characteristic among the materials simulated in this project. Stainless Steel AISI 2205(Duplex) is well recommended material for the sea water impeller to improve the quality and to insure the long wear life. The MSC Nastran Patran software is the powerful method used to identify the critical areas at impeller where the weakness point appear base on the stress distribution results. In addition, Solid works is useful software to model the complex part.

ABSTRAK

Pam selalu mengalami kesusahan dalam mengendalikannya dalam industri. Kegagalan Pam yang biasanya berlaku merupakan hakisan dan kepatahan dalam 'impeller' itu. Tesis ini adalah mengenai kajian rekabentuk dan bahan yang digunakan untuk satu 'impeller' daripada pam air yang menegak, boleh ditengelamkan dan berkitaran di penjanaan kuasa tenaga. Pada masa kini, kilang-kilang dapat menjimatkan wang dengan menggunakan simulasi komputer. Simulasi komputer merupakan kaedah yang penting untuk membuat kajian kejuruteraan dengan Kaedah Unsur Ketakterhinggaan. Tujuan menulis tesis ini adalah untuk menentukan rekabentuk yang terbaik untuk 'impeller' seperti 700 mm, 850 mm dan 1000 mm untuk diameter 'impeller' dan juga menentukan bahan yang terbaik untuk digunakan dalam membina 'impeller' itu dengan menggunakan program simulasi. Tesis ini membuktikan bahawa diameter 'impeller' yang kecil merupakan rekabentuk yang paling baik untuk menyokong tekanan, daya, ketegangan yang tinggi dalam keadaan mengendali mesin. Rekabentuk untuk 'impeller' adalah digalakkan untuk menggunakan diameter 'impeller' yang kecil disebabkan strukturnya lebih kuat. Selain itu, kajian juga menunjukkan bahawa 'Stainless Steel AISI 2205(Duplex)' memberikan faktor keselamatan, 'Young's Modulus' yang tertinggi dan kekerasan yang kuat. 'Stainless Steel AISI 2205(Duplex)' dikenali sebagai bahan yang paling sesuai untuk membuat 'impeller' di dalam laut untuk meningkatkan kualiti dan menjamin hayat penggunanya. MSC Nastran Patran program adalah satu kaedah yang berkesan digunakan untuk menentukan kawasan lemah yang wujud dalam 'impeller' itu. Tambahan pula, 'Solid works' adalah sesuai untuk melukiskan rekabentuk yang lebih canggih.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF CHARTS

CHAPTER 1

INTRODUCTION

1.1 Overview

A pump is a machine used to move liquid through a piping system and raise the pressure of a liquid. Most commonly, this is electricity used to power an electric motor. The purpose for a centrifugal pump is to convert energy of an electric motor driver into velocity or kinetic energy and then into pressure energy of a fluid that is being pump. The energy changes occur by the rotating impeller. The rotating impeller causes the liquid forced into the inlet side of the pump to increase in velocity. Impeller play an important role in a pump working, it just like the heart of a pump. Once the impeller failed in the submersible vertical pumps would most probably cause in a total plant shutdown. It is a high criticality and will cause a great loss for the industry.

The pumping medium for this submersible, vertical circulating pump investigation is sea water. Cavitations typically occurs in a flowing liquid where the local pressure drops under the saturation vapor pressure of the sea water at a specified local temperature, causing sea water evaporation and production of vapor bubbles in the low pressure area. For example on blade surfaces has a consequent possibility of occurrences cavitations. The continuation of cavitations is unwanted as it results in weakening of the hydraulic performance, lead to physical damage affecting the equipment or component structural integrity and higher noise. Historically, the pump had a catastrophic failure of the original pump arising from a broken impeller. One of the impeller blades was awfully broke out from the impeller. From the current impeller design, actually the impeller service life is 5 years, but it was often facing frequent failures in 2 years time. These encounter problems may due to the design impeller error and the material used is weak in corrosion resistance. To overcome these problems, this project is proposing the analysis geometrical design for the broken impeller by considering the size of impeller blades used such as 700 mm, 850 mm or 900 mm diameter of impeller. As could be observe from the original design, the impeller's diameter is in approximately 850 mm. Such variation between 700 mm to 900 mm in considered in this simulation in the event that it can operate and inherently pumping the liquid to the desired operation condition, and hence improved the efficiency of the system. Also, it most complies with the design specification such that the clearances between the blades tip to the pump casing in tolerable. There will be an efficiency reduction with a reduction in the impeller diameter. According to Larry Bachus et al. (2003), it is not recommended to reduce or trim the impeller by more than 20 % of the diameter impeller. On the other hand, different materials analysis also will be done. Some simulations on the impeller will be simulated to observe the deformation and the stress distribution that will lead to the impeller failures.

