Dynamic Analysis of Stick-Slip and Bit Bounce in Oilwell Drillstring

By

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CERTIFICATION OF APPROVAL

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

(DHANARAJ A/L ELIYATHAMBY)

ABSTRACT

Drilling process consisting of drag bits which are used over drilling boreholes concerning generation along with research about oil and gas regularly undergo against caustic vibrations. As mentioned, vibrations will be able to cause the drag bit along with drillstring various breakdown concerning equipments. This project, a non-linear design concerning rotational and axial motions of drillstring plus bit act suggested. Furthermore, dynamics concerning two drive complexes considering translational along with rotational motions regarding drillstring is being advised. Regarding mentioned model, translational along with rotating motions concerning drag bit are reached in the process of result regarding total dynamic action. The consequences concerning numerous viable criteria covering dynamic action are considered including objective in producing an undisturbed drilling. Using appropriate selection concerning operational criteria can help in minimizing the consequences regarding bit-bounce also stick-slip. It is anticipated to aid lower time lost in drilling operation along with costs sustained because of caustic vibrations.

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NOMENCLATURE

Short Form	Meaning
A	Cross sectional area of drill line (m^2)
b_o	The acceleration term in hyperbolic tangent function (-)
BHA	Bottom hole assembly (-)
C_{rt}	Torsional internal damping in gear box (N m s)
C_V	The effective damping due to fluid motion around the drillstring (N m s)
C_{ds}	Axial drillstring damping (N s/m)
d	Depth of cut (m)
D_o	Drill line diameter (m)
E_s	Modulus of elasticity of the drill line (Pa)
F_{break}	The friction force applied on draw works drum (N)
F_{hook}	Hook load (N)
g	Acceleration of gravity (m/s^2)
I	Draw works motor current (A)
I_m	Rotary table motor current (A)
J_{DW}	Inertia of draw works drum (kg m^2)
J_{ms}	Inertia of draw works motor shaft (kgm^2)
J	Lumped inertia of the drillstring (kg m^2)
J_{rt}	Inertia of the rotary table (kg m^2)
J_m	Inertia of the rotary table motor shaft (kg m^2)
J_{BHA}	Inertia of BHA (kg m^2)
k_c	Rock linear contact stiffness (N/m)
K_m	Draw works motor constant (V s)
K_{mo}	Rotary table motor constant (V s)
K_s	The drill line stiffness (N/m)
K	The effective torsional stiffness of the drill string (N m/rad)
k_{ds}	Drillstring axial stiffness (N/m)
L_p	Drill-pipes length (m)
L_b	Bottom hole assembly length (m)
L_o	Initial length of the drill-line from the crown block to the traveling block (m)

L_c	Draw works armature inductance (H)
L_i	Rotary table armature inductance (H)
L	The length of drill line from the crown block till the traveling Block (m)
m_{Top}	Suspension mass (kg)
m_a	The drill string effective mass (kg)
m_f	Fluid mass (kg)
m_{BHA}	BHA mass (kg)
n	Number of blades (-)
n_{DW}	Draw works motor gearbox ratio (-)
N	Number of times the drill line runs between the crown block and the traveling block (-)
n_o	Rotary table motor gearbox ratio (-)
R_b	Bit radius (m)
R_{DW}	Draw works drum radius (m)
R_m	Draw works armature resistance (Ω)
R_{mo}	Rotary table armature resistance (Ω)
ROP	Rate of penetration (m/s)
TOB	Down Hole Torque On Bit (N m)
TOB_f	Torque On Bit friction component (N m)
TOB_c	Torque On Bit cutting component (N m)
T_{mo}	The torque at the motor shaft driving the rotary table (N m)
T_m	The torque at the motor shaft driving the draw works drum (N m)
T_L	The torque applied on draw works drum from suspended weight (N m)
T_{DW}	The torque transformed from the motor shaft to the draw works drum (N m)
T_{fr}	The kinematic friction torque applied on draw works drum through arm break (N m)
V_{DL}	The effective drill line velocity (m/s)
V_d	Desired suspension mass speed (m/s)
V_{CD}	The supplied rotary table motor voltage
V_c	The supplied draw works motor voltage
W_{dd}	Desired draw works drum torsional speed (rad/s)

w_d	Rotary table desired speed (rad/s)
WOB	Down Hole Weight On Bit (N)
WOB_f	Weight On Bit friction component (N)
WOB_c	Weight On Bit cutting component (N)
x_a	The axial response of the bit (m)
x_{Top}	The axial response of the suspension mass (m)
x_{DL}	The drill line displacement (m)
γ	Spatial orientation of wear flats (-)
ε	Intrinsic specific energy (Pa)
ξ	Inclination of cutting force on the cutting face (-)
θ_{DW} ; $\dot{\theta}_{DW}$	The angular displacement and velocity of draw works drum (rad, rad/s)
θ ; $\dot{\theta}$	The angular displacement and velocity of the bit (rad, rad/s)
μ	Friction coefficient between rock formation and bit (-)
μ_P	Draw works break pad friction coefficient (-)
μ_f	Viscosity of drilling mud (N s/m^2)
υ	Poisson's ratio of drilling line (-)
ξ_o	Axial damping ratio (-)
ρ_b	Drillstring material density (kg/m^3)
ρ_f	Mud density (kg/m^3)
σ	Rock normal contact stress (Pa)

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

In the oil and gas industry, rotating drilling systems is portrayed just as system regarding drilling which utilizes drag bit in order to chomp over the sea bed. This system has the ability to chisel through the largely difficult and hardest formations. A rotary drilling system basically consists of rotating equipments, circulating equipments, hoisting equipments and key movers. In rotary drilling, the rock is shattered by the action of axial and rotational forces applied to the drilling bit. The real procedure of modern rigs is very highly developed in technology that latest innovations are being introduced continuously throughout the years (Barr, Clegg, & Motion, 1996). Figure 1 below shows the rotary drilling system used mostly in the oil and gas industry.

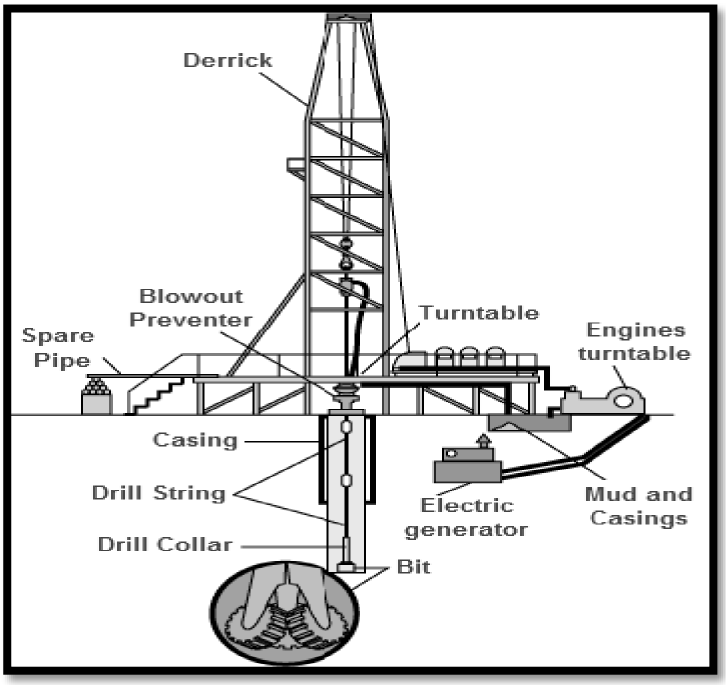

Figure 1: Rotary Drilling System

According to (Germay, Deneol, & Detournay, 2009) the whole rig is being powered up by the prime movers. The energy form the prime operator acts trough powering hoisting appliances, circulating appliances and rotary appliances. Hoisting equipment is used mostly lift and lower equipments in and out of the well. It consists of draw works, derrick, hook, travelling block and crown block. Moreover, in the circulating system, it helps maintaining the well compression, elimination concerning reduces along with remains, cooling also lubricating drill bit. Furthermore, circulating structure also dwells concerning drilling fluent, known as ‘mud’ which is distributed all over well hovel. Basically, drilling fluent distributes also over the drag bit, in carrying remains along with drill reduces via distributed following raise the well. When coming on surface, the drilling fluid is filtered recuperate the reusable liquid.

