MODELLING OF ROTOR DYNAMICS WITH ANSYS

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This report is submitted
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DECLARATION

I declare that this project report entitled "Modelling of Rotor Dynamics with ANSYS" is the result of my own work except as cited in the references

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Name : ....Elsa Lee Sook Theng.....

Date : ....20th June 2021.............

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant and Maintenance).

Signature : ....

Name of Supervisor: PROFEESOR DATUK IR.TS.DR. MOHD JAILANI BIN MOHD NOR

Date : 26/6/2021

DEDICATION

I would like to dedicate this project to my beloved mother and father, my siblings for the love, understanding and support for making this project possible.

ABSTRACT

Rotor Dynamics is important for the analysis of vibration in a rotating structure under mechanics. Rotating structure are widely found in industrial setting, and it is important to have proper analyzing of machinery to avoid catastrophic event. Rotor dynamics characteristic can be determined with aid of Finite element analysis to monitor and diagnose the potential failure due to vibration. The aim of this project is to analyze the effects of design parameter on dynamics properties of a rotor-bearing system and identify the characteristic of vibration on a rotor modal with mode shape, Campbell diagram and critical speed. This project starts with modelling of a simple rotor modal and carried out with applying boundary condition and forces to observing the behavior of the rotor system. The rotor modal is later analyzed with double disk and dynamics properties is observed. The mode shape, Campbell diagram, critical speed and whirling motion has been identified. The critical speed should be avoided to prevent maximum amplitude and failure of rotor. The critical frequency at higher speeds at shaft should be passing through quickly to prevent catastrophic events.

ABSTRAK

Pemutar dinamik adalah sangat penting dalam analisis getaran dalam skruktur berputar di bawah mekanik. Struktur berputar banyak terdapat dalam persekitaraan industri and amat penting untuk melakukan analisis elemen untuk memantau dan mengenalpasti potensi kegagalan akibatkan getaran yang akan memberi kesan yang bahaya. Hal ini demikian, projek ini adalah untuk menganalisis kesan ukuran reka bentuk dengan sifat dinamik dan factor fasa putaran, Campbell diagram dan kelajuan kritikal kepada struktur pemutaran. Projek ini dimulakan dengan reka bentuk struktur rotor yang mudah dan mengaplikasikan syarat-syarat dan situasi dalam sistem rotor. Modal rotor kemudian dianalisiskan dengan dua disk untuk mensimulasikan situasi sebenar. Selepas mengetahui kelajuaan kritikal dalam sistem pemutaran kita dapat mengelakkan amplitude maksimum yang akan menyebabkna kegagalan rotor. Bila frequency operasi perlu melalui frequensi kritical, ia kena memastikan dilalui dengan pantas untuk mengelakkan kejadian kemalangan.

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M	=	Mass
C	=	Damping
K	=	Stiffness matrices
G	=	Gyroscopic effect
ω	=	Rotational Velocity
Φ	=	Mode shape
$\bar{\lambda}$	=	Natural frequency
$\ddot{u}$	=	Acceleration
$\ddot{u}$	=	Velocity
U	=	Displacement
f	=	External Force
G	=	Gyroscopic Matrix
B	=	Rotating damping Matrix

CHAPTER 1

INTRODUCTION

1.1 Background

Rotor dynamics is part of a specialized branch of applied mechanics which is increasingly vital to the industrial user and researchers to investigate and analyze the rotating machinery correctly. Rotating machinery such as steam turbine, compressor, pump etc. in industrial setting is significant as large vibration that could possibly cause failure. Failure of such large machinery if amplitude of critical speed is excessive could create enormous catastrophic failure such as loss of equipment, breakage beyond repair, human injuries even fatalities.

The finite element analysis is chosen to perform the rotor dynamics analyses as it is a versatile tool to understand more accurately the dynamics response of rotor dynamics system (Wagner, 2010). ANSYS could provide sufficient result for route linear analysis of critical speeds, stability and unbalance response, also to expandable to solve more advance problems. The equation of motion was developed in matrix form by assembly of the element mass, stiffness, gyroscopic and damping matrices (Chaudhry, 2010). The modal analysis will predict how speed influences the frequency by running at speed from zero to the maximum rotational velocity of the system.

