

**VIBRATION CONTROL OF A COUPLED CYLINDER UNDER
ROTATIONAL MOTION**

JOSUA TAINRING

B041110233

BMCL

Email: josuataining@gmail.com

**Draft Final Report
Projek Sarjana Muda II**

Supervisor: DR. ROSZAIDI RAMLAN

**Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka**

JUNE 2015

SUPERVISOR DECLARATION

“I hereby declare that I have read this thesis 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 & Maintenance)”

Signature:

Supervisor: Dr. Roszaidi Ramlan

Date:

VIBRATION CONTROL OF A COUPLED CYLINDER UNDER ROTATIONAL
MOTION

JOSUA TAINRING

This Report Is Submitted In Partial Fulfilment of Requirement For Degree of
Bachelor of Mechanical Engineering (Plant & Maintenance)

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

JUNE 2015

DECLARATION

“I hereby declare that the work in this report is my own except for summaries and quotations which have been dully acknowledge”

Signature:

Author: Josua Tainsing

Date:

I dedicate my final year project to my family and my supervisor Dr. Roszaidi Ramlan. A special feeling of gratitude to my loving parents, Tainsing Somundoh and Lotimah Sogiloi whose encouragement and supported me throughout my degree. I will always appreciate all they have done.

ACKNOWLEDGEMENT

To the light, our God, who guided us through the way, to Dr. Roszaidi Ramlan, for his great efforts of supervising and leading me to accomplish this fine work. To my friends and families, they were a great source of support and encouragement. Thank you.

ABSTRACT

In oil drilling process, one the most destructive element is vibration. The phenomenon of vibration causes a lot of problem including drilling efficiency and even safety of the operators. Vibration suppression in drilling has been an ongoing study since years ago up until this century. Accurate prediction and controlling of the vibration problem is essential to achieve a more efficient and safer drilling operation. This research will focus on suppressing the vibration problem by studying the vibration characteristic of different physical parameters of the coupled cylinder and how to control them. Theoretical and experimental study was conducted to study this vibration problem. Theoretical study involves the analysis about the equation of motion of the coupled cylinder. The experimental study includes the investigation of effect of different parameters in a coupled cylinder which include load, rotational speed, cylinder's length, eccentricity, misalignment and different type of coupling. In this research, the line of drill pipes is characterized as coupled cylinder, the linkage as coupling, the rotary table as motor, and the drilling mud as load. The findings of this study lead to the understanding of the vibration characteristic of a coupled cylinder and hence the identifying the effective control method.

ABSTRAK

Dalam proses penggerudian minyak, salah satu elemen yang paling merosakkan adalah getaran. Fenomena getaran menyebabkan banyak masalah termasuk kecekapan penggerudian dan juga keselamatan pengendali. Penindasan getaran dalam penggerudian merupakan satu kajian yang sedang berlangsung sejak bertahun lalu sehingga abad ini. Ramalan yang tepat dan kawalan masalah getaran adalah penting untuk mencapai operasi penggerudian yang lebih cekap dan lebih selamat. Kajian ini akan memberi tumpuan kepada mengurangkan masalah getaran dengan mengkaji ciri-ciri getaran pada parameter fizikal yang berbeza bagi silinder yang disambungkan dan bagaimana untuk mengawalinya. Kajian teori dan eksperimen telah dijalankan untuk mengkaji masalah getaran ini. Kajian teori melibatkan analisis tentang persamaan gerakan silinder yang disambung. Kajian eksperimen termasuk penyiasatan kesan parameter yang berbeza di dalam silinder yang disambung termasuk beban, kelajuan putaran, panjang silinder, kesipian, salah jajaran dan jenis penyambung yang berbeza. Dalam kajian ini, talian paip gerudi mempunyai ciri-ciri sebagai silinder yang disambungkan pula, hubungan sebagai penyambung, meja berputar sebagai motor, dan lumpur penggerudian sebagai beban. Hasil kajian ini membawa kepada pemahaman ciri getaran silinder yang disambungkan dan seterusnya mengenal pasti kaedah kawalan yang berkesan.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	PROJECT TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS	xvi
	LIST OF ABBREVIATIONS	xviii
CHAPTER I	INTRODUCTION	1
	1.1 Problem Statement	1
	1.2 Objective	2
	1.3 Scope	2
CHAPTER II	LITERATURE REVIEW	3
	2.1 Fundamental of Vibration	3
	2.2 Classification, Terminologies and Quantification of Vibration	4
	2.3 Vibration Analysis	6
	2.3.1 Vibration Analysis Procedure	6
	2.3.2 Vibration Sensors	7
	2.4 Vibration of a Coupled Cylinder Under Rotation Motion	9
	2.4.1 Torsional Vibration	12
	2.4.2 Lateral Vibration	13