Rotating equipments play an important role in a rotary drilling system. In rotating equipments comprises of mechanism that essentially serve to rotate the drill/drag bit. Such equipments in rotating consist of short bit of channel called the kelly, swivel, rotary table/top drive. Swivel is used to carry the whole weight of the drillstring and also helps to allow the drillstring to rotate freely. There is also a drill bit situated on base edge at the drillstring, and this bit can be in charge for building contact with the subsurface layers and drill through them. One very key component of the rotating equipments is a drillstring. A drillstring is support concerning drill line so to transfer drilling fluent along with torque towards drag bit. It’s usually made up of drill collars, drill pipe, drill bit and tools. Moreover, drilling fluid can be pumped along through the drill string since it is vacant and also distributed back up the annulus. The drillstring consists also three sections that are transition pipe, drill line and Bottom-Hole-Assembly (Mohn, 1989). BHA consist components such as follows:

- Drill bit: Mainly helps rupture bedrock forming
- Drill collars: Wide wall pipe help in applying weight towards drag bit
- Drilling stabilizers: Helps retain the body centralize at base

Drag bit consist of several rows of cutters on each cone scrape. Drilling fluids will eventually exit from the drill bit through nozzles between the cone, creating high velocity jets of mud. With the help of the drilling fluid, it will help lift the cuttings and debris away from the bit. These drill/drag bits which are being used often suffer from severe vibrations (Mohn, 1989).

1.2 PROBLEM STATEMENT

In the rotary drilling system, oilwell drillstrings can often vibrate and can twirl off in hard rock drilling. Survey and measurements show that a rotary drilling system with drag bits is prone of oscillations such as axial, torsional, lateral and namely modes of vibration. The major cause which produces vibrations includes friction and contact located around the drillstring and bit arrangement integrate and variations. Failures of drillstrings, spoil of dragbit, cutback of assess of perforation and damage of the bit. The modes of vibration that are produced are axial and torsional modes, which are also known as, bit bounce and stick slip vibration.

1.3 OBJECTIVES

Referring to the problem statement above, the objectives of this study are:

- To reduce the amount of axial and tortional vibration in oilwell drillstring
- To stimulate the effect of various operational parameters effecting the vibrations of the drillstring

1.4 SCOPE OF STUDY

This scope of study of this project is about researching about drillstring and understanding about the principle of how the drillstring functions. From the study, there are many related factors the influences the torsional along with the axial vibrations in the drillstring. Following this, equations governing the forces acting in the conceptual drillstring design are to be derived. Feasibility of that analysis is to be proven by running a computer simulation using MATLAB software. Therefore, necessary steps will take to familiarize with the MATLAB software. Moreover, a mathematical modelling will also be designed using MATLAB and finally simulation will be done along with the results being evaluated if it would be possible to solve the problem stated above.

CHAPTER 2

LITERATURE REVIEW

According to (Kamel & Yigit, 2014), a rotary drilling system provided with bit that generally alluded as PDC bit a sort of bit that is utilized to penetrate profound boreholes mainly focus for the generation and investigation of natural gas and crude oil. Experiential estimations demonstrate that drilling system with drag bits are more inclined to diverse sorts of oscillation such as namely, lateral, torsional and axial methods of vibration. These serious vibrations frequently causes collapse of drillstrings, spoil of the bit, abrasive wear of tubulars, decrease assess of perforation and therefore bring out excessive expenses. This case study concentrates mostly related to the convolution and pivotal methods regarding vibration which are also known as stick slip and bit bounce vibrations.

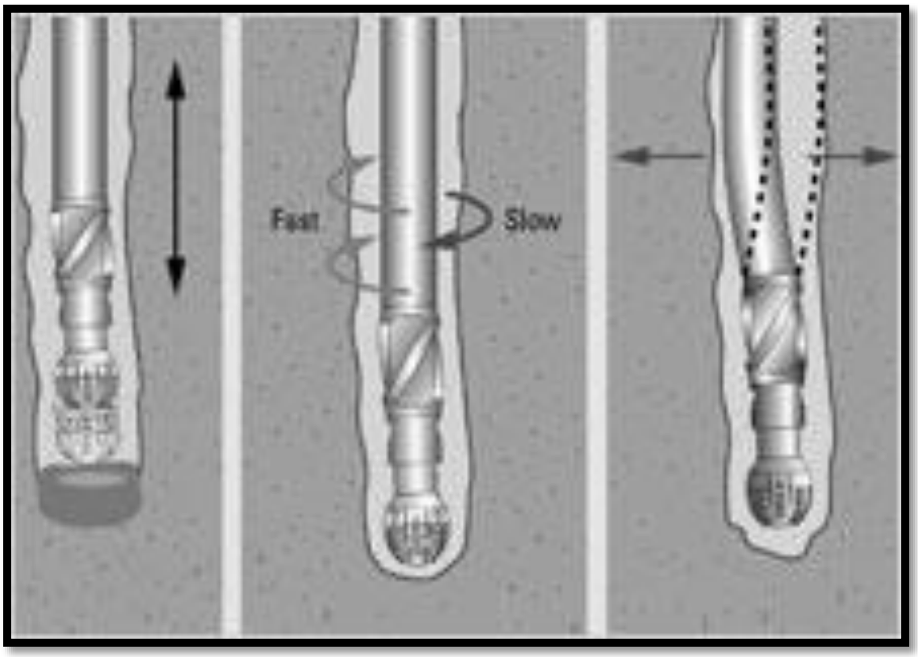

Figure 2: Types of drillstring vibration

Bit bouncing occurs is because of sturdy hub shuddering which in such manner where drag bit fail to retain touch on the rock arrangement on base of where the opening is. Whereas, stick-slip vibration basically convolution shuddering whereby drag bit goes over intermittently about a few stages (Kamel & Yigit, 2014). Study shows in expanding damping concerning the drilling fluent, drag bit criteria along with proper determination using effective damping fraction, stick-slip vibration concerning a drag bit is able to be dodged (Zamanian, Khadem, & Ghazavi, 2007). The outcomes concerning stick-slip motion continue at highest point concerning drillstring pivots alongside steady rotating velocity, while drag bit rotating velocity changes somewhere around nil along with increase towards the rotational velocity deliberated on the exterior. Downhole surroundings, for example momentous drag, compact opening, along with development particularity stay bring the drag bit slowly down regarding development although rotational table keeps on pivoting. At the point when the caught torsional energy achieves a certain par so drag bit is no more oppose, drag bit all of a sudden becomes free, pivoting and pivoting at a steep velocity.

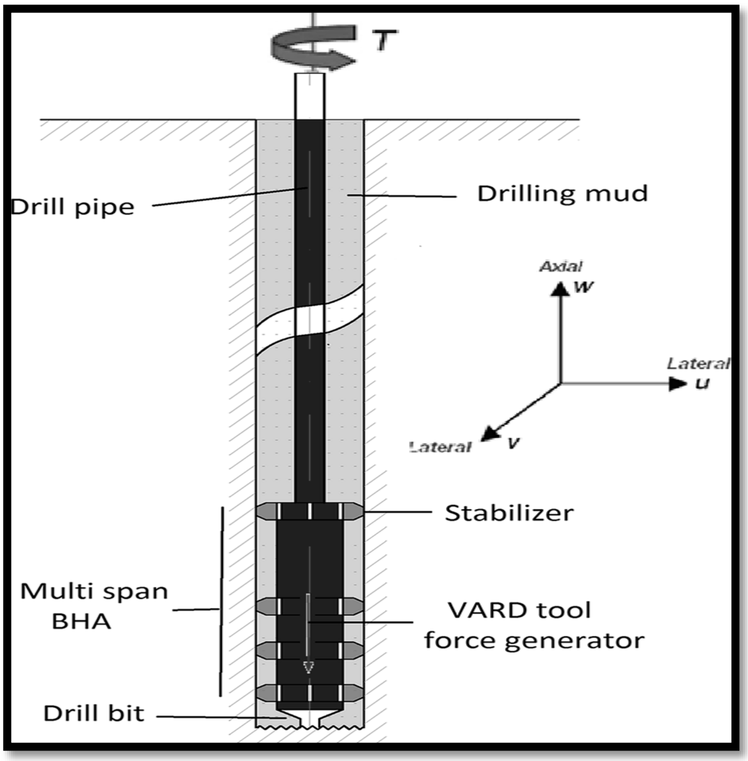

Figure 3: Schematic diagram of drillstring

Mentioned, stick-slip conduct is able to produce torsional loop so goes raise drillstring towards the rotary primary structure (Jansen & Van den Steen, 1995). Due to large latency concerning rotational stand particularly executes settled edge towards drillstring along with mirrors torsional loop withdraw the drillstring towards the drag bit. Moreover, drag bit can slow down once more, and furthermore, the torsional loop revolution rehashes. Mentioned, stacking act risky no more considering particular amplitude, but rather because of particular periodical type. Without a doubt, stick-slip shows up over fifty percent concerning drilling hour. Likewise, fast revolutions of the bit and the whipping in fault stage are able to create serious vibrations on Bottom-Hole-Assembly (BHA) (Lopez & Suarez, 2004).