Based on structural dynamics characteristic of the system, a new method required to interpret the aquired from the experimental data of dynamics performance of machine including the supporting structure and the moving parts for conditioning monitoring. Discrete lumped system into finite number of masses connected by springs and damper representing the stiffness and damping in the system respectively is used for the simulation result. As the first step in turbo rotor design, analysis is performed to determine critical speeds, mode shapes and energy distribution (Gunter, 2001). This report will be focusing on three major concern which are rotor critical speeds, system stability and unbalance response.

In many cases, vibration problem also happens because of wear and loose of rotary part of the machine, such as old compressor and electric motor. The occurrence is due to lack of maintenance and improper set up of the machines.

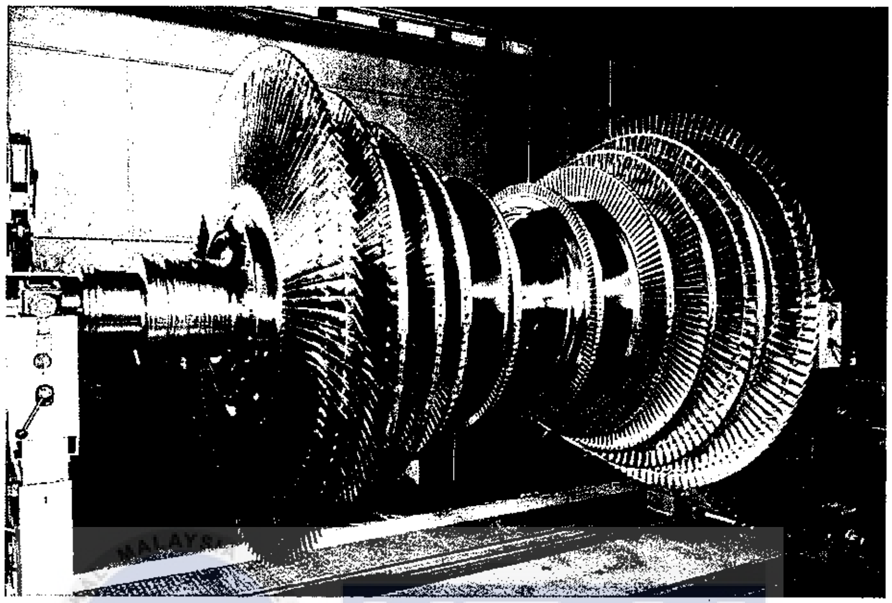


Figure 1.1: Steam turbine rotor and blade (Anonymous)

1.2 Problem Statement

Dynamics properties of a rotating machine will have to be anticipate the vibration phenomena that will encounter during the operation of these machinery. Due to facts that rotating machinery will subject to wears, foundation settle, and parts deform, subtle changes the efficiency of the machine will decrease. Overlooked rotating machinery will encounter fault such as shaft become misaligned, parts begin to wear, rotor become unbalance and clearances increases (Al-Khazali, 2012). As a result of the increased vibration energy which is dissipated throughout the machine experience excites resonance and puts considerable extra dynamics loads on bearing.

An analysing approach should be taken to provide engineering judgment based on understanding of physical phenomena needed to provide the diagnosis and method for correcting machinery fault. The finite element formulation (ANSYS) model will be used to analyse the critical speeds, stability and unbalance response of a rotating machinery. A detailed procedure will be describe focusing on vibration analysis of designing a rotor.

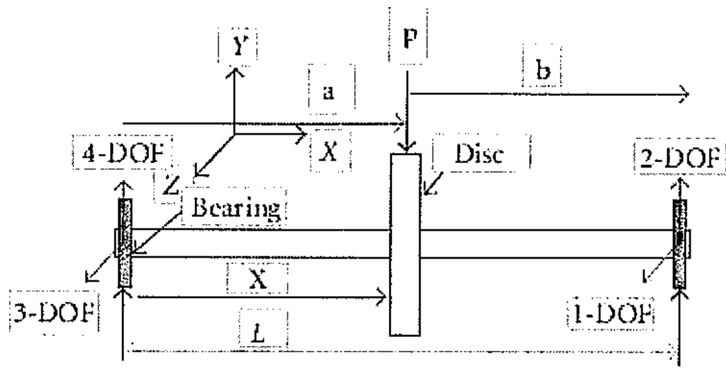


Figure 1.2: Schematic of a rotor setup parameter.

