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Development of Downhole Dynamic Measuring System and Field Trial

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Abstract. Downhole engineering parameters such as weight on bit (WOB), torque on bit (TOB) and vibration play a significant role in safe and efficient drilling when operating in severe geological environment. Monitoring downhole parameters in real-time will improve drilling safety and efficiency greatly. Traditionally, engineering parameters obtained in the well site are based on data collection on surface, which is not an accurate way to estimate downhole conditions. In order to explain dynamical state and stress distribution of bottom hole assembly (BHA), a comprehensive suite of downhole dynamic measuring system (DDMS) is developed. The paper provides an overview of the downhole dynamic measuring system which has the ability to measure axial force, torsional force, annular pressure, internal pressure, vibrations in three orthogonal directions and annular temperature with changeable sampling rate as high as 1000 Hz. The measurement of axial force and torsional force with strain sensors is an intricate issue which relates to environmental factors, therefore calibration of strain sensors in laboratory is included in this paper. In the subsequent content, field trail is covered to illustrate the performance of downhole dynamic measuring system.

Keywords: calibration, dynamics, measuring system, vibration

1 Introduction

Drillstring dynamics has always been a primary concern in drilling industry because it may cause drilling inefficiency, premature of drill bit, fatigue failure of BHA component and measurement-while-drilling (MWD) tools [1-2]. As the consumption of shallow oil and gas resources, we are heading to more deteriorated geology to perform drilling operations. When drilling in such areas, dynamic impact and vibration suffered by BHA become more challenging. Because of uncertainty and complexity of geological condition, dynamic dysfunctions such as bit damage, harmful vibrations always happen which dramatically increase the cost of drilling.

The ability to identify dynamic dysfunctions soon and take correct response quickly is a significant element of both drilling performance improvement and equipment failure prevention. However, dynamic dysfunctions are extremely complex to model [3], and utilizing model based method to depict continually changing conditions is almost impossible during drilling operations. Fortunately, monitoring dynamic parameters with downhole instrumentation has been proved to be a promising way to identify dynamic dysfunction [4-11].

Downhole dynamic instrumentation can be classified into two categories: stand-alone measurement subs with variable sizes and sensor types [12-13], and integrated downhole measurement subs which are part of Measurement While Drilling (MWD) tool suites [14-16]. The stand-along measurement sub may comprise only a single sensor, for instance a radial accelerometer, and may be placed in close proximity

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to the bit or at multiple locations along the drillstring. While integrated tools typically contain an array of sensors, such as accelerometers, magnetometers, strain gauges, pressure and temperature sensors, to collect comprehensive dynamic data. To research on dynamic phenomenon, obtaining correct measurements of related parameters with certain sampling frequency and level of accuracy is necessary since downhole dynamics is an instantaneous issue. Data must be acquired at frequency greater than Nyquist frequency (twice as high as the frequency of the data interested), to prevent aliasing of the data, then band-pass filtered to exclude extraneous frequencies within data outside of the range of interest. Failure to sample and store data at a sufficiently high frequency causes the removal of interested information.

Technically, there are two ways to deal with data stream measured by downhole tools, one way transmitting the data to surface in real-time, another way storing the data stream in memory chip and downloading it at the end of bit run for post-analysis. The low data transfer rate of mud pulse telemetry system may result in missing of high frequency dynamic information. Besides, the high expensive cost and unconvincing reliability of wired drill pipe telemetry hinder its application in field. In view of the above reasons, a downhole dynamic recorder measuring system which captures high frequency dynamic data seems to be a more economical and practical tool to study drillstring dynamics.

2 Description of Dynamic Measuring System

The down-hole dynamic measuring system (DDMS) incorporates multiple sensors (i.e., strain gauges, accelerometer, pressure gauges and thermocouple probe), a complete data acquisition unit, a microprocessor, memory chip unit and battery unit. The DDMS records measurement of axial force, torsional force, tri-axial vibrations, annular pressure, internal pressure and temperature, at a scanning rate of 50 Hz (up to 1000 Hz) to reconstruct the instantaneous drill string kinematics. The sampling rate of data can be preset before running into borehole. Due to its high sampling rate and precision, the DDMS has many benefits, including offering complete vibration monitoring, tracking of bit efficiency and wear, and assessment “real” performance of downhole equipment. In addition, borehole cleaning condition and bit nozzle plugging can be monitored through the fluctuation of pressure in annulus and drill pipe.