1.2 Objectives of the Project

This project is to analyze the characteristic impeller in circulating water pumps in a power generation industry. The main objectives in this project are as following:-

- To understand the blade's profile of the impeller.
- To model the impeller based on the actual dimensions used in power generation.
- To simulate the impeller using MSC Nastran/Patran.

1.3 Scopes of the Project

This project will involve the specific field on the impeller analysis. The scopes that cover in this project are as following:-

- Literature study of impeller used in the power generation industry.
- Simulation of impeller using MSC Nastran/Patran on static stress distribution analysis and deformation.
- Obtain simulation at different conditions such as the different diameter impeller (700 mm, 850 mm and 1000 mm) being used and different material configurations (Stainless Steel AISI 2205(Duplex), Ductile Cast Iron ASTM A536, Cast Aluminum Alloy 201.0 and Stainless Steel AISI 316) to identify the optimum blade profile in which it can sustain high pressure, force and stress under operating condition.

1.4 Problem Statement

In this project on circulating water pump impeller, the conventional problems rising was the blades of the impeller broken, cavitations on the surface of impeller blades, design error that cause vibration in the pump. Generally, these problem will happen is due to the continuously operation during low tide in the condition which pump was inadequate submerged and the combine pumps in parallel. Beside that, the size of impeller, the leading edge geometry and the number of blades in a design of impeller will affect the rotating cavitations rate. While the cavitations were incessant and more apparent, it is critically will shear the blade at the root of the impeller. The phenomenon was shown in Figure 1.1.

Figure 1.1: The failure mode of a sheared blade at the root of the impeller
(Source: Industry, Dec 2003)

Cavitations appear when a bubble collapses near a solid boundary like blade and the direction of the flow liquid almost always towards the boundary. It means the entire energy of collapse is aimed at the impeller's surface and metal erosion occurs.

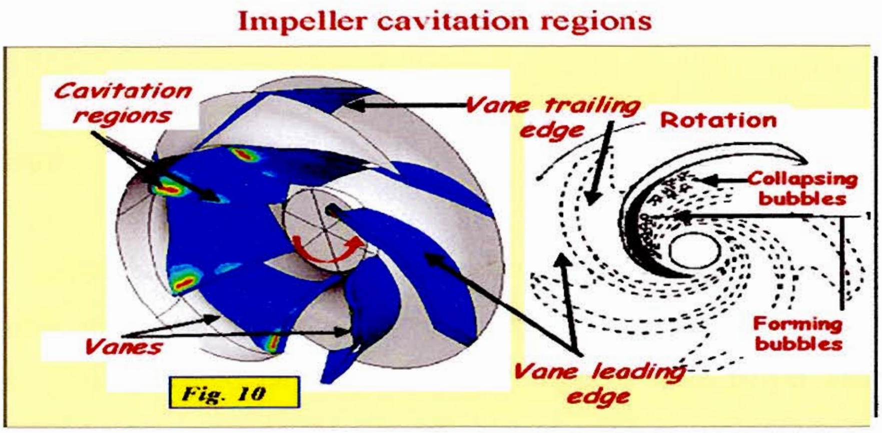

Figure 1.2: Impeller cavitations region and the process form cavitation
(Source: Mukesh Sahdev, www.cheresources.com)

Lastly, the effect of pump over sizing makes operating at low flows. This can result in internal recirculation damage to impeller, operation at less than best efficiency point, high radial loads, bearing failures, seal failures, high internal temperature rise and requirement for minimum flow bypass.