	2.4.3	Misalignment and Unbalance	16
	2.4.4	Eccentricity	18
	2.5	Coupling	20
CHAPTER III	METHODOLOGY		23
	3.1	Analytical Study	25
	3.2	Device Planning	27
	3.3	Device Fabrication	28
	3.4	Apparatus Preparation	30
	3.5	Experimental Study	31
	3.6	Collecting Data and Analysis	33
CHAPTER IV	THEORETICAL ANALYSIS		34
	4.1	Rotational Vibration	34
	4.2	Radial Vibration	36
	4.3	Fast Fourier Transform (FFT)	39
CHAPTER V	DATA AND RESULT		43
	5.1	Baseline Measurement	43
	5.1.1	Motor Uncoupled	44
	5.1.2	Rigid Shaft	47
	5.2	Effect of Load and Rotational Speed to Vibration Characteristic of Rotating Shaft	51
	5.3	Effect of Shaft's Length to Vibration Characteristic of Rotating Shaft	55
	5.4	Effect of Unbalance to Vibration Characteristic of Rotating Shaft	60
	5.5	Effect of Misalignment to Vibration Characteristic of Rotating Shaft	64
	5.6	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft Under Different Condition	68
	5.6.1	Effect of Different Coupling to Vibration Characteristic of Coupled	

	Rotating Shaft With and Without Load	69
5.6.2	Effect of Different Coupling at Different Location to Vibration Characteristic of Coupled Rotating Shaft	73
5.6.3	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft Under Eccentric Load	77
5.6.4	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft Under Misalignment	80
CHAPTER VI	ANALYSIS AND DISCUSSION	83
6.1	Baseline Measurement	83
6.1.1	Motor Uncoupled	83
6.1.2	Rigid Shaft	84
6.2	Effect of Load and Rotational Speed to Vibration Characteristic of Rotating Shaft	85
6.3	Effect of Shaft's Length to Vibration Characteristic of Rotating Shaft	86
6.4	Effect of Unbalance to Vibration Characteristic of Rotating Shaft	87
6.5	Effect of Misalignment to Vibration Characteristic of Rotating Shaft	88
6.6	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft Under Different Condition	89
6.6.1	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft With and Without Load	89
6.6.2	Effect of Different Coupling at	

	Different Location to Vibration Characteristic of Coupled Rotating Shaft	90
6.6.3	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft Under Eccentric Load	91
6.6.4	Effect of Different Coupling to Vibration Characteristic of Coupled Rotating Shaft Under Misalignment	91
CHAPTER IV	CONCLUSION AND RECOMMENDATION	93
7.1	Conclusion	93
7.2	Recommendation	96
	REFERENCES	97

LIST OF TABLES

NO	TITLE	PAGE
2.1	Factors of Vibration for Each Mode	10
2.2	Effects of Vibration for Each Mode	11
3.1	Gantt Chart	25
3.2	Test Matrix	32