Axial force and torsional force can be obtained from strain deformation occurred in BHA. The strain in BHA is measured at point by orienting strain gauges around a collar. In the case of this application, the strain gauges are deployed under three hatch covers machined 120° apart around the circumference of the collar. Each hatch cover contains eight strain gauges, four mounted longitudinally to measure tension or compression along the axis of the collar and four mounted radially to measure the strain resulting from torque. Each set of four strain gauges are connected to a bridge to measure output from the strain gauges resulting from deformation caused by axial force and torsional force. Pressure transducers measure both annular pressure and internal pressure in drill string respectively. A three-axis accelerometer package is mounted in a sensor cave on the center line of collar to measure downhole vibrations in three-dimension, the axial vibration and the lateral vibrations in two orthogonal directions. Moreover, a thermocouple which provides temperature data completes the sensor set.

3 Description of Dynamic Measuring system

In order to ensure accuracy and precision of measurements, a comprehensive calibration is exerted to strain sensors. Strain sensors must be characterized for environmental factors that have influence on measurements. The output of axial force is an intricate issue which relates to weight of BHA beneath the measuring cave, weight carried to bit by formation, buoyant action of drilling fluid acting upward at the bit against the effective cross-section area of the pipe, differential pressure effect acting on the wall of pipe and zero drift caused by temperature. Due to the utilization of thermal compensation strain gauges, thermal effect is neglected in this paper.

Differential pressure effect was calibrated in laboratory to eliminate its influence on measurement output of axial force. When drilling, pressures in annulus and internal of drill string will be different due to pressure drop of bit and positive displacement motor (PDM). Hydraulic pressure was applied in inner of the dynamic recorder sub to emulate differential pressure effect and measurement output in unit of voltage was documented simultaneously corresponding to current pressure. When pressure was changed, output also changed. Hence an explicit relationship between outputs and differential pressures is obtained. Fig. 1 depicts the linear relationship clearly. Using this fitting formula, the contribution of differential pressure to axial force can be subtracted from total measured axial force. Similarly, torsional force with respect to differential pressure was calibrated. Fig. 2 shows linear relationship between different pressure and torsional force output.

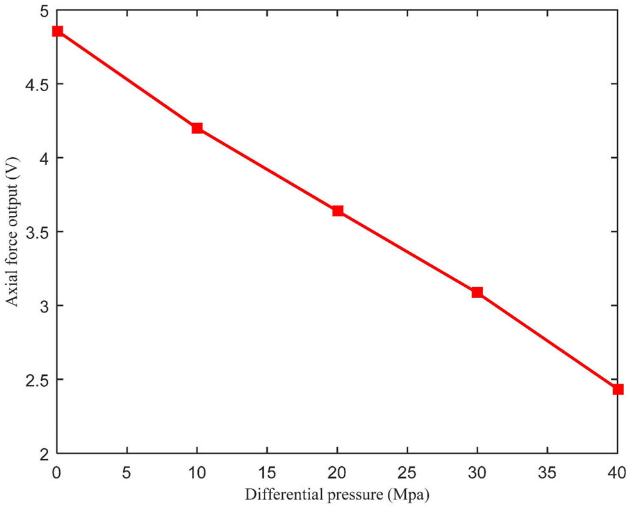

Fig. 1. Relationship between differential pressure and axial force output

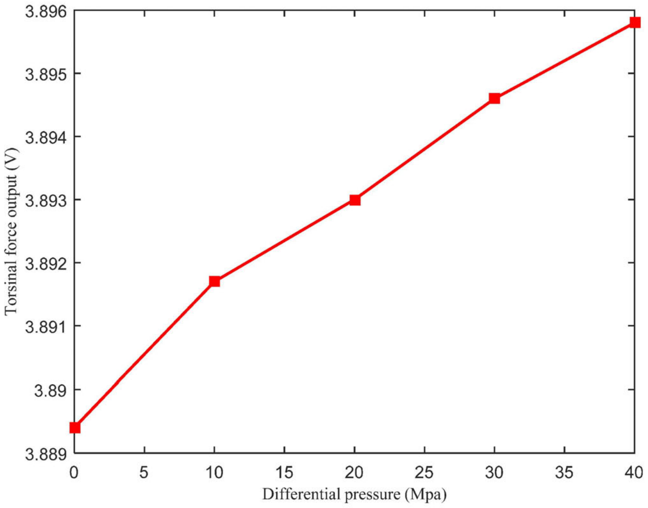

Fig. 2. Relation between differential pressure and torsional force output

Congruent relationship between tension/compression and output in unit of voltage was built up through applying axial compressive force to ends of the dynamic sub with hydraulic jack. The magnitude of axial force ranges from zero to one hundred and sixty in unit of KN. In calibration, the compressive force is applied step by step increasingly and hold the force unchanged for two minutes to get output of every step. After calibration, a correspondence relationship was obtained between exerted axial force and output to quantify the magnitude of exerted axial force when drilling. Torsional force was also calibrated in the same aforementioned procedure to get exact relationship. Fig. 3 and Fig. 4 show the two relationships respectively.

