Measurement of Torsional Vibration of Drill-String

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Introduction

During a downhole drilling process excessive vibrations can occur, which in most cases have a negative impact on the effectiveness of the process and the drilling equipment [1]. Such vibration may lead to an accelerated wear and premature damage of the expensive drilling equipment. Often different dynamic effects such as bit-bounce, stick–slip, forward and backward whirls may appear simultaneously. Recently several attempts have been made to replicate these vibrations in academic laboratories. However, in most studies the cutting process is simulated by a friction between two disks [2]. In this work we focus on the experimental observation of torsional vibration including stick-slip phenomenon while drilling, which nature is still not well understood and can lead to a catastrophic failure of the drill-stings.

Measurement of Drill-string Vibration

A novel experimental drilling rig designed at the University of Aberdeen [3-6] capable to mimic all dangerous effects including drill-bit bouncing, whirling and stick-slip. The rig shown in Figure 1 is equipped with a variety of different sensors and transducers. Angular positions are measured by two quadrature encoders having 500 pulse per revolution, where axial motion of the drill-bit is captured by a P1010 position transducer attached to the Bottom Hole Assembly. Horizontal and vertical forces as well as torque coming from the bit to the rock are measured by a 4-component Kistler dynamometer placed under the rock sample. All the voltage signals are sent to a NI PCIe-6321 data acquisition card which has multiple analogue input (16-Bit, 250 kS/s) and output (900 kS/s) channels and four 32-bit counters/timers. Accessing to 4 counters, allows us to precisely synchronise two encoders. This is important as then the drill-pipe twist can be calculated accurately as plotted in x-axis of phase portraits in Fig. 2 (a-c). Furthermore, the card high performance allows high frequency data sampling up to 30 kHz. This card is controlled by a custom developed LabVIEW graphical interface allowing to monitor responses of the system and to present time histories of variables and phase portraits in real-time. This program also sends the command to the top AC motor through the NI card and the ABB frequency convertor. This convertor can work in speed or torque control modes which control the speed or torque provided by the motor. Different speed or torque nonlinear control methods can be implemented in the LabVIEW program such as a sliding mode control in [4].

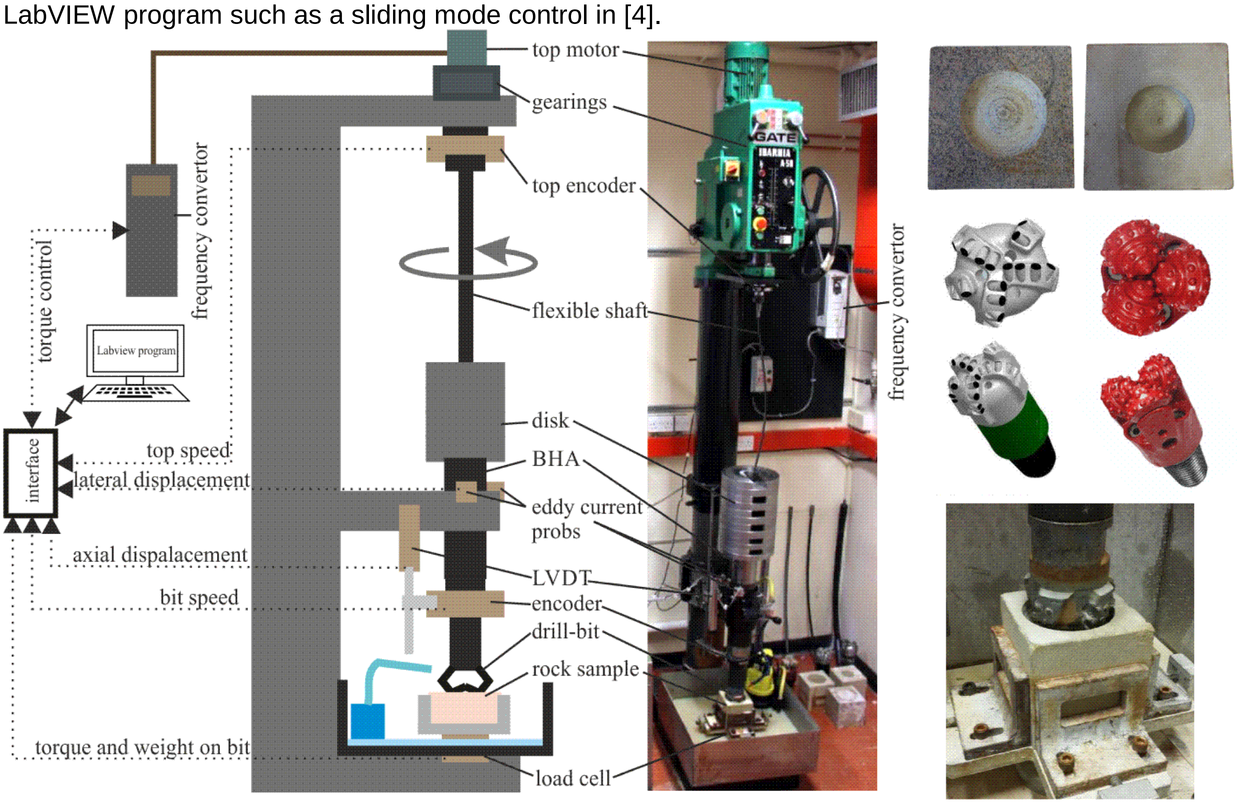

Figure 1: (left) Schematic diagram of the experimental setup, (middle) photograph of the experimental rig and (right) examples of rock samples and drill-bits used in the setup. Main components of the system are: sensors (top and bottom encoders, eddy current probes, LVDT and 4-component load cell), electric motor, flexible or rigid shafts, disks, the BHA, drill-bit and rock samples.