LIST OF FIGURES

NO	TITLE	PAGE
2.01	Amplitude and Period of Sinusoidal Wave	4
2.02	Average, RMS and Peak of Sinusoidal Wave	5
2.03	Sensitivity of Sensors Over Different Frequency Range	8
2.04	Type of Drillstring Vibration	10
2.05	Mechanical Modeling of Torsional Vibration	13
2.06	Type of Whirl	14
2.07	Mechanical Modeling of Lateral Vibration	15
2.08	Parallel Misalignment Frequency Spectrum	16
2.09	Angular Misalignment Frequency Spectrum	17
2.10	Unbalance Frequency Spectrum	18
2.11	Two Types of Eccentricity	19
3.01	Flow Chart of Project	24
3.02	Flow Chart of Analytical Study	26
3.03	Disc Coupling	27
3.04	Jaw Coupling	27
3.05	Rubber Coupling	27
3.06	Apparatus Arrangement	28
3.07	Test Rig	29
3.08	Point of Measurement and Its sensor	30
3.09	Flow Chart of Experimental Study	31
3.10	Flow Chart of Data Collection and Analysis	33
4.01	Mechanical Modelling of Rotational Vibration	34
4.02	Displacement Transmissibility From Pipe 1 to Pipe 2	36
4.03	Mechanical Modelling of Lateral Vibration	37
4.04	Frequency Response Function	39
4.05	Example of FFT Transformation	39

4.06	Unbalance Frequency Spectrum	40
4.07	Parallel Misalignment Frequency Spectrum (Radial Direction)	40
4.08	Parallel Misalignment Frequency Spectrum (Axial Direction)	41
4.09	Angular Misalignment Frequency Spectrum (Axial Direction)	41
4.10	Angular Misalignment Frequency Spectrum (Radial Direction)	42
5.01	Condition of Baseline Measurement	44
5.02	Graph of Velocity Against Order – Motor Horizontal	45
5.03	Graph of Velocity Against Order – Motor Vertical	45
5.04	Graph of Velocity against Order – Motor Axial	46
5.05	Condition of Rigid Shaft Testing	47
5.06	Graph of Velocity against Order – Inboard Horizontal	48
5.07	Graph of Velocity against Order – Inboard Vertical	48
5.08	Graph of Velocity against Order – Inboard Axial	49
5.09	Graph of Velocity against Order – Outboard Horizontal	49
5.10	Graph of Velocity against Order – Outboard Vertical	50
5.11	Graph of Velocity against Order – Outboard Axial	50
5.12	Loaded Shaft	51
5.13	Graph of Velocity against Order – Inboard Horizontal	52
5.14	Graph of Velocity against Order – Inboard Vertical	52
5.15	Graph of Velocity against Order – Inboard Axial	53
5.16	Graph of Velocity against Order – Outboard Horizontal	53
5.17	Graph of Velocity against Order – Outboard Vertical	54
5.18	Graph of Velocity against Order – Outboard Axial	54
5.19	Coupling Located at $\frac{1}{2}$ L from Inboard	55
5.20	Coupling Located at $\frac{1}{4}$ L from Inboard	56
5.21	Coupling Located at $\frac{3}{4}$ L from Inboard	56
5.22	Graph of Velocity against Order – Inboard Horizontal	57
5.23	Graph of Velocity against Order – Inboard Vertical	57
5.24	Graph of Velocity against Order – Inboard Axial	58
5.25	Graph of Velocity against Order – Outboard Horizontal	58
5.26	Graph of Velocity against Order – Outboard Vertical	59
5.27	Graph of Velocity against Order – Outboard Axial	59
5.28	Rotor with Eccentric Bolts Added	60

