Numerical and experimental investigation of nonlinear dynamics of downhole drilling

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Abstract. Drilling operation is essentially achieved and determined with the help of the drillstring which is composed of various accessories that are joined together to deliver the necessary torque from the rotary table to the drill-bit. The drillstring is normally exposed to different nonlinear dynamics that occur an axial, lateral and torsional base excitations, which consequently lead to fail under forms of bit-bouncing, whirling and stick-slip phenomena. This work aims to study the nonlinear dynamics caused by the interactions of drillstring with borehole, contacts of drill-bit with rock formation, instability of the drillstring and variation of the drilling influencing parameters. The characteristic behaviours of the drillstring were analysed by using a constructed experimental rig and were compared with a mathematical model. The experimental rig was able to simulate those undesired nonlinear phenomena which can draw a wider understanding into their mitigation methods.

Introduction

The drillstring, which is one of the main mediators to transmit the required torque from the surface to a drill-bit, has been remarkably responsible to produce necessary strength to drill rock formation during drilling operation along with an axial force. The operation of rock drilling encounters several undesired dynamic vibrations such as coupled or uncoupled axial, lateral and torsional modes that occur predominantly due to the difference of drillstring slenderness ratio between its diameter and length [1]. These nonlinear phenomena are significant causes for precocious issues of drillstring components and drilling performance when they are exposed to severe intermittent contacts of drillstring with borehole and intricate interactions of drill-bit with rock. They turn the drilling fulfilment to a catastrophic failure due to tool wear and damage which consequently increase the drilling non-productive time and cost [2]. This study provides a significant technical support to understand and analyse the nonlinear drillstring by experimentally optimising drilling parameters as shown in Fig.1 (a) and predicting its vibrations. An extensive work was conducted to model the nonlinear dynamics of drilling in different theoretical approaches while inadequate works have been conducted experimentally as a fully coupled vibration in both vertical and horizontal drillstring [3]. The present work is intended to extend by involving a flexible drillstring to analyse the influence of slenderness ratio using different types of rocks.

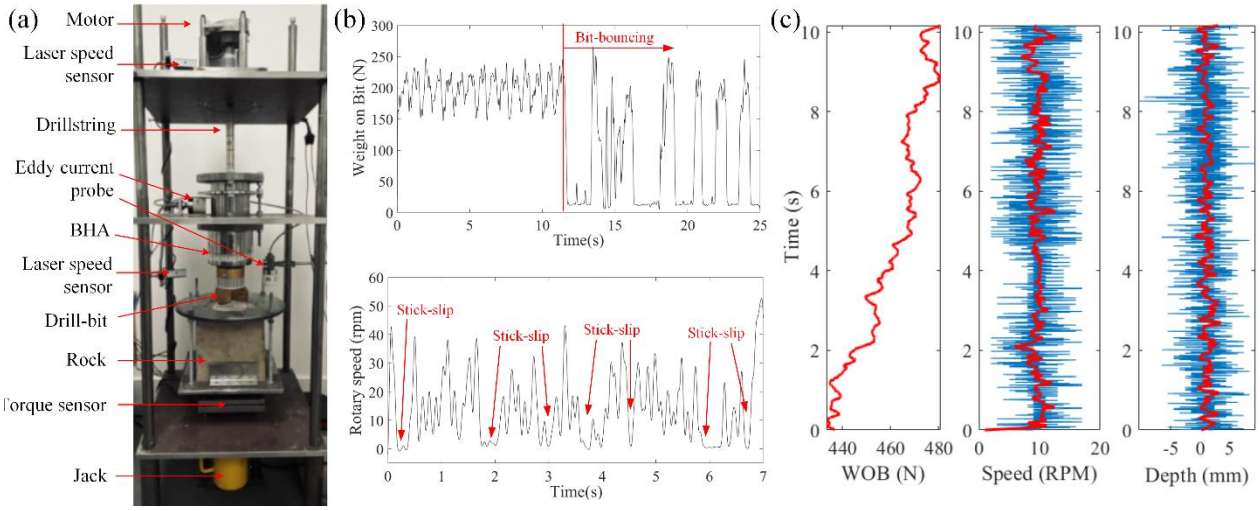

Fig. 1: (a) Experimental rig, (b) drillstring dynamic phenomena: bit-bouncing and stick-slip, and (c) drilling performance: time histories of weight-on-bit (WOB), rotary speed and rate of penetration (ROP) during a drilling process.

Results and Discussion

Experimental results shown in Fig. 1(b) reveal the complex behaviours excited during the drilling operation, such as stick-slip and bit-bouncing, in which a particular intention is paid to understand the various influencing factors that limit safe drilling, see Fig. 1(c). Experimental results present a good agreement with the proposed numerical model to visualise the nonlinear dynamics of the experimental drilling rig. The severity of lateral and torsional vibrations increases significantly within high impact and frictions of rotary speed and weight on bit compared to the axial vibrations.

References

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