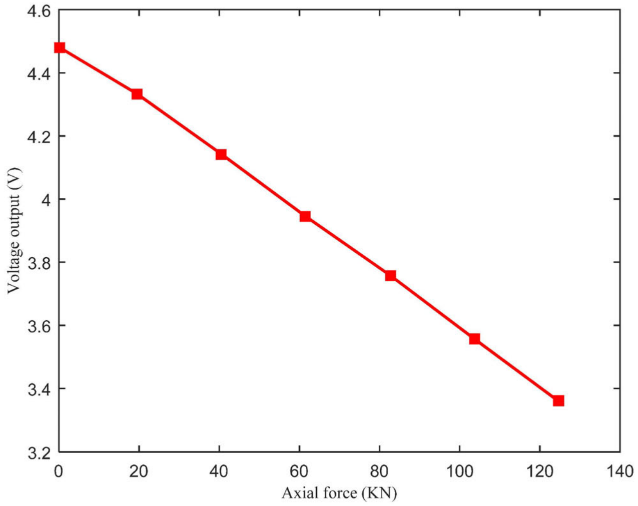

Fig. 3. Relation between axial force and output

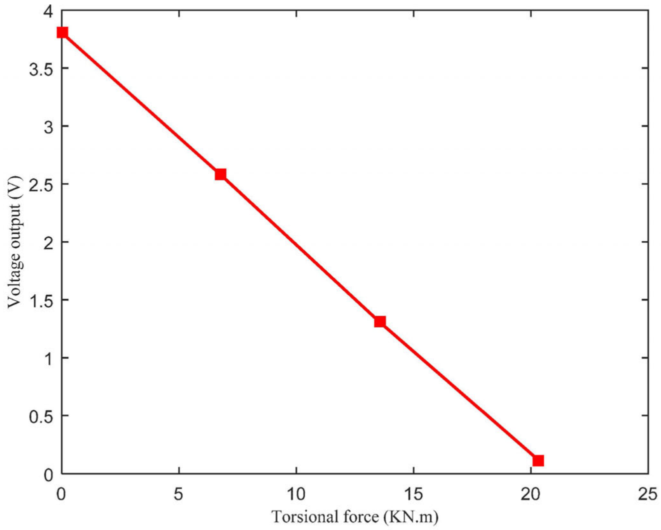

Fig. 4. Relation between torsional force and output

4 Field trail of Dynamic Measuring System

To verify its performance of the dynamic measuring system in filed application, a trial was conducted in the 8 1/2 section of a directional well in Jidong Oilfield. The trial lasted 108.5 hours and well depth was drilled from 3376 to 3492 meter. A second running was done after the drill string was tripped out because of dysfunction of PDM. The BHA configuration, listed in Table 1, was similar in the two runs, only a new PDM was replaced in second run.

Table 1. BHA configuration used in the two runs

Component	OD (in)	Length (ft)	Component	OD (in)	Length (ft)
Bit	8.5	1.148	MWD	6.38	4.887
PDM	6.77	26.634	Nonmagnetic drill collar	6.77	30.766
Float valve	6.77	1.64	Dynamic down hole sub	6.77	10
Nonmagnetic drill collar	6.77	30.766	WDP	5	523.127

4.1 Axial force Measurement

As mentioned above, the bridge of strain sensors mounted in axial direction of BHA measures the resultant force in axial. During process of drilling, forces, pressures in annular and internal of drill string and vibrations are recorded by the DDMS.

Fig. 5 shows part of data recorded when trip in. Due to the existence of float valve in BHA configuration, the pressure in drill string stays constant while that in annulus increase with increase of depth. The differential pressure between annulus and drill string affects the measurement of axial force greatly, which lead to the decrease of axial force. As drilling pump starts working, circulation is built up between drill string and annulus, and differential pressure effect is compensated which results in axial force increasing gradually with the decrease of differential pressure.

