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Drill String Dynamic Improving the Drilling Performance by Optimizing the Speed Limit and Study the Resonance of the Experimental Drill String System

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Abstract: Drill string failures have increased tremendously over the past 10 years and have become a serious problem resulting in significant financial losses. Existence of vibrations in drill string is known as a complex and unpredictable. Hence, solving and minimizing the vibration are substantial and cost effective to the oil and gas organisation. Previous research conducted has led to breakthrough in exploration of oil and gas either sea or land. Narrowing to most common problem in rotary drilling system, vibration in aspect of axial, lateral and torsional is widely studied. In this study, an experimental drill string set up is examined in different speed with brake and without brake. Labview NI environments is used for execution and data acquisition. Data acquisition recorded by using sensors; encoder and accelerometer. Motor driving voltage responds linearly to the rotational speed and single sided magnitude spectrum measured for different speed with and without brake.

Key words: Drill string dynamic, two contact point, lateral, axial and torsional vibration component, examined, without

INTRODUCTION

The operation of oil well drilling is essential for huge oil and gas production and exploration industry that takes place in a wide range of geographical and climate environment operating in both on-shore and off-shore. A phenomenon that may cause deprived operational performance and even develop into catastrophic failure of the well is the presence of vibrations in the drill string.

In order to understand and analysed the vibrations of axial, lateral and torsional which mostly lead to drill string failure, an experiment was conducted to verify correlation results. The important feature that resemblance rotary oil rig is assembled in the laboratory by a simple experimental set-up. The prototype used in this research is prominent due to the method for a sudden and linear brake mechanism in which two contact point of vertical force is applied at the top and bottom of the lower disk representing Bottom Hole Assembly (BHA).

Literature review: A drill string experience several number of mechanical actions, the most significant are the tension force, longitudinal uniform drill string, torque centrifugal and compound centrifugal forces induced by the drilling fluid flow inside drill string, friction forces interaction between drill string and ground, etc. (Gulyaev *et al*., 2009).

These elements initiate axial, torsional and lateral vibrations in the string and result to its flexural buckling. Eventually would lead to stuck drill string, wellbore collapse in and effect on overall instability of the system (Gulyaev and Gorbunovich, 2008). These vibration as mentioned earlier are the main cause of premature failure of drill string components and drilling efficiency. Vibration is the result of bit or formation and drill string or borehole nonlinear interaction. These non linear interactions act as excitation source and drill string vibrates in 3 basic modes or directions: axial, lateral and torsional (Patil *et al*., 2010). The nonlinear dynamics of this system are not well understood given that the occurrence of axial, torsional and lateral vibrations. Not to mention with the operational difficulties including sticking, buckling and string fatigue. There are many aspects that contribute in vibration of drill strings and these include bore-hole angle, drilling fluid types, heave, bit type, bit-lithology interaction, lithology, borehole size, BHA stabilization and back reaming with excessively high rotational speed (Majeed, 2013). As per information obtained in the oil rig field, it is well-known that a common type of failure which is drill-string washout (cracks in drill string) occurs twice per week and drill stem separation occur one in seven oil rig wells and more than 40% of the drill stem separations are related to drill string failures. It is reported that most of the failures are occur in the BHA region (Spanos *et al*., 2003). It has been reported

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that cost of drilling a well for oil or gas extraction can be measured up to ten of millions dollar (Macdonald and Bjune, 2007). Hence, the incident of down-hole failure of drill string may further increase the cost. This cost is subjected to time delay for recovering drill string from the well and recommence drilling and the material cost of the damaged of drill string components can be costly. The drill string failure, stem separation which is induced due to high torsional vibration, washout failure which is occur due to severe lateral shock or corrosion, torsional failure causing a stretched or parted pin if the connection is weak, tensile failure from the fracture surface will be jagged and oriented at 45° to the axis of the pipe.

Rotary drilling is commonly affected by three major modes of vibrations; Lateral, axial and torsional. These vibrations may xist independently or coupled during drilling and result of various non-linear failure mode such as drill, bit bounce, bit whirl, stick slip, etc. Furthermore as for in homogenous borehole lead to a bent drill strings and most frequently drill bit damages. The existences of major vibrations are induced from borehole friction and critical speeds of operation and lead to drilling failure. Narrowing to most common problem in rotary drilling system vibration in aspect of axial, torsional and lateral is widely being studied. Consequently, this research is aim to narrow down this research gap and conduct two ways approach by investigating the vibration effect (Axial, torsional and lateral) through various mode of speed. In addition, analysed and minimize the vibration in rotary drilling rigs by applying modern technology control techniques. In order to achieve that it is essential to investigate the mode of vibration (Lateral, torsional and axial) with respect to speed variability. Furthermore, data collection of real-time rotational speed and vibration mode is required from experimental approach. The test rig can be further utilized to study and characterize the occurrence of contact/impact between BHA and borehole which involves a complicated non-linear dynamic behaviour (Khulief and Al-Sulaiman, 2009). The rig allows for different configurations which enables the experimental study of various phenomena such as stick-slip oscillations, whirling and drill-bit bounce (Wiercigroch *et al*., 2015). Modelling the entire drillstring system and validating the results using the laboratory experiments or the field data have been the best practice (Patil and Teodoriu, 2013). Operational recommendations are made based on experimental observations (Dykstra *et al*., 1994).