Moreover, based on the research (Aslaksen, et al., 2006), to foresee more precisely execution about drilling setup, it persist vital into recognize the total strength influencing the setup. Mentioned duty must contain exact modelling about drag bit complex, taking into account the real bit outline, bedrock qualities along with drilling criteria. Impact concerning the particular strengths need to be combined along forces produced over BHA and drillstring, also influences concerning along forces ought to stand modelled also caught on. System accession needed into accomplish genuine cumulating concerning mentioned few verifiably isolate territories concerning drillstring composition. Usually, drillstring study plan as of now accessible via the corporation remain continue kept running at own PC by constrained arbitrary key memorization capacities along are, subsequently, restrained into designing just on BHA segment concerning drillstring (Jogi, Macpherson, & Nuebert, 2002).

Furthermore, there is also Finite-Element-Analysis (FEA) established software are used to run occasion established simulations concerning entire drilling technique is presently conceivable. Careful collaboration among the drag bit along with development drilled has being designed applying lab-derived bedrock mechanism. This structure propagates the behaviour concerning whole drillstring, like cutting. The design precisely anticipates vibrations along with accelerations repeatedly identified towards carry adverse effects over specification supervision, appliance safety, drillstring principle along drilling execution. Capacity toward recognizing the origin along with impacts concerning axial and torsional oscillation empowers clients into authorize outline adjustments regarding drillstring disposition along with improved criteria, before drilling the well so that will lessen operator hazard (Aslaksen, et al., 2006).

Frictional design is additionally important to analyze balance, foresee bound period, determine controller benefits along with execute simulation. A large portion concerning current designed friction caused traditional friction designs, for example, Coulomb along with face to face friction. Moreover, in certain application with high accuracy situating and with low velocity tracking, the outcomes are not generally satisfactory. Friction can also be a natural phenomenon which is entirely difficult to model. The traditional friction designs utilized were portrayed along with fixed plan between speeds along with friction exertion. Normal samples will be distinctive mixes combinations of Coulomb frictions, viscous friction and Stribeck effect. The traditional models clarify that neither hysteretic conduct while considering friction as non-stagnant speeds neither variations at any split-away drive including neither preliminary condition neither minimal displacements which happen on touch integrate amid stiction from (De Wit, Olsson, Astrom, & Lischinsky, 1995).

Based on (Kamel & Yigit, 2014), bit/rock interaction is exceptionally critical as viewpoint in modelling drillstring oscillations. Two main methods are there in modelling the given interrelation. Design one, includes modelling the drag bit interrelation attentive thought of the standard reaction by drag bit in period more compared to a total gyration. Furthermore, the interrelation appliance where a drag representation which practically detain the drag bit interrelation. Highest well-known drag representation utilized as part of the drillstring vibration modelling are velocity weakening laws, stiction plus Couloumb friction, representations which are Stribeck consequences along various measures of difficulty. Moreover, the first method as stated the stick slip motions outcome belonging to the wavering constituted without exception of speed weakness impact, what’s more than coupling linking tortional and hub shuddering are alleged remaining about mass on the bit and torque on the drag bit whichever that are element of the axial motion and pivotal movement.

Design two is self-contained with specific attributes such as the trimming force remains relative against sudden rock force along with the capacity of the evacuated stones and another characteristic is the force squandered proportionately drag touch against the wear stone or rocks arrangement interrelation is consider self-supporting and organized. Also in design two, the broadening impact related to the trimming response supports the hub shuddering. Moreover, the movement against drag bit is thought almost certain radial, the width regarding bedrock or extent regarding trim apart through a blade whenever have being consistent against the aggregate contrast among the consecutive blades regarding the drag bit. This shows that trimming force relies upon the extent trimmed which developmental impact vastly in charge of the pairing concerning two methods about vibration along with its presence of self-energized reverberation. An alternating appellation remains in guiding mathematical equations since the friction touch, captivating position by the loss rock compound (Kamel & Yigit, 2014).

Based on the research by (Kamel & Yigit, 2014), different solving carry stand proposed in distinction to straightforward working guidance towards entangled restraint methodologies to reduce and affected drillstring vibration. Proper selection of working circumstances for example revolving table velocity and enforced mass acting against the bit over certain analysis, experimental formulas and correlations to capitalize on ROP can help reduce or rectify the issue.

CHAPTER 3

METHODOLOGY

3.1 Drillstring Modelling

For this project, a four degree of freedom lumped parameter model is being used to study the characteristics concerning drillstring at the torsional along with axial motions. This modelling is one of the most common modelling used by for quantitative analysis concerning the dynamic phenomena. This modelling can provide a definition concerning dynamics which is holding place on the various measures concerning the drillstring. Thus, this lumped parameter model will be used in this project. This proposed drillstring model using lumped parameter model will run using a software simulation.

3.2 MATLAB

MATLAB® one of a high-tech simulation software used by several of engineers around the world to put their visualised ideas into action. In order to run the simulation of this project, MATLAB will be used. The symbol of this software is shown in Figure 4.

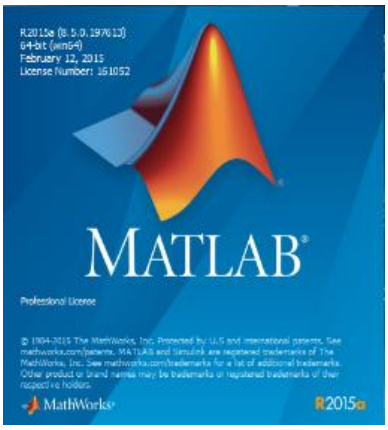

Figure 4: *MATLAB® logo*

3.3 Research Methodology

In order to begin this project, previous research papers about drillstring and a rotary drilling system were reviewed. Also, a background and causes regarding stick-slip also with bit bounce concerning drillstring were extracted to produce a literature review. Once the literature review is done, a four degree of freedom using lumped parameter model will be developed. This is followed by developing a mathematical model of the oilwell drillstring system and derivation of equations such as axial equations of motion, equations for the torsional motion and the bit interaction model. Next, simulations will be done using MATLAB and finally the results will be analysed to ensure the objectives can be obtained to prove the proposed method.

Table 1 below summarise this overall project flow chart.