CHAPTER 2

LITERATURE REVIEW

An impeller is a rotor inside a tube or conduit to increase the pressure and flow of a fluid, formed by rotating blades arranged in a circle. Impeller is the most vital part which the only rotating element of the centrifugal pump. It usually made of iron, steel or aluminum which transfers energy from the motor that drives the pump to the fluid being pumped by forcing the fluid outwards from the centre of rotation.

2.1 Background

A lot of studies had been done by researcher are related to pump field. However, it is only reviewed fewer studies which were focus on investigate on impeller failures. A catastrophic failure of impeller happens in a power plant. Although the broken blade was welded back, refurbished and also replaced with a new impeller with different design, but it still shown frequently failures.

Parrondo et al. (1998) investigated about the development of a predictive maintenance system for a centrifugal pump that takes fluid-dynamic perturbations into account. A methodology has been proposed based on signal monitoring and intended for rotor dynamic pumps. They found out the frequency of rotation increased by the number of blades of the impeller which causes flow disturbances. Particularly high turbulence levels are generated in the pump when operating low or high flow-rates, due to the incidence angle of the incoming flow. Cavitations also the source for excitation in hydraulic pumps specifically when the generation of small vapor bubbles at the inlet of the impeller that collapse when reaching a somewhat higher pressure along their trajectories while producing material erosion.

Tan, C.Z, Salman, M.L and Lee, Y.C (2006) wrote a paper on field investigations of cavitation and flow induced vibrations in submerged vertical pumps in a power plant. Their vibration analysis indicated cavitations and flow induced vibrations in a power plant. The investigations conclude the inadequate submergence during operations at low tide and consist pumps operated in parallel where was recognized as a probable reason for the impeller failures. The pumps failure modes showed broken blade of impeller at its root and cavitation erosion. In addition, the studies firmly implied a combination between the system design error and pump operating conditions had resulted in frequent failures of the pumps.

Evans, Ph.D. (2007) discussed about the boiling is the precursor to cavitation in a centrifugal pump. Boiling is not necessarily destructive, but it arise a very powerful force if those bubbles don't burst. Liquid water and the heat is the major component of this energy release. However, the burst is generated very small shock wave because the pressure in the bubble is just slightly more than one atmosphere, and its energy release is in all directions above the surface of the water. Further more, the entire energy of collapse is directed at a tiny area of the impeller's surface and metal erosion occurs.

2.2 Geometrical Impeller Effect

Geometrical impeller is one of the factors that influence the rotation cavitation and pump failures modes. Hofmann, M. et al. carried out similarities and geometrical effects on rotating cavitation in two scaled centrifugal pumps in cooperation with DFG (Deutsche Forschungsgemeinschaft). The authors proved the similarity of the pumps based on the investigation on the two scaled pumps of low specific speed running at the same Reynolds number. This article clarify the result of experimental investigations of different configurations in both pumps show that the onset of rotating cavitation can be characterized by an constant value of dimensionless parameter $\sigma/2\alpha$ which independent from the leading edge geometry. Both pumps can hold different runner geometries as well as different leading edge geometries within the same runner. They also observed the interaction of the cavity and the leading edge of the following blade. In every one impeller-revolution of rotating, cavitations were observed at all operating points. Rotating was relatively against the impeller.

Mununga, L, Hourigan, K and Thompson, M (2003) wrote a paper on numerical study of the effect of blade size on pumping effectiveness of a paddle impeller in an unbaffled mixing vessel. They demonstrated that increases in blade width have been seen to be result in corresponding increases flow of pumping number (Nq), power number (Np), and pumping efficiency (λp). However, it exhibited some sensitivity to variation of blade width in the laminar region.