MATERIALS AND METHODS

Methodologies/expermintal setup: As the drill string instrument has been modelled and designed, it is then investigate through practical experiment. Under experiment, the design is further bring to a real through fabrication as shown in Fig. 1. The instrument is equipped with power source, motor, microcontroller and sensors for operation and data acquisition. In order to run the instrument as desired it is necessary to calibrate and troubleshoot the instrument mostly in data feedback (sensor).

Fig. 1: Laboratory experimental setup (right) drill string experiment; Catia V5 (left)

Drill-string setup: The experiments were carried out by manipulating the rotational speed of drill string from minimum speed of motor able to operate about 47-340 RPM according to Table 1. The overall duration for drill string to rotate is about 45 sec with sudden hard brake applied at about 35 sec and gap of 3 sec for brake to release back to its default position. The data acquired from accelerometer and encoder are captured and monitored through waveform graph in Labview NI. As the experiment for particular speed is done, the data are captured into excel and used for data analysis. It is then repeated back with next speed until whole of the rotation speed are tested.

Labview NI environment: Labview NI is used as a platform for interfacing execution and data acquisition between the host (computer), microcontroller and motor and sensor devices. It is known as the functionality for embedded control and monitoring system. Two labview environments is used for execution and data acquisition; For DC motor operation, it provides user to input value for rotational speed, duration for motor to run and time for hard brake motor to execute. Meanwhile as for the data acquisition, click on the button provided to read and measure the signal send to microcontroller.

Data acquisition 2: On the subject of data acquisition, all the data from the sensors; encoder and accelerometer are

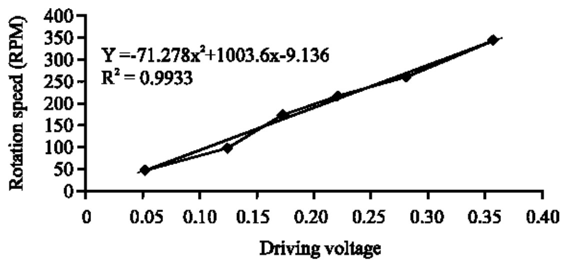

Fig. 2: Motor driving voltage to rotational speed relationship

Table 1: Range of rotational speed for investigation in drill string vibration

Voltage	RPM
0.052	47
0.124	100
0.172	170
0.280	215
0.356	260
0.600	340

recorded in a real time and the data recorded are monitored through Labview NI environment. It is noted that a dozen amount of digital pins I/O required to read the changes in phase for 11 bit encoder. The 12 digital pins are needed for individual encoder to function as accordingly. The data read for all the pins are in binary code where each pin will read in phase changes from high to low. Hence, it is necessary to covert the grey code into binary and decimal that gives a number from 0-2048 for one cycle of rotation. Each degree of rotation will result in cumulative of number until it reaches 2048 and repeat again from 0; indicate one cycle has been count.

Brushless DC motor: Experimental results are obtained at different rotating speed in RPM as listed out in Table 1, different levels of rotation speed are used to drive the DC motor based on the voltage required which responds in a linear relationship to the rotational speed. The minimum speed able for the motor to start is around 40 rev/min. This is the initial and the lowest speed tested for this research. The corresponding relationship is shown in Fig. 2 and Eq. 1 . The relationship is polynomial curve fit with obtained equation of with lowest linear least regression of 0.9933. The experimental conducted initially cover 3 level of speed comprised from low, medium and high. Equation 1 shows that:

$$RPM = -71.278\,(Voltage)^2 + 1003.6\,(Voltage) - 9.136 \quad (1)$$

RESULTS AND DISCUSSION

Experimental results: Referring to Fig. 3-8, the investigation of resonance is done throughout the

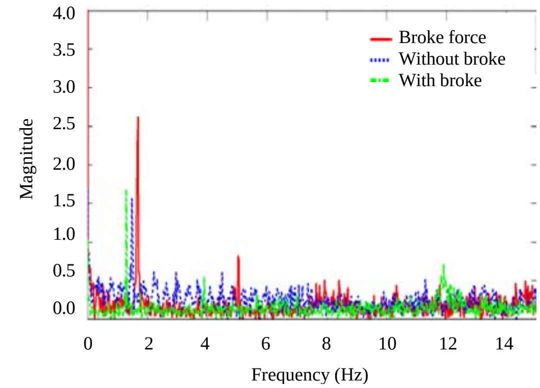

Fig. 3: Single sided magnitude spectrum for 47 RPM with and without applying brake