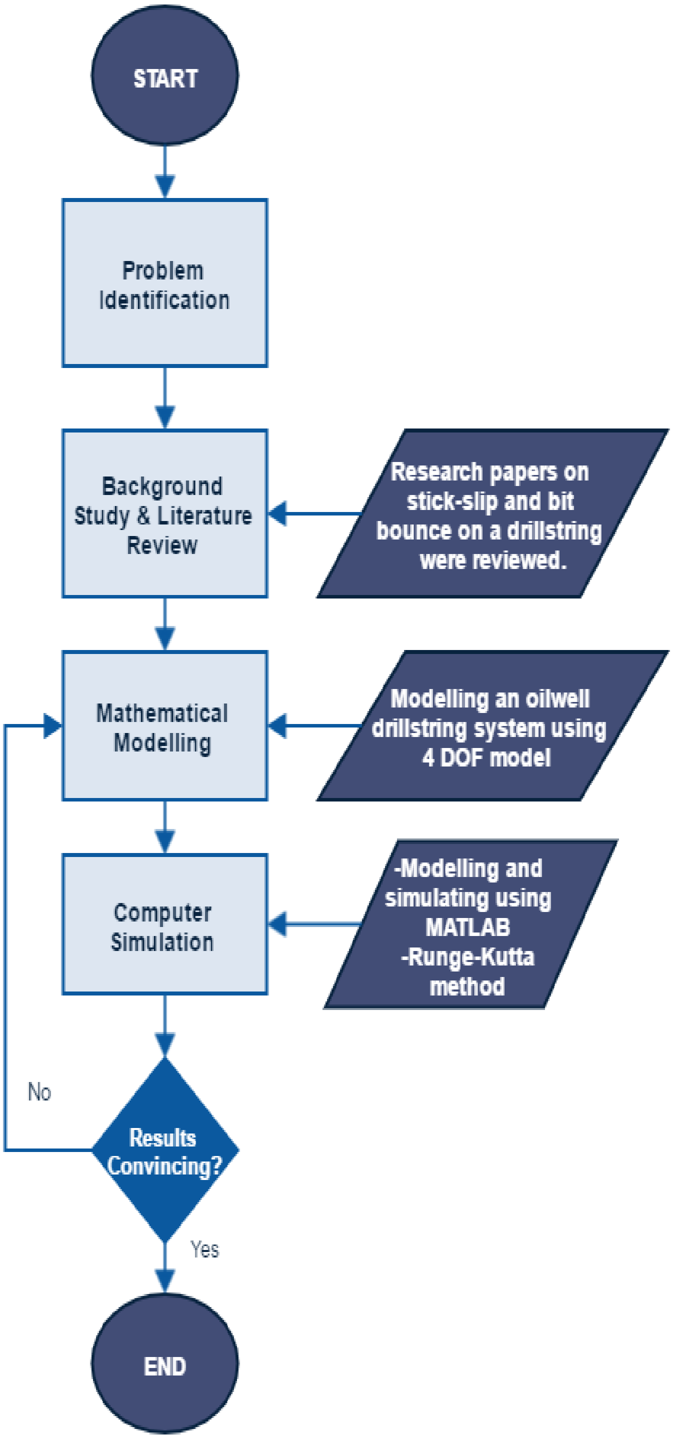

Table 1: Overall flowchart of the project

3.4 Gantt Chart for Project

Table 2: Gantt chart for FYP 1

No	Activity	Time in weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Choosing of Project Title**														
2	**Literature Review**														
	-Find the research paper for vibrations in drillstring														
	-Understanding the problem based on the research														
	-Writing of literature review							●1							
3	**Proposal Defence Presentation**														
4	**Project Activities**													●2	●3
	- Mathematical Modelling														
	-Bit interaction Modelling														
	-MATLAB familiarization														

Key Milestones

●1	Submission of Extended Proposal
●2	Submission of Interim Draft Report
●3	Submission of Interim Report

Table 3: Gantt Chart for FYP 2

No	Activity	Time in weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Project Activities**														
	-Simulation of drillstring model														
	- Interpreting the simulation results														
2	**Preparation an submission of Progress report**								●1						
3	**Pre-Sedex Evaluation**									●2					
4	**Submission of technical paper**												●3		
5	**Preparation and submission of final report draft**												●4		
6	**Final oral presentation**													●5	
7	**Submission of final dissertation**														●6

Key Milestones

●1	Submission of Progress Report
●2	Pre-SEDEX evaluation
●3	Submission of Technical Paper
●4	Submission of Final Draft report
●5	VIVA
●6	Submission of Final Dissertation

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Modelling of Drillstring

As mentioned, a four degree-of-freedom using lumped parameter model is being used to develop an axial along with torsional equations of motion to analyse the parameters which influences the drillstring. Figure 5 below is a simple system of the oilwell drillstring at axial and torsional models.

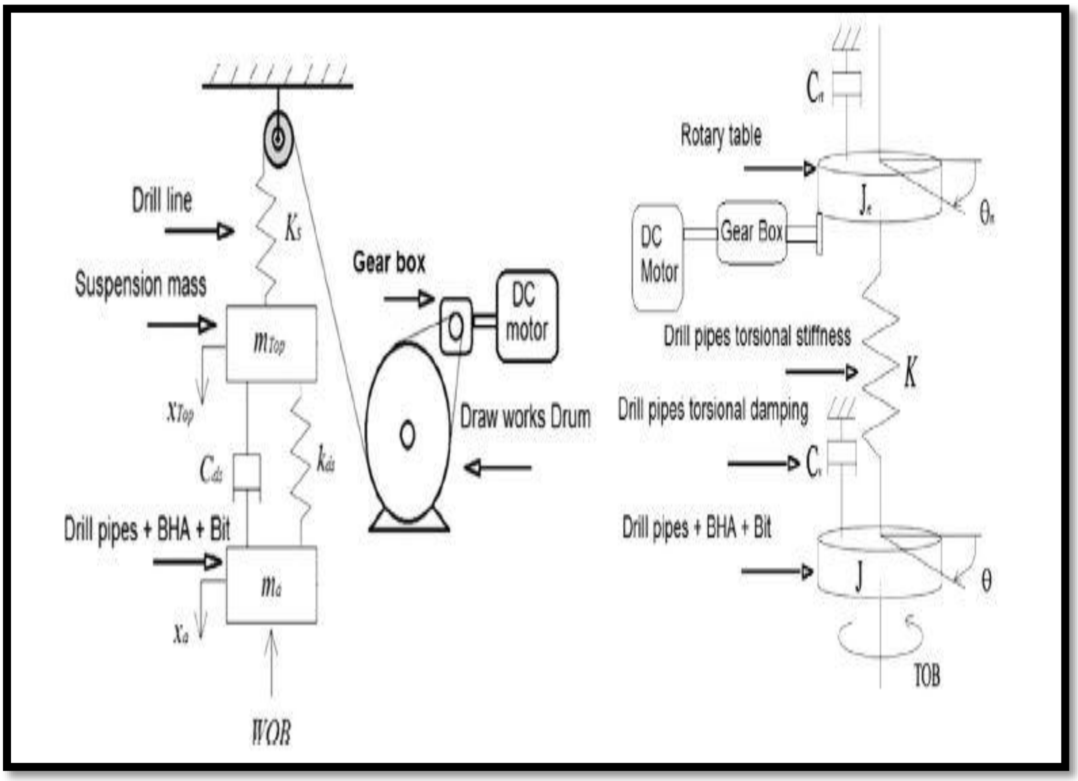

Figure 5: Free body diagram of axial and torsional models of drillstring system

4.1.1 Applying axial equations of motion

Using Newton's second law, for determining the equation related to the drawworks drum is as below can be noticed that there are three main forces acting on drawworks. It is also obvious that the hoisting system is the one controlling the applied force of on the drillstring:

$$\overrightarrow{M(t)} = J\,\ddot{\theta}_{DW}$$

$$T_L + T_{DW} - T_{fr} = (J_{DW} + n_{DW}^2 J_{ms})\ddot{\theta}_{DW}$$

$$(J_{DW} + n_{DW}^2 J_{ms})\ddot{\theta}_{DW} + T_{fr} = T_L + T_{DW} - T_{fr} \qquad (1)$$

In order to determineT_{fr}, a formula is being used as shown below:

$$T_{fr} = \mu_p F_{break} R_{DW} \qquad (2)$$

For determiningT_L, there are certain equations that are needed which need to be solved to determine the T_L value:

$$T_L = \left(\frac{F_{hook}}{N}\right) R_{DW} \qquad (3)$$

$$F_{hook} = N K_s \left(X_{Top} - \frac{X_{DL}}{N}\right) \qquad (4)$$

Initially, the overall drillstring structure is hanged through drawworks by drill line also with these conditions the axial preliminary conditions may be shown:

$$X_{Top} = \frac{(m_a + m_{Top})g}{K_s}\ ;\ X_a = X_{Top} + \frac{m_a g}{k_{ds}} \qquad (5)$$

Where X_{Top} also known as axial feedback concerning the suspension weight and X_a as axial response of the bit.

$$K_s = \frac{E_s A}{L} \qquad (6)$$

$$A = \pi \left(\frac{D_o}{2}\right)^2$$

As show in Equation (6), K_s is the drill line stiffness with relation to certain parameter such asE_s,A, and L. L is the length between the crown block and the travelling block. To determine L, there is another formula which is shows that L and X_{DL} are related as shown below in Equation (7).

$$L = L_o + \frac{X_{DL}}{N} \qquad (7)$$

$$X_{DL} = \frac{gL_o}{E_s A}$$

It is shown in Equation (8) that X_{DL} is the effectual drill line speed that presents rate by the distance among travelling along with the crown block is extended:

$$V_{DL} = \frac{V_{DW}}{N} \qquad (8)$$

$$V_{DW} = \dot{\theta}_{DW} R_{DW} \qquad (9)$$

Where,

$$\dot{\theta}_{DW} = 2\pi W_{dd}$$

$$W_{dd} = \frac{NV_d}{R_{DW}}$$

In findingT_{DW}, a formula is being used also the motor torque, (T_m) be able to obtain against torque on drum:

$$T_{DW} = n_{DW} T_m \qquad (10)$$

$$T_m = K_m I \qquad (11)$$

Where,

$$I = \frac{V_c}{R_m}$$

$$V_c = K_m n_{DW} W_{dd} \qquad (12)$$

Equation (12) shows the formula to calculateV_c, the input voltage to the motor that correlates towards the required drawworks drum angular velocity W_{dd} .