Bakir, F and Kouidri, S et al. (2003) conducted experiment of the blade leading edge on the performances in cavitating regime. The experiment for the various geometries of inducers obtained by successive cutting and sharpening of the leading edge, presented overall performances at 1450 rpm in noncavitating regime. On the other hand, in cavitating regime was observing the development of the cavitation versus the cavitation number. They found out the increase in the slope of the leading edge likely to significantly improve the cavitations performances at high flow rate and to ease the pressure fluctuations. This studies inducers incline the leading edge towards the outlet can reduce the critical cavitation number. They concluded that sharpening improves these same performances in the vicinity of the nominal flow rate.

Schiavello, B. and Cicatelli, G. (2007) wrote a proceeding of the twenty-third international pump users symposium discussed on vibration field problem resolved with analytical diagnostics approach and innovative impeller design. They used a nine blades new impeller to replace the five blades old impeller for their investigation. It was full evident that the vane pass frequency radial vibrations at bearing housing are significantly reduced with the new impeller geometry.

Dyson (2005), wrote a proceeding of the twenty-second international pump users symposium of impeller rerate to reduce hydraulically generated vibration. He concluded that using CFD analysis and in the same time using the best practice mechanical design it is possible to reduce vibration levels at off design flows. The off design flows is by designing the impeller to closely match the operating condition of the pump. Moreover, he discovered that by using different vanes numbers and angle and then evaluating the designs, a balance between the hydraulic performance and low vibration potential can be achieved. On the other hand, high vane angles and increased vane numbers generate more head for a given diameter so their used allows a machine lower in size and cost to be produced.

Donald, M. S., Asadullah Syed et al. (2006) had proposed that that the reliable and robust impeller design can be done with elaborate engineering analyses and testing, including static and dynamic finite element analysis (FEA), and transient computation fluid dynamics (CFD). The loading on an impeller can easily influent by a few aerodynamic flow phenomena such as swirl, wave formation, flow separation, surge and other fluctuation. According to their case study, the impeller design which modified with 17 blades experienced incidents. However, it is only the blade loading edge cracks happen. Whereas, the impeller design which reduced the number of inlet guide vane was successfully operating for several years. Moreover, it is already for used in several years. This investigation also had accomplishment to calculate the factor of safety for these modified geometry impeller. This paper concluded that the use of this toolkit result in better understanding of impellers in a dynamic environment and provides greater reliability, profitability and reduce risk for both the client and manufacturer.

2.3 Material Impeller Effect

Pump industry have a desire for a combination of a hard material to resist wear and a corrosion resistant material to insure long life. This is the problem in material impeller because we will lose the corrosion resistance when we heat treat a metal to get the hardness we need. The softer metals can have corrosion resistance, but they lack the hardness for long wear life. The best materials that combine these features are called the "Duplex Metals".

Miyasaka and Yakuwa (2007) of Ebara discussed the solutions currently on offer for surmounting crevice corrosion and concern at the latest advances in this field. Corrosion is the greatest problem encountered in stainless steel (SS) structures widely used in seawater pumps. Ebara carried out immersion tests of different stainless steels in the Middle East seawater also known as the Arabian Gulf and the Red Sea. The results verified that Super Duplex SSs provide excellent crevice corrosion resistance in these areas. Super SS9 are identified as Stainless steels with a Pitting Resistance Equivalent (PRE) of 40 or higher and have high crevice corrosion resistance. In others words, the SSs is perform better than the economic material inside a Type 316 SS vertical seawater pump.

Matthew, S.A, Oluwafemi, A.O, Oladeji, A.O, (Federal University of Technology) studied on casting of brake disc and impeller from aluminum scrap using silica sand. The casting yield was found to be 73.59% for the impeller blade and 85.1% for the brake disc which indicate that sound casting was achieved. Aluminum is used because it produces good mechanical properties in casting, such as good surface finish, light weight, fewer tendencies to oxidation, lending to modification, resistance to corrosion and its availability. It is fluidity and good physical properties. This casting is less expensive and gives less distortion and dimensional accuracy. In their study done, the defects were found on the two casting. It may be due to entrapped air and poor surface finish of the mould, although the defects are minor.