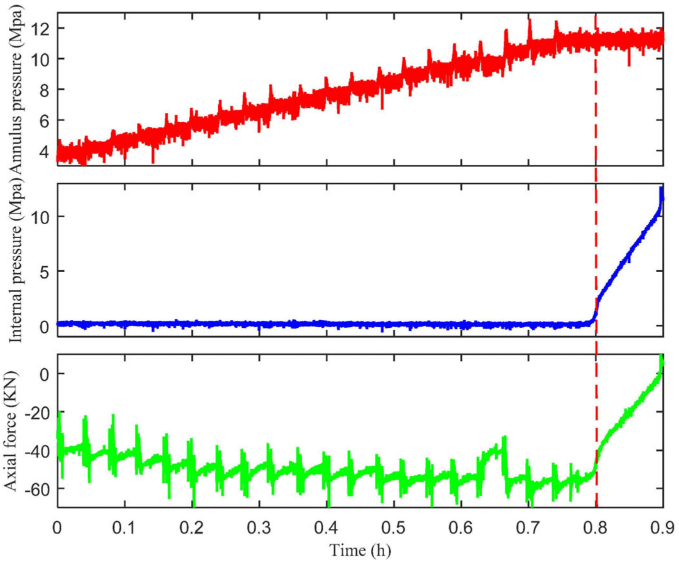

Fig. 5. Data recorded in trip in procedure

On the bottom of Fig. 6, high frequency data of axial force is exhibited when rotating drilling is on. For high revolution, segment data is plotted on top. A Fast Fourier Transform (FFT) of the data reveals the domain frequency of 1Hz which corresponds to Revolutions per minute (RPM). These fluctuations indicate a proportional relation between frequency of measuring data and RPM of BHA. While the magnitude of fluctuations need to be more analyzed.

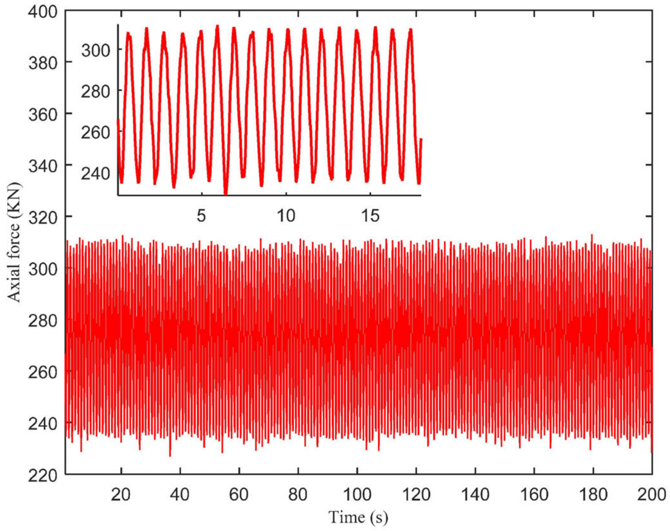

Fig. 6. Recorded axial force when drilling

4.2 Pressure Measurement to Identify Downhole Event

Pressure plays an important role in drilling industry. In order to keep safe and efficient drilling, annular pressure need to be maintained between the pore pressure and fracture pressure of current drilling formation to avoid unplanned events happening. Generally speaking, pressure in annulus and drill string will keep almost constant during a period of time. If change happens in a short time, that always means unwanted events occur, which consist of gas kick, loss, poor cleaning condition, pack-off, bit nuzzle plugging and etc. Fig. 7 illustrates an event happening in the process of field trial.