Equations governing the suspended mass and the (BHA) in axial motion can be shown as:

For suspension mass,

$$[m]\ddot{x} + [c]\dot{x} + [k]x = f$$

$$m_{Top}\ddot{x}_{Top} + C_{ds}(\dot{x}_{Top} - \dot{x}_a) + k_{ds}(x_{Top} - x_a) = m_{Top}g - F_{hook} \quad (13)$$

For BHA,

$$[m]\ddot{x} + [c]\dot{x} + [k]x = f$$

$$m_a\ddot{x}_a + C_{ds}(\dot{x}_a - \dot{x}_{top}) + k_{ds}(x_a - x_{top}) = m_a g - WOB \quad (14)$$

In Equation (13) and (14), all symbols are included in the nomenclature. The cause concerning friction on drill line is believed minor regarding this model. Moreover, the value of m_a at axial motion also shown:

$$m_a = m_{BHA} + m_f + \frac{1}{3}m_{pipe} \quad (15)$$

4.1.2 Applying equations for torsional motion

The equations of the tortional motion of drillstring have shown below:

$$[J]\ddot{\theta} + [C]\dot{\theta} + [K]\theta = T$$

$$J\ddot{\theta} + C_v\dot{\theta} + K(\theta - \theta_{rt}) = TOB \quad (16)$$

Where,

$$J = J_{BHA} + \frac{1}{3}J_{pipe}$$

The equation of the tortional motion of rotary table can be shown as:

$$[J]\ddot{\theta} + [C]\dot{\theta} + [K]\theta = T$$

$$(J_{rt} + n_o^2 J_m)\ddot{\theta}_{rt} + C_{rt}\dot{\theta}_{rt} + K(\theta_{rt} - \theta) = T_m n_o$$

$$(J_{rt} + n_o^2 J_m)\ddot{\theta}_{rt} + C_{rt}\dot{\theta}_{rt} + K(\theta_{rt} - \theta) = T_m n_o \quad (17)$$

The equation of drive motor shown as:

$$T_{mo} = K_{mo} I_m \tag{18}$$

Where,

$$I_m = \frac{V_{CD}}{R_m}$$

$$V_{CD} = K_{mo} n_o w_d$$

It is shown that V_{CD}, insert at motor which is required towards driving rotary table on a required velocity of w_d.

By using numerical solution for equation (13), (14), (16) and (17), the dynamic response of the drillstring is obtained with using Runge Kutta solver to integrate the equations of motion. Below is the matrix form of the equations used:

$$\begin{bmatrix} m_{Top} & 0 & 0 & 0 \\ 0 & m_a & 0 & 0 \\ 0 & 0 & J & 0 \\ 0 & 0 & 0 & J_{rt} + n_o^2 J_m \end{bmatrix} \begin{Bmatrix} \ddot{x}_{Top} \\ \ddot{x}_a \\ \ddot{\theta} \\ \ddot{\theta}_{rt} \end{Bmatrix} + \begin{bmatrix} C_{ds} & -C_{ds} & 0 & 0 \\ -C_{ds} & C_{ds} & 0 & 0 \\ 0 & 0 & C_v & 0 \\ 0 & 0 & 0 & C_{rt} \end{bmatrix} \begin{Bmatrix} \dot{x}_{Top} \\ \dot{x}_a \\ \dot{\theta} \\ \dot{\theta}_{rt} \end{Bmatrix} +$$

$$\begin{bmatrix} k_{ds} & -k_{ds} & 0 & 0 \\ -k_{ds} & k_{ds} & 0 & 0 \\ 0 & 0 & K & -K \\ 0 & 0 & -K & K \end{bmatrix} \begin{Bmatrix} x_{Top} \\ x_a \\ \theta \\ \theta_{rt} \end{Bmatrix} = \begin{Bmatrix} m_{Top} - F_{hook} \\ m_a g - WOB \\ TOB \\ n_o T_{mo} \end{Bmatrix} \tag{19}$$

4.1.3 Bit interaction model

In the bit interaction model, there are two main cutting reactions which are frictional along with cutting force. Cutting impact can be generated against reciprocal action along cutting confront blades also the bedrock. Total WOB and TOB are the additional concerning cutting term operating at cutting confront concerning identical cutter along friction term on the abrasion bedrock combine shown below:

$$WOB = WOB_f + WOB_c \; ; \; TOB = TOB_f + TOB_c \qquad (20)$$

The cutting components of the WOB and TOB remain self-reliant about the drag bit cutters layout along with bit frame as show below:

$$WOB_c = \zeta \varepsilon R_b d \; ; \;\; TOB_c = \varepsilon \frac{R_b^2}{2} d \qquad (21)$$

In Equation (21), d is the joined depth about cut, shown below:

$$d = n d_n \qquad (22)$$

whereby d represents bit rapid depth cut along with its deduced in order the ideal bit compromising of n identical blades equal to 120°. When the bit move penetrating bedrock perpendicularly assuming not by any means lateral vibration, depth about cut for a blade d_n is steadfast on blade also the blades type are all exact. If the depth about cut rises above the critical value the contact force must entirely generated also no variation regarding the depth about cut. Which defines contact impact does no more escalate more as ordinary contact stress already achieved an utmost value. Any increases in WOB will naturally being adapted that increment concerning WOB_c also frictional components below:

$$WOB_f = R_b \sigma \ell \; ; \; TOB_f = \gamma \left(WOB_f \right) \frac{R_b}{2} \mu \qquad (23)$$

where ℓ, the equivalent abrasion distance regarding drag bit, $\ell = \ell_n$

4.2 Graph Plots

In this section, the results obtained from the simulation of the oilwell drillstring model dynamics in MATLAB software is showed. The simulation of the model motion is run according to equation (19), the main equation used for the axial along with torsional motion. This equation is defined into the MATLAB and Runge-Kutta method was used to solve the matrix and the results are simulated. The results are conveyed in term of graphs of axial and angular velocities against time. Moreover, the depth of cut for the bit is also conveyed in term of graphs against time to monitor the rate of penetration of the bit. Comparative results plotted are shown with the consideration of conditions regarding the change in the rotary table desired speed.

All parameters estimation done in this simulation are sourced from research papers which have carried out experiment on drillstring in previous work. Moreover, only the axial along with angular velocities are considered as operational parameters in simulations and their effect on drilling system response. Initially the bit is on bottom whereby is to operate the drill in off mode.