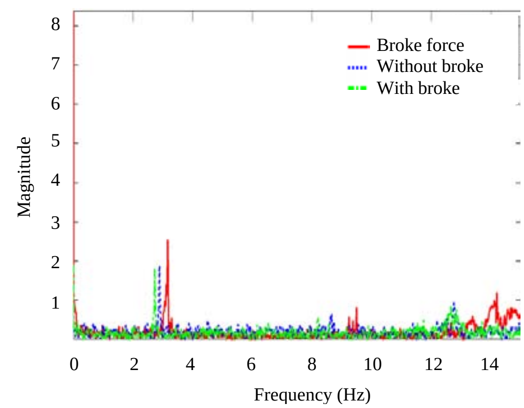

Fig. 4: Single sided magnitude spectrum for 100 RPM with and without applying brake

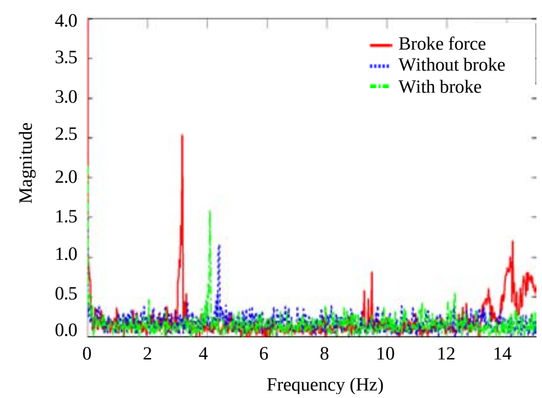

Fig. 5: Single sided magnitude spectrum for 170 RPM with and without applying brake

operation without braking system applied to the bottom disk. Analysing the plots, it was noticed that each of the speed level possesses individual resonance. The resonance frequencies for each of operation speed are well tabulated in Table 2.

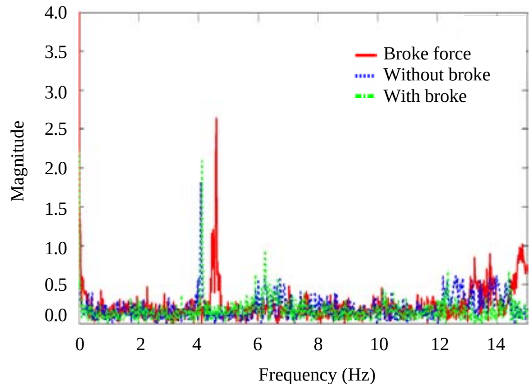

Fig. 6: Single sided magnitude spectrum for 216 RPM with and without applying brake

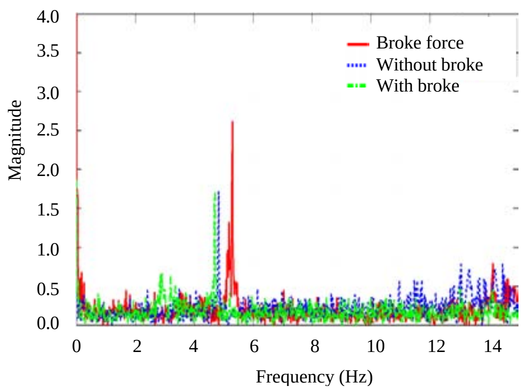

Fig. 7: Single sided magnitude spectrum for 47 RPM with and without applying brake

Table 2: Natural frequency of the system with "no brake" "with brake" and "with force brake"

	Natural Frequency of the drill string experiment			
Speed (RPM)	Natural frequency (Hz)	Without brake frequency (Hz)	With brake Frequency (Hz)	With force brake Frequency (Hz)
47	0.783	1.32	1.37	1.72
100	1.667	2.74	3.88	3.97
170	2.833	3.88	3.96	4.21
216	3.600	4.60	4.62	4.38
260	4.333	5.20	5.25	5.46
340	5.667	5.81	5.81	5.96

Speed without brake: From Fig. 3-8 (dotted blue line), it shows that the investigation of resonance is done throughout the operation without braking system applied to the bottom disk. Analysing the plots, it was noticed that each of the speed level possesses individual resonance. The resonance frequencies for each of operation speed.

Speed with hard brake system: Referring to Fig. 3-8 (dashed green line) an external friction is applied to the experiment drill string operation which is to represent the behaviour of the rotary drill string drilling the ground formation. This external friction is induced by a sudden hard brake clamped the bottom disk, BHA to provide a vibration in lateral, axial and torsional.