1.3 Objective

The objectives of this project are as follows:

1. To analyse the effect of design parameter on dynamics properties of rotor-bearing system.
2. To identify the effect of vibration on rotor modal with natural frequencies, mode shapes, Campbell diagram and critical speed.

1.4 Scope of Project

The scopes of this project are:

1. Only results of vibration measurement are presented in this report. The results will be limited to the interface between the rotor and the support structure.
2. All the simulation will be carried out in finite element formulation (ANSYS) for the support structure flexibility effect within the vibration frequency range.

CHAPTER 2

LITERATURE REVIEW

2.1 Rotor dynamic system

The dynamic analysis of rotor is applicable to deepen the understanding of different phenomena that will occur in rotating machineries. Knowledge of rotor dynamic get to apply to the design and maintenance of machines. As we study about the operational behavior of rotating machines we get to determine the proper functioning of the machine and avoid variety of physical phenomena that could lead to failure (Ritto, 2015).

Figure 2.1: Manufacturers routinely perform modal analysis to determine the shaft's critical speed and to determine the geometry of the dan a facility requires. (Courtesy: New York Blower).

Rotor dynamics as a branch of mechanics defines critical speed as the angular velocity of rotating object excited at its natural frequency. In the case of pump as example, the rotational speed is measured at the occurrence of natural vibration. It will be common to expect a radial deflection caused by overhung impeller's weight that causing vibration in horizontal pump, even when the impeller was perfectly balanced. Similar vibration can be noted at vertical operation with no radial deflection due to impeller weight (Evans,2011).

General dynamic Equation:

$$[M]\{\ddot{u}\} + [C][\dot{u}] + [K]\{U\} = \{f\} \tag{2.1}$$

In rotor dynamics, the gyroscopic effect[G] and Damping effect [B] are added

$$[M]\{\ddot{u}\} + ([G] + [C])[\dot{u}] + ([B] + [K]\{U\} = \{f\} \tag{2.2}$$

2.2 Importance of rotor dynamics

Rotor dynamics is discipline in machine specifically about vibration behaviour of axially symmetric rotating structure. Rotating equipment tends to costly to design, develop and manufacture, therefore it is crucial to ensure the behavior of the equipment when it operate does not jeopardize other components. From point of preventive maintenance, a proper rotor dynamics analysis can guarantee the reduction in expensive maintenance and repair cost. Rotor dynamics analyses will aid engineers to identify the sudden equipment failures that will lead to costly consequences.

In additional, rotor dynamics could prevent excessive downtime and unexpected breakdown of machine because of vibrational issues. Turbomachinery and rotating equipment are widely used from power generation, aircraft propulsion to computer disk storage. These machines can be critical and affecting lives depended by having unscheduled shutdown. Neglected rotor dynamics analyses could cause wear excessively in short period of time and forced out of service due to premature excess wear and even catastrophic failure(Green, 2019).

Figure 2.2: A Coupling Failure in an Induced Draft Fan System (*Wang,2012)*

Rotating structure have generally modeled by lumped mass and the center of the mass is used to determine the influence of rotation attached or proximal components. The biggest constraint is the nonspecific assumption of both the location and distribution of the mass and inertia, along with inaccuracy in the calculation of internal forces and stresses in the components. The use of finite element (FE) method with ANSYS, allowed us to define and accurate modeling of rotor dynamic system by having accurate of mass and inertia, wide range of element supporting gyroscopic effect, CAD geometry when meshing in solid elements, able to mesh solid element for flexibility of the disk and coupling between disk and shaft vibration also to include stationary parts within full model or as substructure. According to Royal aeronautical society, typical analysis will be frequency response with given rotor speed, rotor modes and stabilities for complex model with whirl modes, Campbell diagram and critical speeds, transients at start-up, stop or through a critical speed.

Two factors are taken for the determination of shaft critical speed is shaft stiffness and rotor weight. The increase in diameter of shaft, increases the stiffness of the shaft and raises the natural frequency of the rotor. Critical speed should be prevented from resonate in response to normal fan operation that could result in fan damage and commonly rotor cracking due to material fatigue. (Power, 2020)

2.3 Terminology of Rotor Dynamics

The theory of rotor dynamics can be demonstrated with the assistance of simple rotor modal of Jeffcott rotor model for easier understanding and verification of rotor dynamics analysis before building complex model.