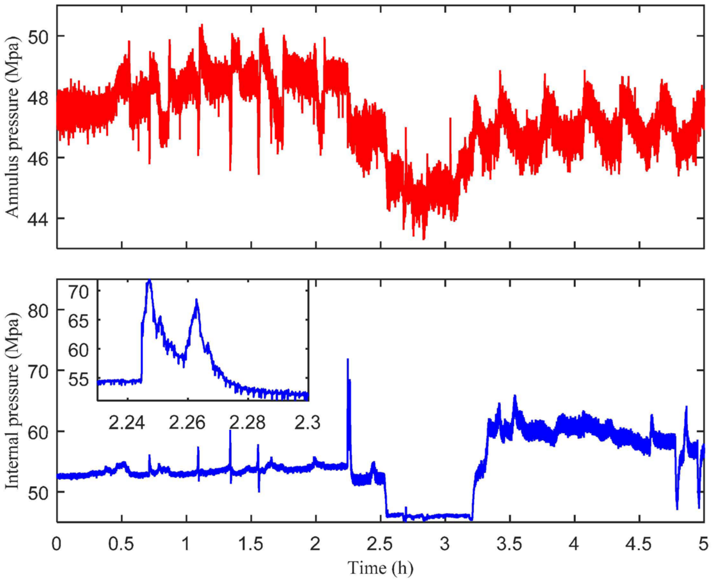

Fig. 7. Data recorded an event happening

According to the readings obtained from downhole pressure sensors, annular pressure and drill string pressure are both stable at beginning of Fig. 7. The pressure drop of PDM, together with pressure drop of bit and frictional pressure drop in annulus and drill string beneath pressure sensors lead to the differential pressure. Nearly in half an hour later, pressure begins to fluctuate slightly and shows a trend of increase gradually, which indicates something unusual is forming. Because of its high sampling rate, the sudden spikes are recorded completely. Without the data seen by driller, event happening was realized in two hours later. After discussion among driller and engineers, the bit was lift off bottom and circulation was conducted to eliminate the event. After hours' effort, this situation was not improved and the decision of trip out was made. When BHA was pulled out, we found that the rotor of PDM was stuck which result in the increase of drill string pressure. Post-analysis of the data correctly confirmed what happened downhole.

4.3 Vibration Measurement in Interlayer Formation

Due to the interaction between bit and formation, drill string has always been vibrating in drilling process. Typically, downhole vibrations are classified into three types: axial vibration, lateral vibration and torsional vibration. Severe drill string vibration can cause serious problems such as premature bit failure, low rate of ROP and failure of MWD tools and other BHA components. In addition, Dangerous lateral vibration is especially difficult to be detected at surface because of attenuation. For these two reasons, monitoring vibration of BHA to detect and mitigate harmful vibration with suitable downhole tools will be a necessary issue to make safe drilling.

In this paper, the tri-axial accelerometer is deployed on the center line of the above-mentioned downhole dynamic recorder sub. According to theory in [11], we measure only axial vibration in Z direction and lateral vibration in two orthogonal directions, X and Y direction respectively, because the distance between center of drill string to that of accelerometer equals to zero. Fig. 8 shows a segment of data recorded in field trial when drilling in interlayer formation of sandstone and argillaceous sandstone. The figure indicate that the amplitude of Z vibration is 0.5g smaller than that of vibration in X and Y direction. The fluctuations of Z vibration are caused by changing of formation. Lateral vibration is more stable which indicate a much safer drilling condition.

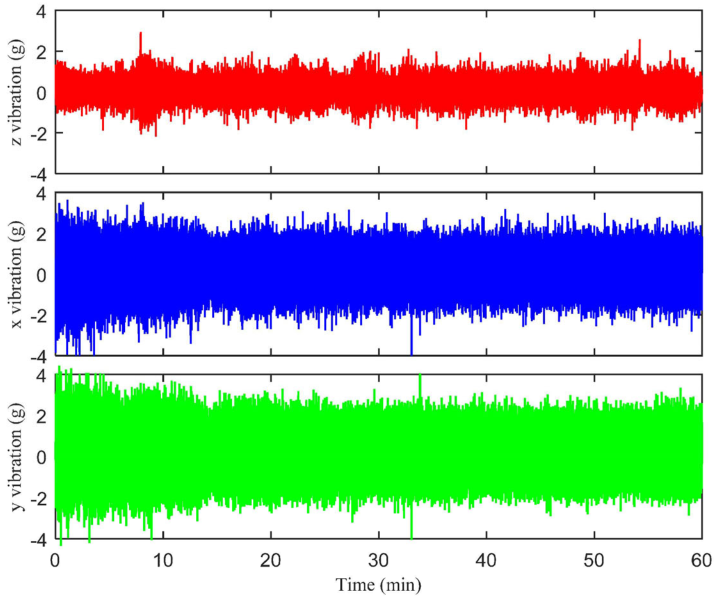

Fig. 8. Vibration data recorded in field trail

5 Conclusion

The downhole dynamic measuring system can record data of axial force, torsional force, internal pressure, annular pressure, annular temperature and vibrations in three orthogonal directions with changeable sampling rate. Strain sensors for axial force and torsional force are sensitive to environmental factors. In order to ensure accuracy, a comprehensive calibration is exerted to strain sensors to quantify the influence of environmental factors through indoor experiment. The down-hole dynamic measuring system is capable to capture dynamic motions and vibrations of drill string, even though sudden spikes of measurement can be recorded clearly. In the field trail, a dysfunction of PMD rotor sticking is successfully recorded and identified. We in the future attempt to obtain down-hole weight on bit (DWOB) from measuring data. Therefore, further DWOB calibration method need to be studied to guide drilling operation.

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