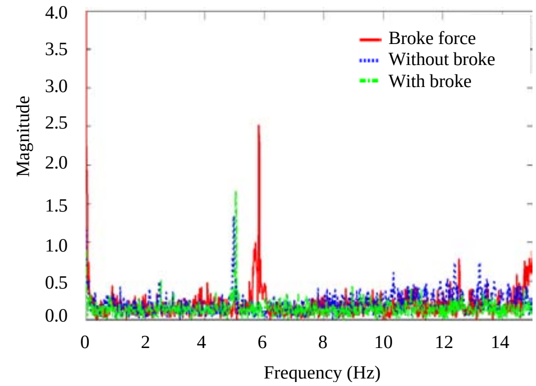

Fig. 8: Single sided magnitude spectrum for 340 RPM with and without applying brake

Speed with force brake @ linear brake system: Referring to the Fig. 3-8 (straight red line) an external friction also has been applied to the experiment but this external friction is induced by linear actuator brake system and force applied onto brake disk.

Previous case has analysed the natural frequency of the system at each particular rotation speed. External vibration ensured that well defined prominent vibrations were now present by the system. It was noticed that the frequency of each individual speed are sharper and higher than before. The frequency response plot based on the FFT for those cases proved that the vibrations exhibited by the drilling system were aggravated in the presence of brake friction. Analysing the plot, it was noticed that the resonant frequencies of the system did vary with the operational speed. Comparing the FFT plot Fig. 7 and 8, it was noted the resonant modes are excited and more significant when the linear actuator brake system is present.

Experimentally, the lateral and torsional vibrations exhibited by the drilling system were prominently more severe under the hard brake and linear friction effect. The analysis of the natural frequency of the system for no brake with brake, force brake apply is projected through below for further understanding and investigation.

By referring to Table 2, comparison is made between the natural frequency possess by the system and the resonance experienced by the experiment drill string with "without" braking force applied "with" sudden hard brake applied and "with force @ linear brake" applied. The analysis is concerning on the resonant region zone where vibration is amplified and problems of fatigue and deformation of the drill string are almost certain to occur. It can clearly see that when the experiment drill string is operating at speed from 100-260 RPM with brake applied; the resonance frequencies obtained are deviated further that the critical natural frequency of the system. As for the lowest and highest rotation speed; 47 and 340 RPM, the deviation is comparably smaller and closer to the critical natural frequency. This indicates that the possibility of the excitation vibration may occur vigorously at this range of speed.

Based on the drill string vibration mode SDS (2007), chances stick-slip, bit bounce and bit whirl to happen are high based on the frequency excitation of each vibration modes.

CONCLUSION

The behaviour of vibration and relation with resonance are well defined and distinguished. Static simulation on the finding fundamental frequency of the operation system and experimental study proved that the data recorded and analysed are comparable. The drill string vibration modes which are axial, lateral and torsional are significant where it is measured in respect to acceleration and time domain. The vibrations experienced throughout the operation are then undergoes fast fourier transform analysis where time domain are transform into frequency domain. This permit on the analysis of resonance that is crucial in vibration study within drill string field. The resonance experienced by the drill string experiment depends on the operation speed provided.

Hence, the speed optimization operation suggested based on this study of vibration behaviour is about the range of 216 RPM which gives a minor vibration according to this study based on vibration amplitude and occurrence of resonance. However, the experiment shows that the effect of operation vibration is significant that added disturbance inducing high vibration throughout the experiment. These vibrations were present in the system and were visible as the drill string stabilizes.

The research also analysed and demonstrated the hard brake and linear actuator brake application inducing friction and critical speeds of operation aggravated the lateral and torsional vibration during drilling. The studies reveals that vibrations were excited either at lower and high rotation speeds. This is proved by analysis in vibration acceleration amplitude and resonance intensity of each individual operation speed.

SUGGESTIONS

For future analysis and investigation, wider scope of investigation can be made through modification on existing experiment drill string such as implementation of borehole that representing the drill collar. Full spectrum of vibration able to analyse as the vibration occur when the drill bit is in-contact with bore hole. Besides that image processing using camera are potential to mitigate the displacement of the drill string as it whirling from its axis. Vibrations in sense of lateral are possibly more accurate and realistic as high speed camera such as CCD or a CMOS are potential to record and captured typically 1,000 frames per sec. Furthermore, control strategies can be devised and implemented to reduce the occurrence of the vibration in respond to operation speed. Closed loop communication between operation speed and vibration feedback are interchangeable and optimization of vibration can be achieved. Last but not least, experimental data validation used from a real drill string and comparing with experimental and numerical response based on the suggested optimized speed.

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