5.29	Graph of Velocity against Order – Inboard Horizontal	61
5.30	Graph of Velocity against Order – Inboard Vertical	61
5.31	Graph of Velocity against Order – Inboard Axial	62
5.32	Graph of Velocity against Order – Outboard Horizontal	62
5.33	Graph of Velocity against Order – Outboard Vertical	63
5.34	Graph of Velocity against Order – Outboard Axial	63
5.35	Position of Inboard(left) and Outboard(right) for Misalignment Test	64
5.36	Graph of Velocity against Order – Inboard Horizontal	65
5.37	Graph of Velocity against Order – Inboard Vertical	65
5.38	Graph of Velocity against Order – Inboard Axial	66
5.39	Graph of Velocity against Order – Outboard Horizontal	66
5.40	Graph of Velocity against Order – Outboard Vertical	67
5.41	Graph of Velocity against Order – Outboard Axial	67
5.42	Different Type of Coupling	67
5.43	Position of Coupling for With and Without Load Test	69
5.44	Graph of Velocity against Order – Outboard Horizontal	70
5.45	Graph of Velocity against Order – Outboard Vertical	70
5.46	Graph of Velocity against Order – Outboard Axial	71
5.47	Graph of Velocity against Order – Outboard Horizontal	71
5.48	Graph of Velocity against Order – Outboard Vertical	72
5.49	Graph of Velocity against Order – Outboard Axial	72
5.50	Coupling Located at $\frac{1}{4}$ L from Inboard	73
5.51	Coupling Located at $\frac{3}{4}$ from Inboard	74
5.52	Graph of Velocity against Order – Outboard Horizontal	74
5.53	Graph of Velocity against Order – Outboard Vertical	75
5.54	Graph of Velocity against Order – Outboard Axial	75
5.55	Graph of Velocity against Order – Outboard Horizontal	76
5.56	Graph of Velocity against Order – Outboard Vertical	76
5.57	Graph of Velocity against Order – Outboard Axial	77
5.58	Coupled Shaft Wit Eccentric Bolt Attached	78
5.59	Graph of Velocity against Order – Inboard Horizontal	78
5.60	Graph of Velocity against Order – Inboard Vertical	79

5.61	Graph of Velocity against Order – Inboard Axial	79
5.62	Position of Inboard(left) and Outboard(right) for Misalignment Test	80
5.63	Graph of Velocity against Order – Outboard Horizontal	81
5.64	Graph of Velocity against Order – Outboard Vertical	81
5.65	Graph of Velocity against Order – Outboard Axial	82

LIST OF SYMBOLS

f	=	Frequency
T	=	Period
t	=	Time
x	=	Displacement along x -axis
y	=	Displacement along y -axis
A	=	Amplitude
φ	=	Phase
ω	=	Angular frequency
e	=	Exponential
j	=	Imaginary
J_r	=	Inertial mass of rotary
J_b	=	Inertial mass of bit
J_1	=	Inertial mass of pipe 1
J_2	=	Inertial mass of pipe 2
d	=	Radius
T	=	Transmissibility
T_m	=	Torque on motor
T_b	=	Torque on bit
T_r	=	Torque on rotary
θ	=	Angular displacement
$\dot{\theta}$	=	Angular velocity
$\ddot{\theta}$	=	Angular acceleration
m	=	Mass
c	=	Damping
k	=	Stiffness
ξ	=	Damping ratio
ω_n	=	Natural angular frequency

r	=	Ratio of angular frequency to natural angular frequency
F_f	=	Fluid force
F_b	=	Force on bit
F_x	=	Force on x direction
F_y	=	Force on y direction
F_N	=	Normal force
F_T	=	Tangential force
L	=	Length from inboard to outboard

LIST OF ABBREVIATIONS

RMS	-	Root mean square
BHA	-	Bottom hole assembly
ROP	-	Rate of penetration
PDC	-	Polycrystalline diamond compact

CHAPTER I

INTRODUCTION

This research is about the study of vibration control of a coupled cylinder under rotational motion as faced in oil drilling process. Oil drilling process is prone to many types of vibration problem. This research will lead to the understanding of the vibration problem and how to control them.

1.1 Problem Statement

The line of drill pipes in oil drilling process is subjected to three modes of vibration which are axial, radial and torsional. The real situation in oil drilling process was imitated in laboratory, where the rotary table, drill pipe, connection and drilling mud is characterised as the motor, cylinder or shaft, coupling and load respectively.

Axial vibrations, is a motion along the lengthwise axis of the cylinder. In drilling process, this is mostly due to the interaction between drilling bit and the hole bottom. This vibration is called “bitbounce”. Axial vibration was introduced by introducing angular misalignment as this type of misalignment tends to create a strong vibration in axial direction.

