Measurement of Lateral Vibration of BHA

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Introduction

During a downhole drilling excessive vibration can occur, which in most cases have a negative effect on the drilling process. From all the possible vibration modes, whiling poses a significant threat to the expensive drilling equipment, leading to its accelerated wear and premature damage. In principle there are two types of whirling motion forward and backward whirls, for which the direction of rotation of the Bottom Hole Assembly (BHA) coincides (forward) or differs (backward) with the direction of whirling motion. From those two, the backward whirl is a bigger threat to the drilling process, as it induces high frequency vibration. Besides, lateral vibration can lead a drill-string to bend and as a consequence it can compromise the borehole stability [1]. This paper presents a careful procedure for accurate measurement of lateral vibration of drill-string.

Measurement of Drill-string Lateral Vibration

In order to gain a deeper understanding of drill-string lateral vibration, a novel experimental drilling rig [2] has been constructed at the University of Aberdeen, which apart from whirling is capable of reproducing stick-slip and bit-bounce phenomena. In this paper we focus on the measurement aspect of whirling of the BHA, thereby for general overview of the design of the rig and its capabilities, refer to [2-4]. In our experimental facility, the drill-string is driven from top by a 3kW electric motor that can provide up to 1032 rpm. Depending on the chosen configuration either rigid or flexible shafts are used to transmit rotary motion to the BHA section and ultimately to the drill-bit. The BHA is made of a heavy steel shaft, held in transversal direction using a loose bearing, as shown schematically in Figure 1 (a). The radial clearance of 2.8 mm between the BHA and the loose bearing allows for the lateral motion of the BHA due to imbalance of the structure. An axial static force or a WOB is realized by placing steel disks on the top of the BHA providing WOB within the range 0.93 to 2.79 kN.

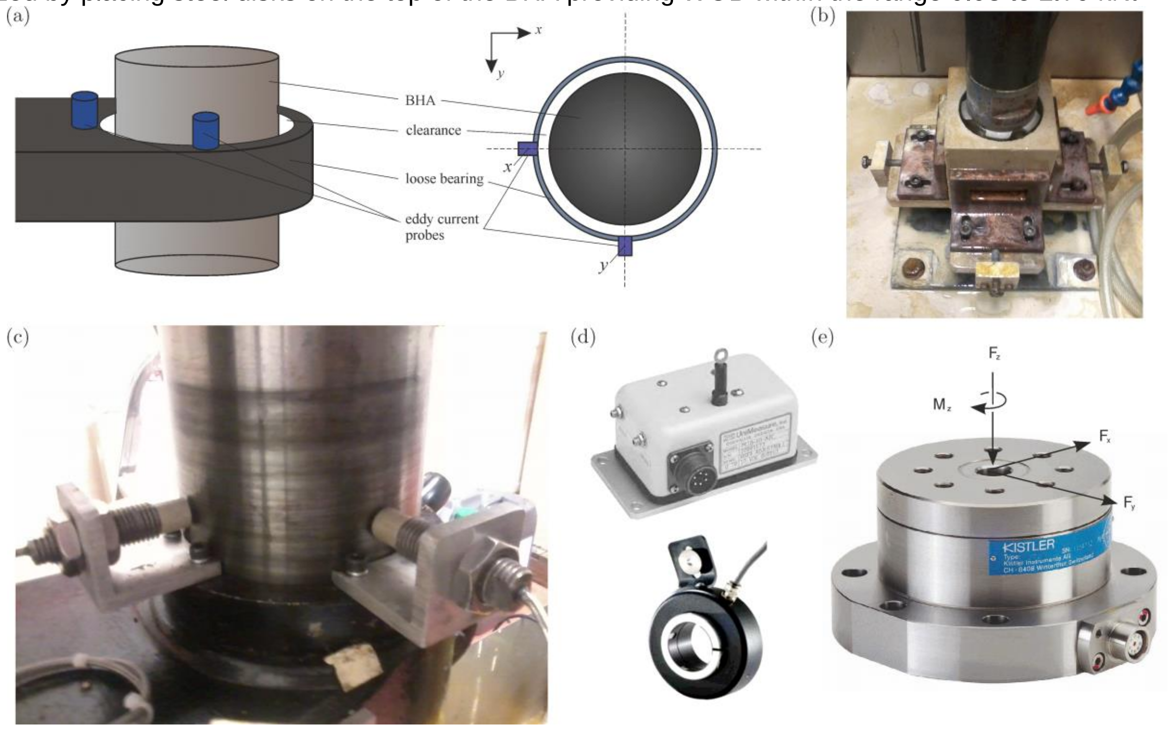

Figure 1 (a) Schematic diagram and photograph of the experimental setup. Main components of the system are: electric motor, flexible or rigid shafts, disks, the BHA, drill-bit and rock samples. (b) Drill-bit rock interface and the BHA with position of the eddy current probes, (c) 4-component load cell (d) top and bottom encoders and LVDT.

A variety of different sensors are used in the experimental setup, which allow to conduct detailed measurements of the most important variables of the drilling process. These include two incremental rotary quadrature encoders (**Figure 1**(d)) to measure top and bottom angular velocity, an axial position transducer (**Figure 1**(d)) to observe Rate of Penetration (ROP) and most importantly two eddy current probes to measure the lateral position of the BHA within the range 0-5mm (see Figure 1(c)). The most advanced sensor in our setup is the four component dynamometer (Kistler 9272), placed directly below the rock sample, as shown in Figure 1 (e), which allows to measure the axial force F_z, reaction torque T_z, and two forces acting in transversal directions F_x and F_y as depicted in Figure 1 (c). The ranges of measurement for TOB and WOB are: ±200 Nm and -5-20 kN respectively.