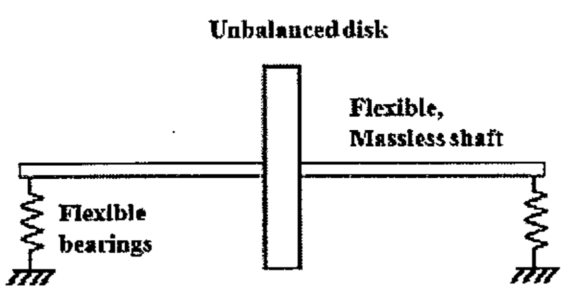


Figure 2.3: Generalized Laval-Jeffcott rotor model. (Srikrishnanivas, 2012)

The Jeffcott rotor consist of two major component which are long and flexible massless shaft with flexible bearing on both ends. The bearing have supported stiffness of Kx and Ky associated with damping Cx and Cy in x and y direction of the shaft. The disk is located at the center of the shaft and center of gravity of the disk is offset from the shft geometry by eccentricity of e.

The finite element analysis efficiently performed the full analysis by obtaining the Campbell diagrams, critical speeds, and response of unbalance due to mass unbalance at the cutting tool. A research paper is conducted to evaluation of the results and how the program was verified with beam finite element (FE) model are performed. Mechanical and geometrical properties of a grinding machine tools spindle-bearing modal system and its analysis of rotor dynamic was done by ANSYS (Jauhari,2017).

2.3.1 Mode Shape

Mode is defined as the resonance of the structure which is inherent the properties of the structure (Bae *et al.*, 2007). The motion behaviour at each natural frequency is called mode shape when the structure is vibrating. The number of mode shapes of the structure depends on the number of degree of freedoms. When a structure vibrates near to its natural frequency, the vibration shape of the structure tends to be shaped like mode shape of resonance. Mode is a property of structure without any load is applied when calculated. Mode are associate with structural resonance as majority of the structures can be resonate under a proper condition vibrating with excessive, sustained motion. Resonant vibration is caused by the interaction between the inertial and elastic properties of material within the properties of structure. Resonance has contributed to many of the vibration related problem, in structures and operating machinery. Furthermore, most if the failure was due to the failed in tolerance, noisy operation, uncontrollability, material failure, premature fatigue and shortened the product life.

Hence, for gaining insight of the rotational machinery by targeting the structural vibration problem and character of the resonance structure. A common way is by defining the modes of vibration with mode frequency, modal damping and mode shape of rotor modal. Mode shape also helps in visualizing the rotor vibration at discrete natural frequencies. The bearing stiffness to the shaft stiffness has a huge impact on mode shape as soft and medium type of bearing, the bending will not be initiated in first two modes and will be called as "rigid rotor" mode.

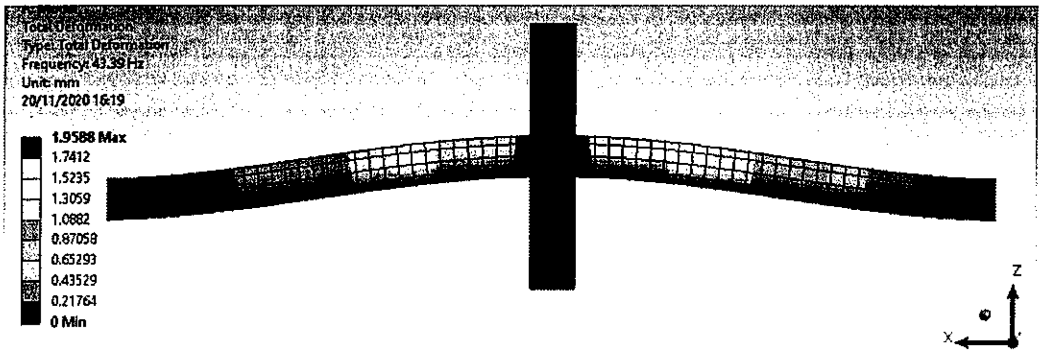


Figure 2.4: Mode shape of rotor modal.