Lateral vibrations, often caused by pipe eccentricity, leading to centripetal forces during rotation, named as drillstring whirl. This problem was imitated in the

laboratory by introducing eccentric mass at the rotating coupled cylinder. Eccentric mass will generate centrifugal force which is in radial or lateral direction.

Torsional or rotational vibrations caused by nonlinear load magnitude. The rotational vibration of the cylinder characterized by alternating stops during which the pipe sticks and intervals of large angular velocity of the pipe. However, due to equipment availability restriction in the laboratory, only analytical analysis was conducted for this type of vibration.

Different physical parameters of the oil drilling equipment were also studied. That includes the effect of different parameters in a coupled cylinder which include load, rotational speed, cylinder's length, and different type of coupling.

1.2 Scope

The problem imitates the real problem during oil drilling process. Involve theoretical mechanical modelling of the dynamics of the coupled cylinders. A test will be fabricated and tested. The study will lead to understanding of what governs the good vibration control properties of the coupled structure. The study will also gain knowledge on how to control the vibration.

1.3 Objective

1. To study the vibration characteristics of a coupled cylinder.
2. To study the effect of coupling mechanism and how to control the vibration at the coupling.
3. To fabricate a test rig to investigate the vibration characteristic of coupled cylinder and performance of coupling.

CHAPTER II

LITERATURE REVIEW

In this chapter, all of information related to vibration analysis and control that used for the study of vibration characteristic of coupled cylinder under rotational motion was elaborated. Literature review is important process to get all information related to this research.

2.1 Fundamental of Vibration

According to Putra (2013a), Vibration is the motion of a particle or a body from a position of equilibrium. Vibration occurs when a system is moved from equilibrium position. The system will return to equilibrium position under the action of restoring forces such as the elastic forces, as for a mass attached to a spring, or gravitational forces, as for a simple pendulum. The system keeps moving back and forth across the equilibrium position.

Most vibrations are undesirable in machines and structures because they produce increased stresses, energy losses, causes added wear, increase bearing loads, induce fatigue, create passenger discomfort in vehicles, and absorb energy from the system. Vibration causes noise which creates discomfort and annoyance to human. In some field, vibration is found to be beneficial such as in tooth cleaning, massage chair, music instrument and energy harvesting.

Vibration is due to imperfection in machine or structure. The possible factors are imperfection in design process. Defect in manufacturing, installation or assembly cause the machine or structure to vibrate. Improper operation and maintenance also

cause vibration problem. Rotating machines need proper balancing in order to prevent damage from vibrations.

2.2 Classification, Terminologies and Quantification of Vibration

Vibrations can be classified into three categories which are free, forced, and self-excited. Free vibration occurs with the absence of external force in the system. An external force that acts on the system causes forced vibrations. In this case, the exciting force continuously supplies energy to the system. Self-excited vibrations are periodic and deterministic oscillations. In contrast to forced vibrations, the exciting force is independent of the vibrations and can still persist even when the system is prevented from vibrating.

Below are some basic terminologies in vibration (Putra 2013b):

- Mass - store of kinetic energy
- Stiffness - store of potential (strain) energy
- Damping - dissipate energy
- Force - provide energy
- Amplitude - level of vibration from the equilibrium position (displacement, velocity, acceleration)
- Frequency - Frequency is the number of cycles repeated per second. The unit is Hertz (Hz)
- Phase - Angle difference between a measured point and a reference point

Quantification of vibration:

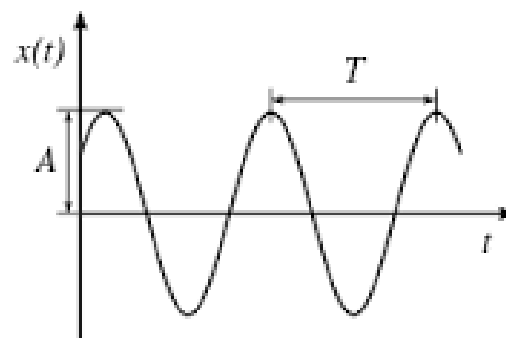


Figure 2.01: Amplitude and Period of Sinusoidal Wave (Putra 2013c)