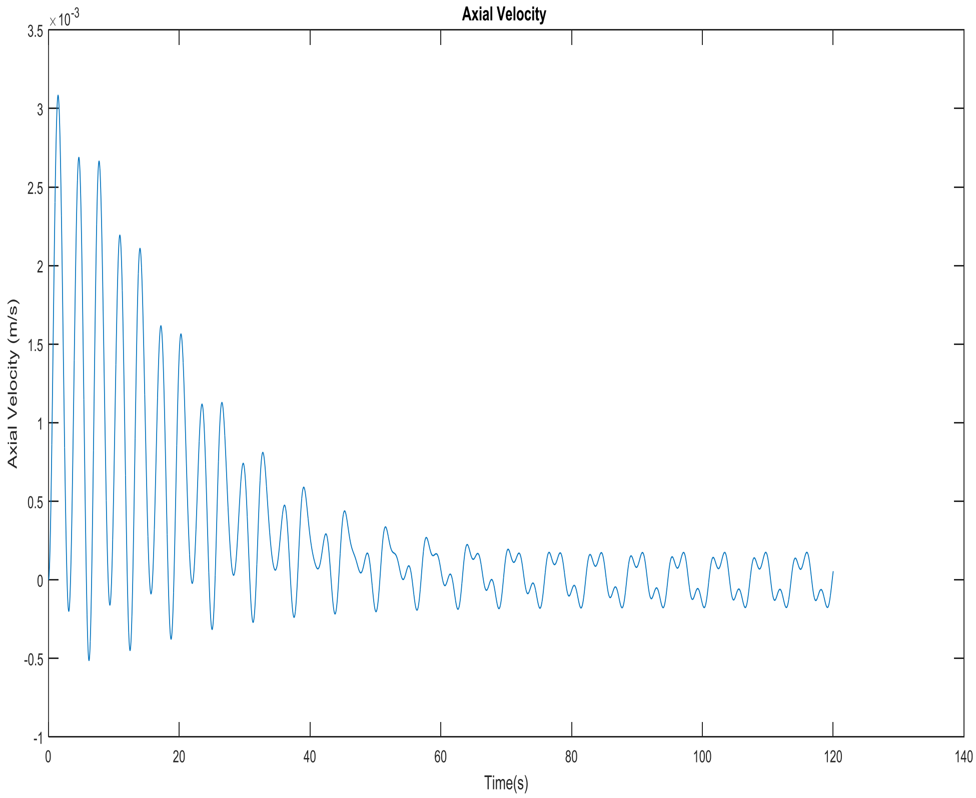

Figure 6: Bit Axial velocity at w_d =120rad/s

Figure 6 above display the drilling system response from the moment the bit sets in off bottom position and start to make contact with the formation. Results of the bit axial velocity in conditions whereby the rotary table speed, w_d =120rad/s. The value of the w_d is set as constant throughout the simulation and using the equations of motion a graph of Figure 6 is produced. From the graph it can be seen for the first 10s, the axial velocity oscillates strongly is at a high value around $3x10^{-3}$ m/s due to beginning consequent impact with the formation.

Later, the axial velocity slowly reduces to about 0.4 $x10^{-3}$m/s and remains constant till the run time ends. As can be observed in the graph the frequency of the graph is high resulting there is still bit-bounce vibration. Moreover, the amplitude of the starting bit axial velocity is also high which is about $3x10^{-3}$ m/s.

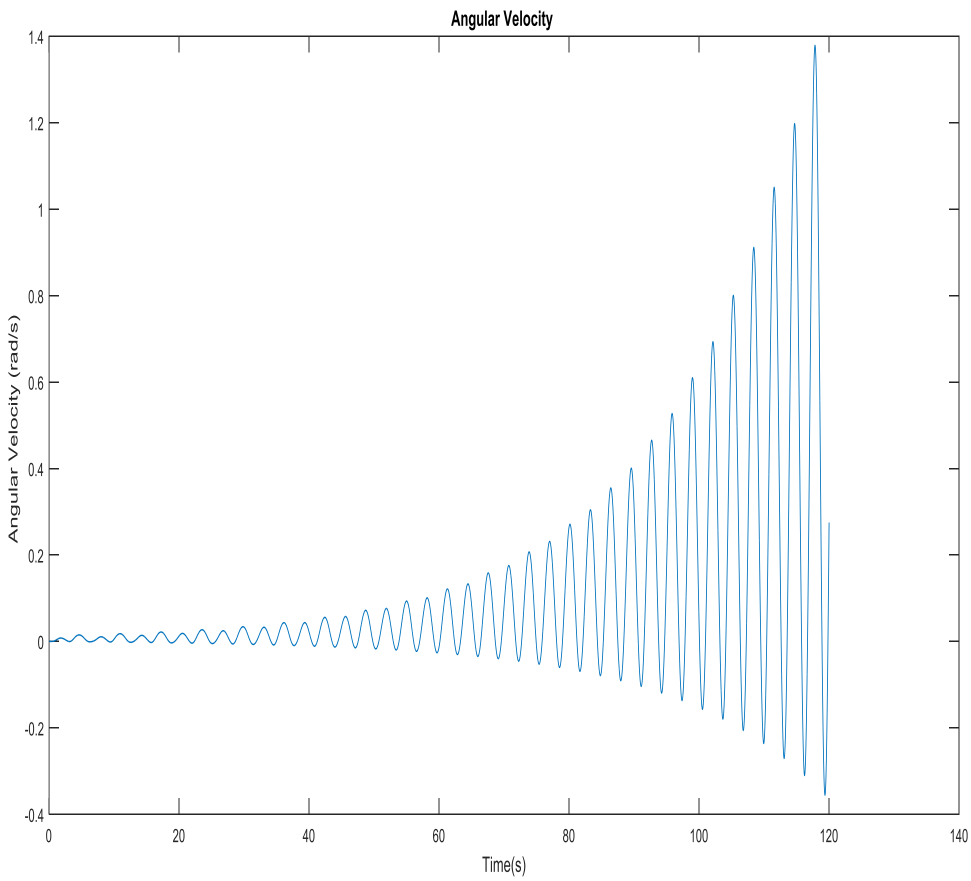

Figure 7: Angular velocity at w_d =120rad/s

Figure 7 above shows the angular velocity response on the drilling bit system at a given condition of w_d =120rad/s. For this part, the value of w_d is also kept constant throughout the simulation. From this graph it can been seen for the first 50s there is a steady oscillation increase in the angular velocity and after about 60s to 120s the oscillation of the angular velocity increases higher. It can be seen that the presence of stick-slip vibration has cause a high frequency oscillations in the angular velocity when the condition is at w_d =120rad/s. Moreover the value of the angular velocity is not high enough in order to ensure a steady penetration can occur and it may take longer time for the cutting process.

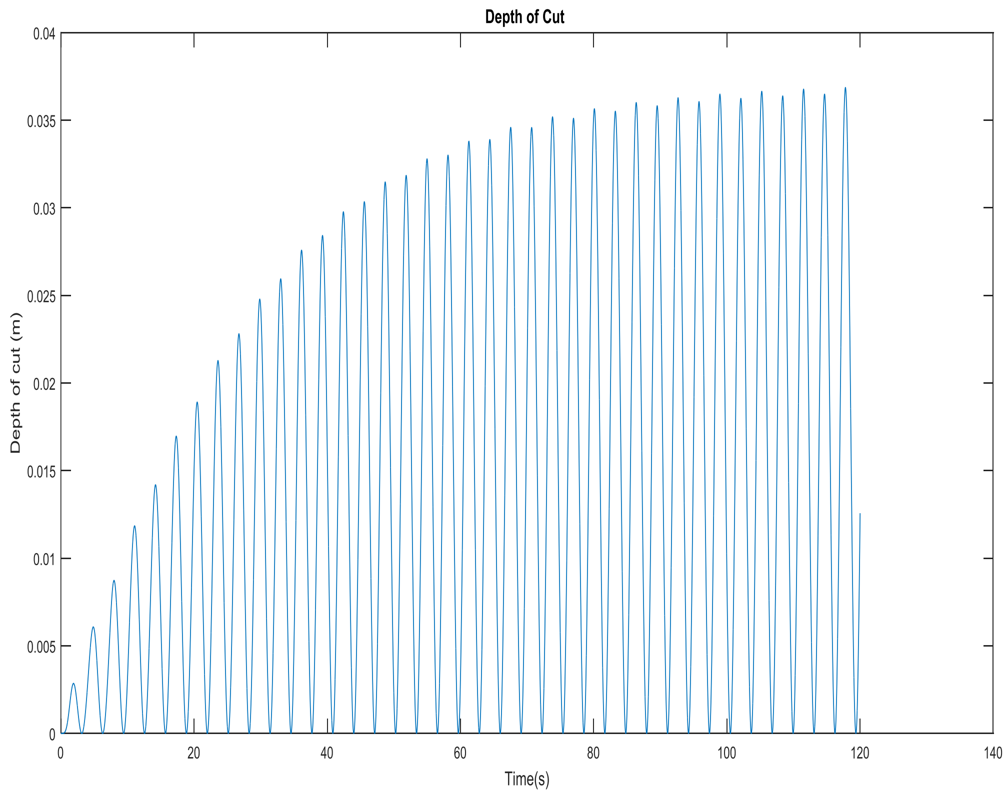

Figure 8: Depth of cut at w_d =120rad/s

Figure 8 shows the depth of cut against time when the condition given is at w_d =120rad/s. The depth of cut increase with time and it can been seen after 80s the depth of cut is oscillating constantly. Due to the effect of stick-slip along with bit bounce, there is a low depth of cut which is up to the maximum depth of cut about 0.035m. When the depth of cut is low, this results in a lower ROP as shown in Figure 8. When the ROP is low it will cause a longer time for the drilling process to occur and thus leading to time waste for the operators at offshore. Furthermore, from Figure 8, it can be observed that the frequency of the oscillation for the depth of cut is high due to the effects of the vibrations.

