A Novel Data Science Approach to Borehole Dysfunction Analysis

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ABSTRACT

During drilling activities, monitoring the quality of the borehole is an essential task. Borehole dysfunctions such as constrictions, ledges, and differential sticking can cause significant amounts of non-productive time that decreases overall operational performance. The dysfunctions are most troublesome during tripping operations when the drill string is moved in and out of the borehole. Identification of dysfunctions before significant operational issues occur, such as stuck pipe, can allow proactive mitigating actions to reduce the impact on the tripping operation. Modelling methods for expected sliding friction for good borehole conditions provide a baseline for hook load operating parameters during tripping out of the borehole. Assuming the baseline hook load estimation is somewhat accurate, the anomalous high hook loads above baseline, referred to as overpull, provide measurements that should capture the resistance in the borehole due to dysfunctions. The focus of this study is to utilize overpull signatures and the drill string configuration to produce a resistance depth profile that can provide better depth resolution to place dysfunctions along the wellbore and also characterize the dysfunction mechanism. This paper represents the initial steps of developing a forward modelling strategy using a source signal (i.e. the drill string) convolved with a resistance signal (i.e. the dysfunctions) to produce overpull signals. Initial tests show promising similarities compared to overpull real data.

INTRODUCTION

Real-time monitoring during drilling activities is crucial for optimizing operational performance. There are many factors that affect operational performance such as the energy input (e.g. rotational force, axial load, flow rate), the physical system parameters (e.g. well path design, drill string length, mud weight), and inherent resistive forces (e.g. friction and rock strength). Friction in the wellbore is commonly studied through torque and drag models. The objective of torque and drag modelling is to predict the friction forces that resist rotation (i.e. torque) and sliding (i.e. drag) of the drill string in the borehole (Johancsik et al., 1984). Analytical friction models are used to predict the torque and drag based on the 3D geometry of the well path (i.e. inclination and dog legs) and dynamic effects such as axial movement, rotation, and fluid flow (Aadnoy et al., 2010). The predictive model establishes a baseline for torque and drag that can be used for anomaly detection of excessive torque and drag.

Considering an accurate model is used for the baseline, excessive torque and drag can be caused by wellbore dysfunctions such as micro-tortuosity, ledges, keyseats, differential sticking, sloughing hole, and cuttings buildup caused by poor hole cleaning. During tripping operations, early detection of dysfunctions provides the opportunity to execute mitigating actions to minimize the effect on operational performance due to pack-off or stuck pipe. Cayeux et al. (Cayeux et al., 2012) developed a real-time monitoring system that effectively detected abnormal borehole conditions using physical models calibrated to real-time borehole conditions. The warning system monitors parameter threshold limits and alerts key personnel to interpret the warning. Automatic identification of the specific borehole dysfunctions has been studied by various authors. Cordoso et al. (Cordoso et al., 1995) applied a type curve matching approach to distinguish between normal borehole conditions versus certain dysfunctions (borehole closures, differential sticking, and borehole wall ledges). HL time plots for each stand were visually compared to single stand type curves (Figure 1).

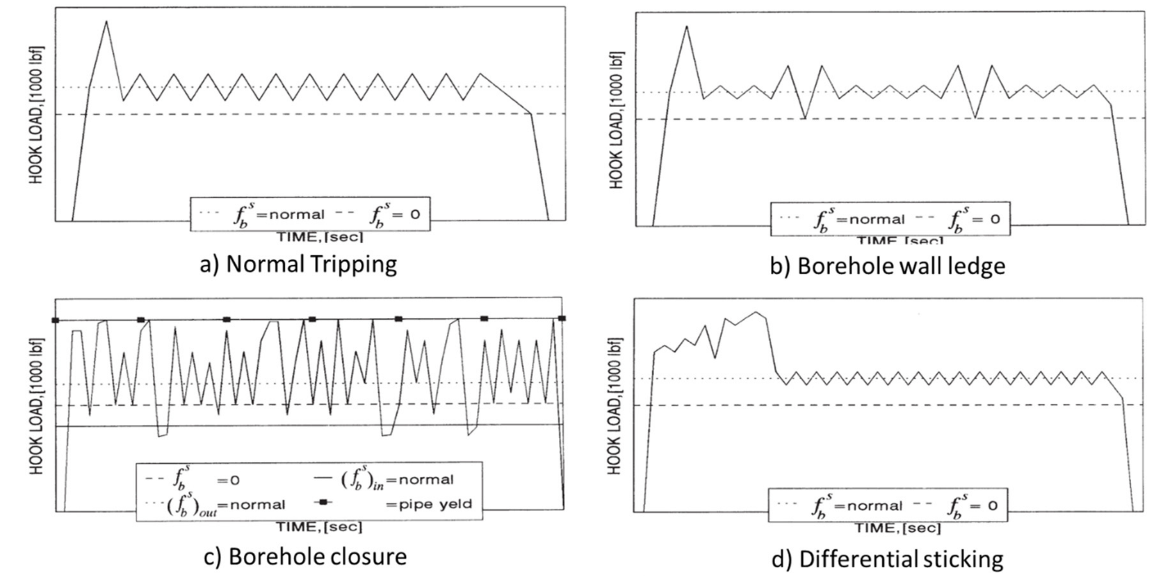

FIG. 1. Type curves a single stand for normal tripping HL-time response (a) versus different dysfunctions (b-d). Modified from Cordoso et al., 1995.