Bennekom, A.V, Berndt, F. and Rassool, M.N. (2001) accomplished a compendium of case studies of pump impeller failures. In this studies, this CF-8M (cast equivalent of type 316 stainless steel) impeller, which fragmented when pump a nickel sulphate solution after a few hours in service. They detect some pitting and slight cracking along the interface between the web and flange of the impeller. The failure was due to insufficient feeding of the casting with molten metal during the solidification process. This failure could overcome if apply additional runners and risers in the casting. Beside that, they also study on a bronze impeller in a pump. It also experience failure which start-up a significant amount of vibration, followed by fragmentation of the impeller a few minutes later and the presence of a pre-existing crack. From these two case studies, it can be concluded that metallurgical defects result in very rapid failure.

2.4 Simulation on Impeller

Longatte and Kueny (1999) studied on analysis of rotor-stator-circuit interactions in a centrifugal pump. This paper presents a numerical analysis of pump-circuit coupling. It considered simultaneously the interactions between mobile and fixed elements of a centrifugal pump. A full modeling of the flow in the machine must be undertaken, that suppose a computational code able to solve rotor-stator flow. In previous work, a two dimensional, unsteady, viscous and incompressible numerical code by Croba et al. (1996) was developed to analyze the flow in centrifugal pumps. Numerical results from Fortes et al. (1995) obtained considering stationary boundary conditions (constant flow rate at the inlet of impeller and static pressure profile at the exit of volute) provided pressure fluctuations values ten times higher than in experiments of Talha (1996). The first results show the essential to consider the influence of the circuit to quantify the pressure fluctuations in the pump. In addition, the pump is a source of flow and pressure fluctuations in the circuit. The flow rate and the head are minimum when a blade is placed just opposite to the volute tongue. Numerical results seem to indicate that the pump is a source of flow rate fluctuations. Comparisons with pump alone calculations point out the height influence of the boundary conditions on pressure fluctuations calculation and indicate that the connected circuit should be taken into account to improve numerical simulations and to evaluate pump boundary conditions. This influence of pump-circuit coupling will be analyzed with other pump configurations (blades number, radial gap) in 2D and 3D geometries.

Mikio Oi, Mariko Suzuki and Natsuko Matsuura (1999) investigated on structural analysis and shape optimization in turbocharger development. This paper introduces the transitions of the structural analyses of the impeller as the most important component of the turbocharger and some examples of analyses. These samples analysis is using the MCS/Nastran (post treatment:FEMOS or I-DEAS) as CAE. To cope with a big change in flow of product development from the 2D to 3D designing, the role of various types of CAE is very important. It is ideal that CAE be incorporated in the development design process and used in the initial phase of development designing.

Matej Vesenjak, Zoran Ren and Matjaz Hribersek (2004) analyzed on fluid structure interaction in multiphase mixing vessel. The finite element method was used for determination of the deformation and stress fields of the blade under a form of pressure distribution as load field. For the structural analysis of the blade, we defined the material properties for the blade as follows: elasticity modulus 210000 MPa and Poisson ration 0.3. The blade has a constant thickness of 35 mm and was meshed with 3-node shell elements. It was fixed at the edge were it is welded to the shaft. The largest computed deformation of the blade was 0.076 mm at the leftmost free corner, while the stresses were the highest at the point of attachment to the shaft in the upper right corner and equal to 32.23 MPa. The resulting deformations and stresses are evaluated. The proposed procedure can be effectively used for optimization of structures with significant fluid flow influences.

After reviewed all related journals, papers and article published, it was observed that the impeller failures usually were due to the error on geometrical impeller design and the impeller pump corrosion occurs upon which unsuitable materials have been chosen for the specific application. To overcome the impeller failure, this thesis will present more enhanced work on the diameter impeller blade and the material selection will be carried out as not much investigation had been published.