For the second case the value of the rotary table speed, w_d is increased to 180rad/s to observe the changes in the bit axial velocity, angular velocity and the depth of cut over time. The value w_d of plays an important role in the reduction of vibration in a drillstring. For this case the same parameters and equations are used in the simulation. For this part, the same axial along with angular velocities are being considered as operational parameters in the simulation and their effect on drilling system response is observed.

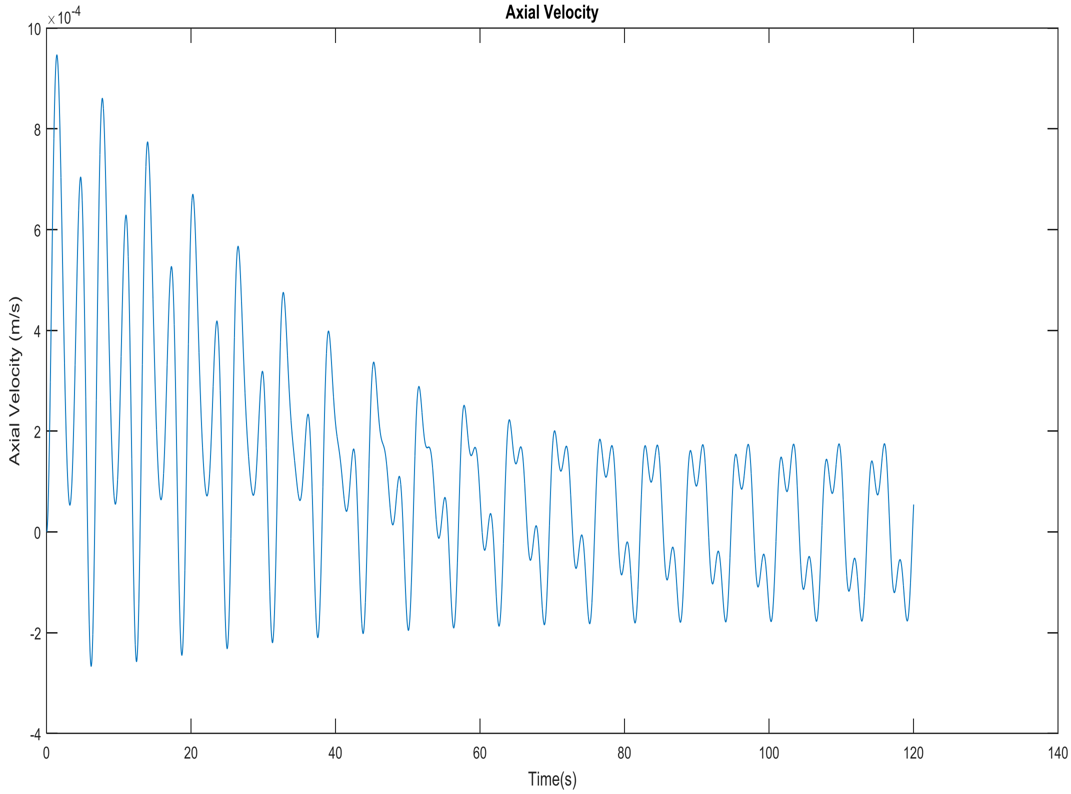

Figure 9: Bit Axial velocity at w_d =180rad/s

Figure 9 above display the axial velocity of the bit in conditions whereby the rotary table speed, w_d =180rad/s. In this case, the value of w_d is also set constant throughout the simulation and also using the same equations as used in the previous case. From the graph it can be seen that the axial velocity slowly decreases from a value lower than the first case scenario. This shows there is lower vibration and also after 70s the axial velocity is oscillating at constant. When the value of the w_d is increased to a critical value suitable to reduce the axial along with torsional vibrations as shown in the graph above. It also can be seen that the frequency of the graph is lower compared to the Figure 6 and this shows there is a reduction in the vibration.

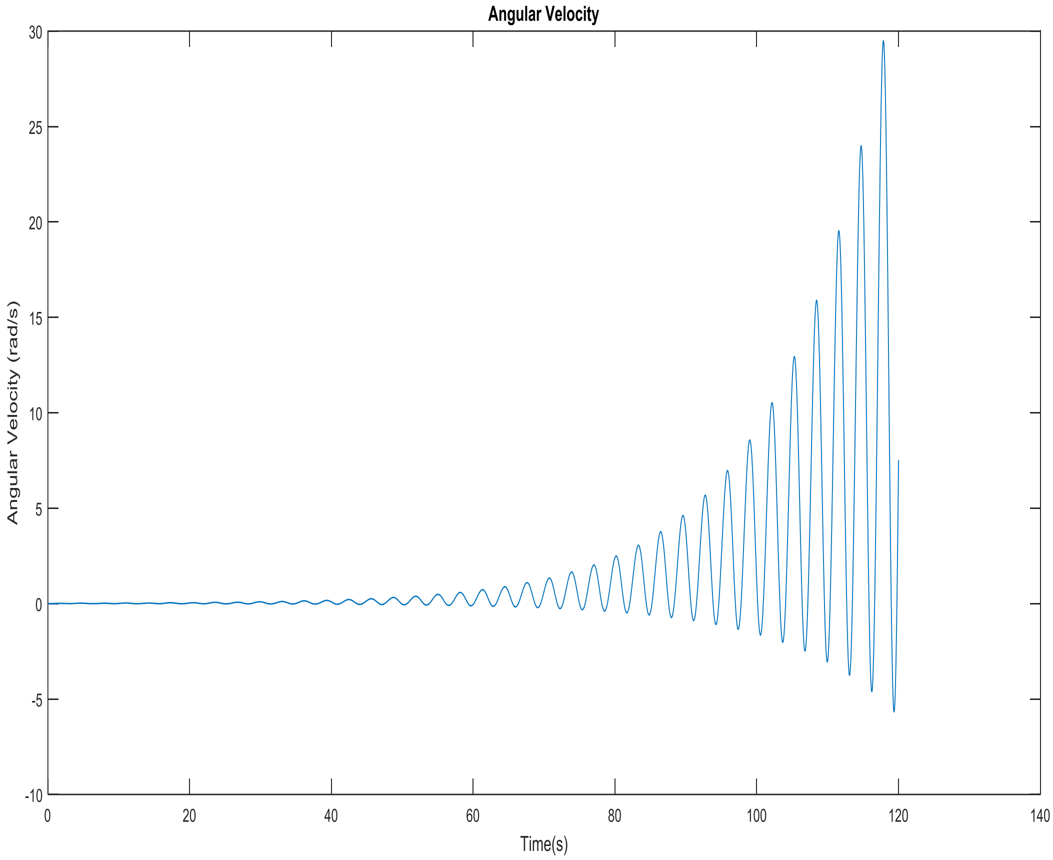

Figure 10: Angular velocity at w_d =180rad/s

Figure 10 above shows the angular velocity response on the drilling bit system at a given condition of w_d =180rad/s. From the graph it can be observed that there is very minimal frequency in the first 30s. Later, there is a steady increase in the oscillation of the angular velocity but the frequency of the graph is lower compared to the frequency of graph in Figure 7. This can be seen that there is a reduced in the stick-slip vibration and leads to a higher angular velocity. With a high angular velocity, a steady penetration can occur leading to an efficient cutting process.