Here we present three examples of experimental results showing torsional oscillations of the drill-string exhibiting stick-slip phenomenon. In all the results shown in Figure 2, we used a flexible shaft of 10 mm diameter, a 3-7/8" PDC drill-bit and sandstone rock samples. In each case we saved the data in the LabVIEW program after 100 periods, letting the system settle down in its steady state. The angular velocities of the top and the drill-bit are calculated as the derivative of their angular positions captured by the encoders with continuous wavelet transform method. To have a better quality of the measured signal, the lowest possible ranges are chosen for each channel of the dynamometer avoiding overload as well as providing the highest possible accuracy. Then in the LabVIEW program, these voltage signals are converted to the SI units using corresponding converting factors. In Figure 2, 20 seconds of the steady state response of the drill-bit are depicted for 3 different experiments where the red and blue curves are the bit and top angular velocities respectively. Top panel shows a typical torsional vibration of the drill-string, where the drill-bit angular velocity varies with high amplitude around the angular velocity of the top of the drill pipe. In extreme cases of torsional oscillations, the drill-bit can come to a standstill for a short period of time, resulting in stick-slip as shown in panels (b and c) [3-4]. Figure 2 present detailed time histories of drill-bit angular velocity, WOB and torque-on-bit (TOB) during period-one stick-slip motion. As expected during sticking phase there are abrupt changes in TOB. Also note that the WOB fluctuates as the bit angular velocity varies.

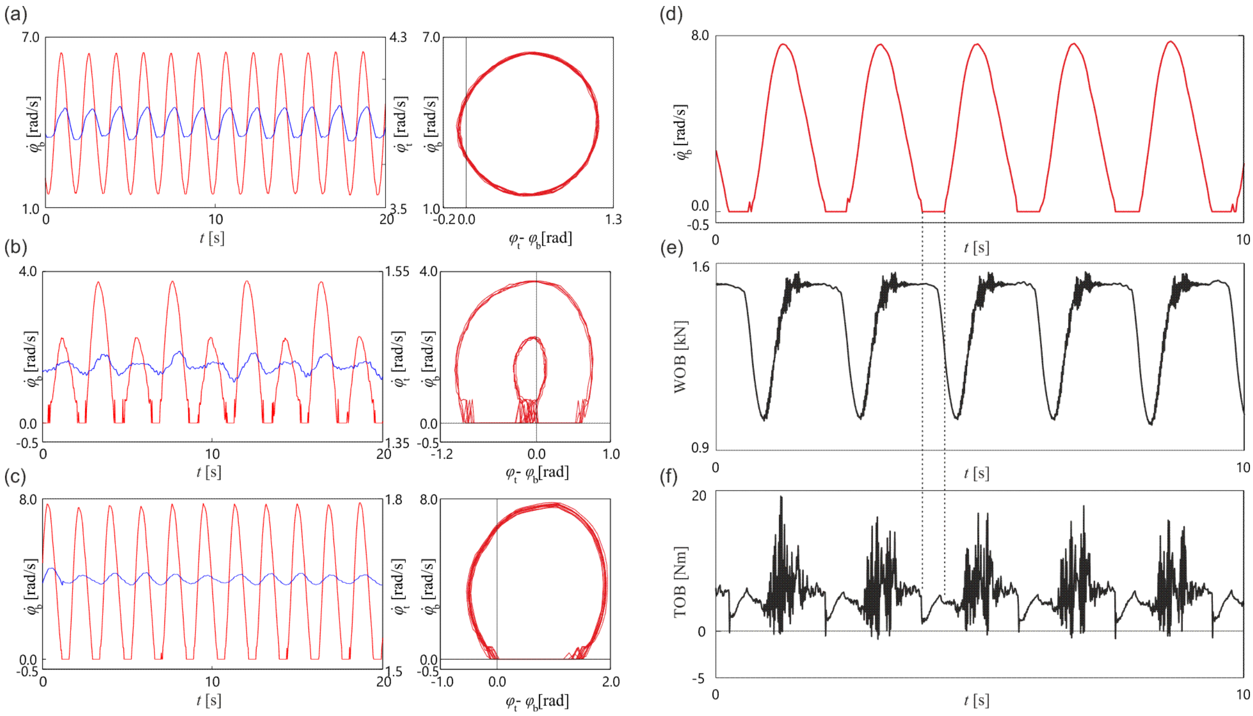

Figure 2 Examples of experimental time histories and phase portraits of (a) torsional vibration for WOB of 1.13 kN, (b and c) stick-slip oscillations for WOB of 1.95 and 1.4 kN respectively. Experimental time histories of WOB (e) and TOB (f) during stick-slip oscillations as shown in panel (d).

Conclusion

In this paper, we focused our attention on careful measurement of torsional vibration of the drill-string. A detailed rig description and the instrumentation were presented and the post processing procedure were explained. This setup allows us to monitor real-time responses, to capture dynamics of the drilling system up to 30 KS/s and to control the speed/torque transmitted to the drill-pipe. Three measurement examples were given showing the torsional vibration and stick-slip oscillation and corresponding changes in WOB and TOB while drilling.

References

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