In the current work, we use the flexible shaft of torsional stiffness (28.07Nm/rad), a 3 7/8" PDC drill-bit and sandstone rock samples [2-4]. For a given set of system parameters (drill-bit, rock sample, flexible shaft and WOB), experiments are run at different top speeds and the dynamic responses of the BHA are recorded. This is performed by using a LabVIEW based Data Acquisition System (DAQ), which allows to observe in real time readings as well as to save the data for subsequent data processing and analysis in Matlab. In Figure 2 we present example family of time histories of a typical experiment for the configuration with 20 disks (each of mass 10.5 kg). The drill-string is driven from the top with angular velocity of 11 rad/s, computed using the angular position reading provided by the top encoder and depicted in panel (c). Figure 2 (a) and (b) show the displacement of the BHA in transversal directions *x* and *y*, which are measured using two eddy current probes, placed as in Figure 1 (c) with 90 deg separation from each other, providing the trajectory of the BHA. As shown in Figure 2(c), the driving top speed has oscillatory characteristics of small amplitude oscillations, which directly affects the response of the angular speed of the BHA, presented in Figure 2(d). One observes here oscillations of peak to peak amplitude of 6 rad/s, which is a direct consequence of low stiffness of the flexible shaft. Note, that the lateral and torsional oscillations have different frequencies, as can be seen when comparing time histories of x(t), y(t), $\dot{\varphi}_t$(t), $\dot{\varphi}_b$(t), shown in panels (a)-(d). As mentioned above, the experimental rig is equipped with accuracy load-cell (Kistler 9272) capable of high quality force measurements including the axial force and resistive torque, presented in panels Figure 2(e) and (f) respectively. As a result of varying speed of the BHA, a small amplitude variation in both F_z and T_z, can be observed. Additionally the load-cell gives us information about forces in transverse directions F_x and F_y, shown in Figure 2(g) and (h) respectively.

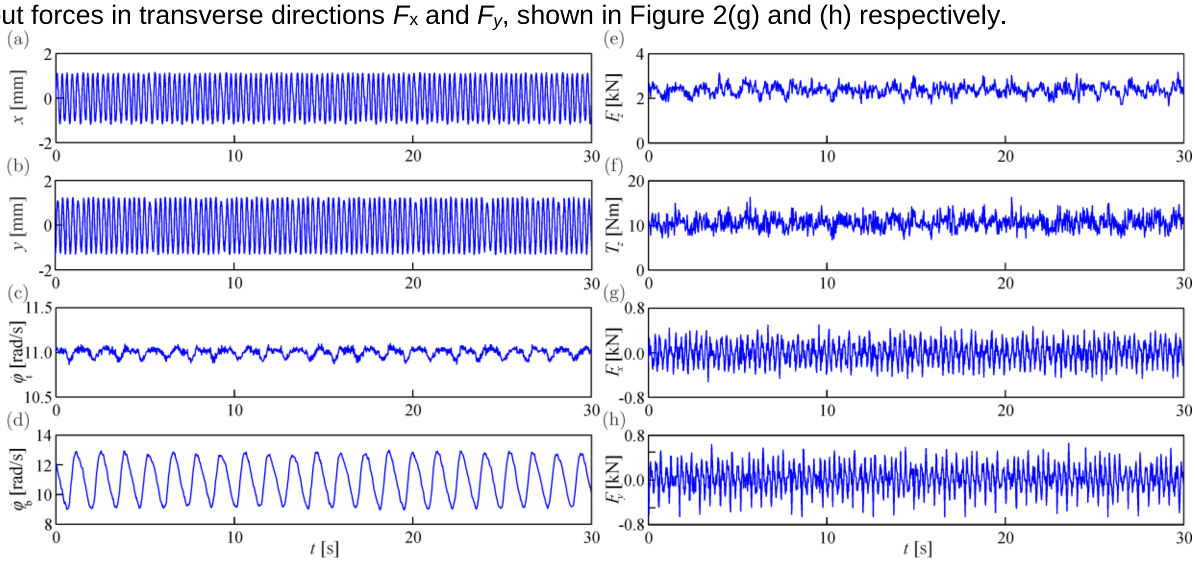

Figure 2 A sample of the recorded experimental time histories for configuration with 20 disks; (a) and (b) displacement of the BHA in the *x* and *y* direction respectively, (c) and (d) top and bottom speed, (e) F_z, (f) T_z, (g) and (h) transverse forces on x and y direction acting on the drill-bit.

Conclusion

In this work we concentrate on the experimental analysis of whirling of the BHA on a novel experimental rig, designed to analyse drill-string vibration. Particular attention is given to describe in detail the procedure and the instrumentation necessary to accurately measure all important variables that trigger whirling. This includes measurement of the BHA position that is carried out using two precise eddy current probes, placed 90 deg apart from each other, what allows to capture the full trajectory of the BHA. Additionally forces acting on the drill-bit while drilling, measured using a high precision 4-component dynamometer, provide a much needed insight into dynamics of the drilling process in presence of whirling.

References

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