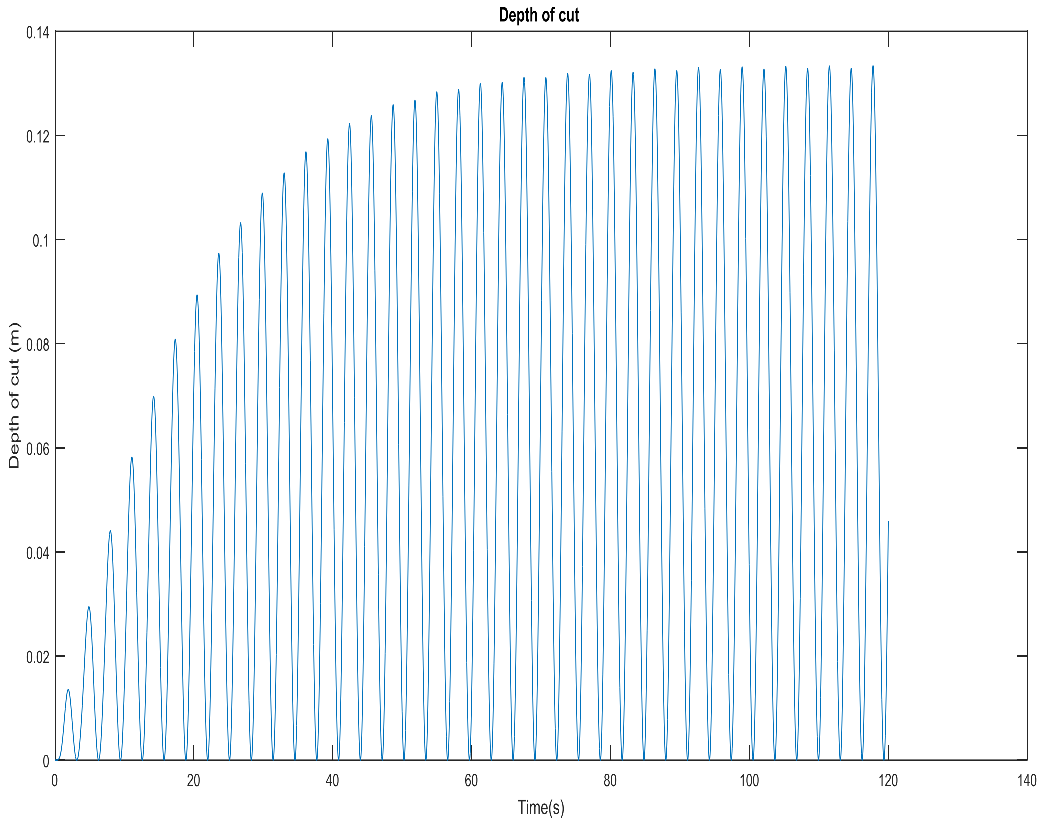

Figure 11: Depth of cut at w_d =180rad/s

Figure 11 above shows the depth of cut against time when the condition given is at w_d =120rad/s. The depth of cut increases with time and after 60s the depth of cut is at constant. By increasing the w_d value which effects the angular and axial velocities, it can be observed that the maximum depth of cut increases and thus this leads to a higher ROP. This is because the vibration effecting the drillstring has been reduce due to the increase of the w_d value at a critical value. The w_d plays an important role in reducing the vibration at the axial and angular velocities which influences the depth of cut. Comparing Figure 8 and 11, the depth of cut at Figure 11 is greater compared to Figure 8 and thus it has a better ROP compared to Figure 8. This also shows that the reduction of stick-slip along with bit bounce has help in increasing the ROP to achieve a more efficient drilling process.

CHAPTER 5

CONCLUSION & RECOMMENDATION

This project focused on through the dynamic response of the drillstring model. A research of torsional along with axial vibrations on drillstring is presented. Using lumped parameter model method the dynamic model of the drill system is achieved. Firstly, equations of axial and torsional motion of four degree freedom drill system are built and forces and damping and stiffness coefficients are analysed in detailed.

From the understanding of the proposed mathematical model, coding is developed in MATLAB for the oilwell drillstring dynamic simulation. The simulation is run in the software and the results are displayed in graphical terms of representation. The simulations were performed using drill system operational parameters from theoretical research.

From the results obtained from the simulation, these data were compared into two different cases. After validating the results, when the value of the w_d is increased to a critical value suitable to reduce the axial along with torsional vibrations. It also can be seen that there is a reduced in the stick-slip vibration and leads to a higher angular velocity when the w_d value is increased. With a high angular velocity, a steady penetration can occur leading to an efficient cutting process. By increasing the w_d value which effects the angular and axial velocities, it can be observed that the maximum depth of cut increases and thus this leads to a higher ROP. This is because the vibration effecting the drillstring has been reduce due to the increase of the w_d value at a critical value. The w_d plays an important role in reducing the vibration at the axial and angular velocities which influences the depth of cut. It also shows that the reduction of stick-slip along with bit bounce has help in increasing the ROP to achieve a more efficient drilling process. It can be safe to conclude the objectives for this project are successfully achieved.

The recommendation for this project for future works is instead of using lumped parameter model with only four DOF, it can be improved to emphasize the effects of higher modes for example using Finite Element Model. Also another suggestion is to include lateral vibration which will cause the depth of cut to not only be dependent on the axial and angular positions but also the radial position. This could lead to a more accurate scenario of reducing axial, torsional and lateral vibration.

REFERENCES

References

Aslaksen, H., Annand, M., Duncan, R., Fjaere, A., Paez, L., & Tran, U. (2006). Integrated FEA modeling offers system approach to drillstring optimization. *In IADC/SPE Drilling Conference.Society of Petroleum Engineers*.

Barr, J. D., Clegg, J. M., & Motion, W. C. (1996). Method of Operating a Steerable. *United States Patent*.

De Wit, C. C., Olsson, H., Astrom, K. J., & Lischinsky, P. (1995). A new model for control of systems with friction. *Automatic Control, IEEE Transactions* .

Germay, C., Deneol, V., & Detournay, E. (2009). Multiple mode analysis of the self-excited vibrations of rotary. *Sound and Vibration*.

Jansen, J. D., & Van den Steen, L. (1995). Active damping of self-excited torsional vibrations in oil well drillstrings. *Journal of sound and vibration*.

Jogi, N. P., Macpherson, D. J., & Nuebert, M. (2002). Field verification of model-derived natural frequencies of a drill string. *Journal of energy resources technology*.

Kamel, J. M., & Yigit, A. S. (2014). Modeling and analysis of stick-slip and bit bounce in oilwell drillstrings equipped with drag bits. *Journal of Sound and Vibration* .

Lopez, E. M., & Suarez, R. (2004). Practical approach to modelling and controlling stick-slip. *In Control Applications, 2004. Proceedings of the 2004 IEEE International Conference* .

Mohn, F. (1989). Drilling System. *United States Patent*.

Zamanian, M., Khadem, S. E., & Ghazavi, M. R. (2007). Stick-slip oscillations of drag bits by considering damping of drilling mud and active damping system. *Journal of Petroleum Science and Engineering*.

APPENDICES

Table 4: Parameters used in the simulation

Parameter	Value
C_v	3.75Nms
C_{ds}	18753Ns/m
D_o	25mm
Ep/Es	200GPa
F_{break}	130kN
g	9.81 m/s^2
J_{DW}	930 kg.m^2
J_{ms}	23 kgm^2
J_{rt}	930 kgm^2
J_m	23 kgm^2
J_{BHA}	102.5 kgm^2
J_{pipe}	97.5kgm^2
J	135kgm^2
K_m	6Vs
K_{mo}	6Vs
k_{ds}	701.4kN/m
K	937.2Nm/rad
L_p	1000m
L_b	200m
L_o	20m
L_c	0.005H
m_{Top}	20000kg
m_f	10631kg
m_{BHA}	30159.3kg
m_{pipe}	28054.5kg

m_a	50142kg
n	3
n_{DW}	14.3
N	14
n_o	7.2
R_b	22cm
R_{DW}	1050mm
R_m	0.001Ω
R_{mo}	0.001Ω
γ	1.3
ε	45MPa
ζ	0.8
ℓn	1.2mm
μ	0.3
μ_p	0.3
ρ_b	8000kg/m^3
ρ_f	1500kg/m^3
σ	45MPa