2.3.2 Whirling

Shaft whirling is the stability in rotor structure means the self-excited vibration due the increase of vibration amplitude over time. This occur when rotor is set into motion and tends to bend according to orbital motion. The elastic properties of the shaft will produce a restoring force, helping to bring the shaft back into position.

Referring to figure 2.5, whirling is classified into forward whirling and backward whirling. The deformation motion of rotor acting same direction of the rotational speed as called as forward whirling and if opposite direction of the rotational speed are called backward whirling. The frequencies of whirling motions are the natural whirling frequencies and the shapes of whirling are called natural whirling modes.

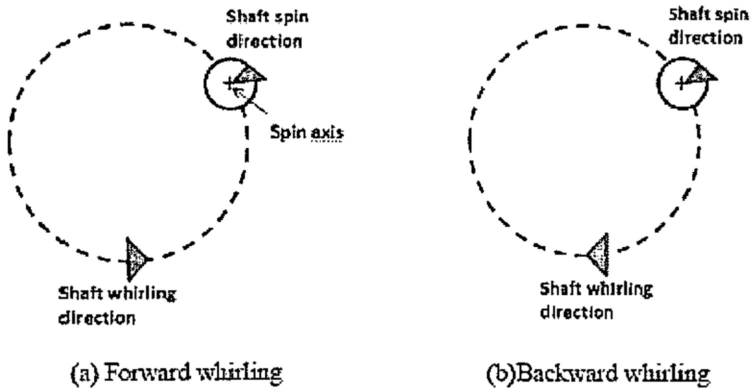
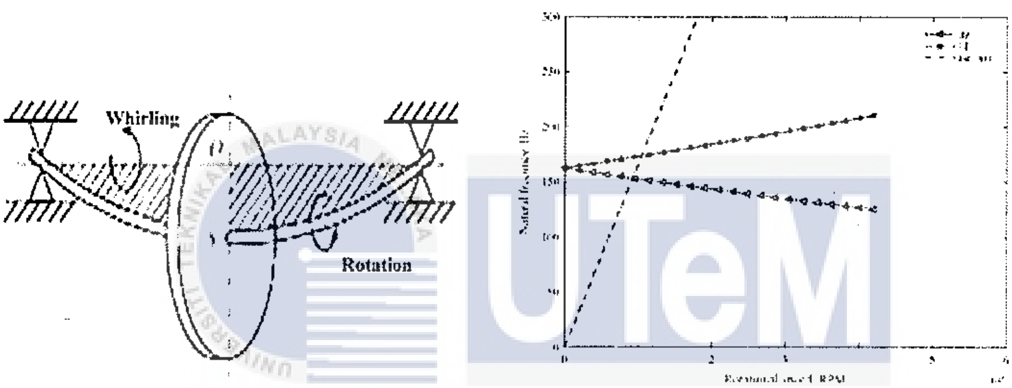


Figure 2.5: Types of whirling

For rotor that designed to rotate at high speed increase the efficiency of the machines, the whirling natural frequency of shaft changes with different in shaft speed and design will need to be determined to prevent points of resonance where whirling frequency equals the shaft speed. A shaft will carry huge torque along and torsional effect influenced by high speed which has been neglected in past shaft analyses (Wahab, 2017).

Figure 2.6 (b) shows Campbell diagram of a shaftwith both forward whirl and backward whirl. Shaft whirling can produce several different modes of deformation where inertial and restoring forces balance. This behaviour is governed by partial differential equation (PDEs) to helps in predicting the failure due to shaft whirling.



(a) (b)

Figure 2.6: (a) The whirling of a shaft (b)The Campbell diagram of a shaft. (Wahab, 2017)

2.3.3 Critical speed

Critical speed represents the rotational speed that corresponds to the structure's resonance frequency. Critical speed shows when the natural frequency is equal to the excitation frequency. The excitation can be due to the unbalance that is synchronous with the rotational velocity or any asynchronous excitation.

Critical speed also can the determined by performing a Campbell diagram analysis, where the intersection points between the frequency curves and the excitation line are calculated.

For undamped rotor, the dynamics equation can be rewritten as:

$$[M]\{\ddot{U}\} + \omega[G]\{\dot{U}\} + [K]\{U\} = 0 \tag{2.3}$$