Freithofnig et al. (Freithofnig et al., 2003) applied a similar time-based approach to wash and ream data in order to identify non-problematic wellbore conditions and avoid unnecessary wash and ream operations. The authors suggest that utilizing HL versus bit depth could allow HL peaks to be correlated with drilling log lithology. Figure 2 shows the average HL versus bit depth for a single stand indicating a borehole dysfunction, but specific problem depth cannot be interpreted. Because there are multiple locations along the drill string that could create an anomalous HL measurement at the same bit depth, the actual depth location of the disfunction cannot be determined.

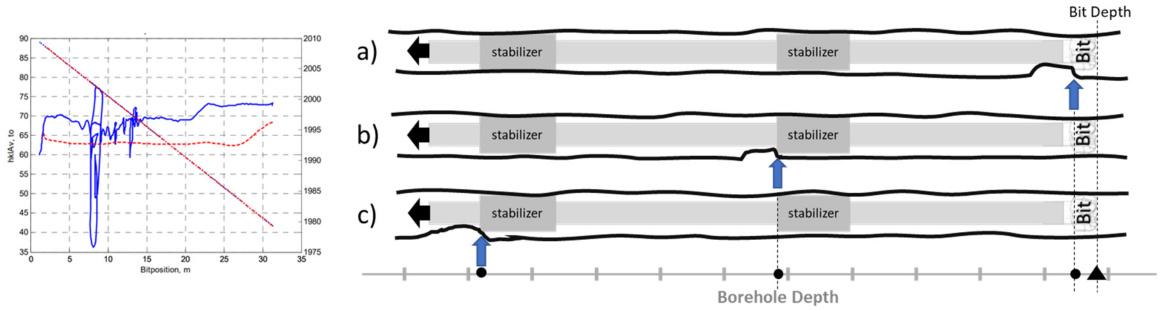

FIG. 2. The average HL versus bit position plot on the left from Freithofnig et al. exhibits an anomalous HL (blue line) associated with a dysfunction. Three example schematics of a drill string tripping out of the hole in the direction of the black arrow to the left demonstrate how dysfunctions at varying depths such as at a) the bit, b) the first stabilizer, or c) the second stabilizer would be measured at the same bit depth reference (denoted by the triangle).

This study builds on the previous method by accounting for the locations on the drill string that are closest to the gauge of the borehole, such as the drill bit, stabilizers, and roller reamers. These components are more likely to get stuck at tight spots or ledges for example. Forward models of the HL values above baseline (i.e. overpull) are compared to real HL measurements. The modeled data has visual similarities to the measured data, suggesting a depth profile of resistance could be generated. This would specifically highlight depths with potential dysfunction but may also give insight into the specific dysfunction type based on characteristics of the depth profile.

HOOK LOAD AND TRIPPING

The HL measurement in a drilling operation is a critical parameter to control and monitor drilling operations. In simple terms, HL measures the total force pulling down on the hook equipment of the drilling rig hoisting system (Figure 3a). The total force on the hook includes the sum of the weight of the drill string in air and any phenomena that tend to modify the weight, such as buoyancy, friction, and the drill bit being in contact with the bottom of the borehole. The hoisting system is used to lower the drill string into the hole (i.e. tripping in), raise the drill string out of the hole (i.e. tripping out), or to control the amount of force applied at the bit (i.e. weight on bit). Tripping out operations are a non-drilling activity and are typically performed when the target drilling depth has been reached, or when drilling performance has decreased to a minimum threshold and a decision has been made to change the drill bit, for example. During tripping, real-time measurements of HL are compared to an expected HL value derived from modelling of the sliding friction for good borehole conditions (Bible et al., 1991, Johanscik et al., 1984, Sheppard et al., 1987, Aadnoy et al., 2010, Cayeux et al., 2012). HL measurements above the theoretical baseline, commonly referred to as overpull, indicate either a poor model (i.e. under estimation of the theoretical HL) or increased resistance due to a wellbore dysfunction. For the purpose of this study, the model for the expected HL will be considered accurate and the high HL values will be considered overpull (Figure 3b).

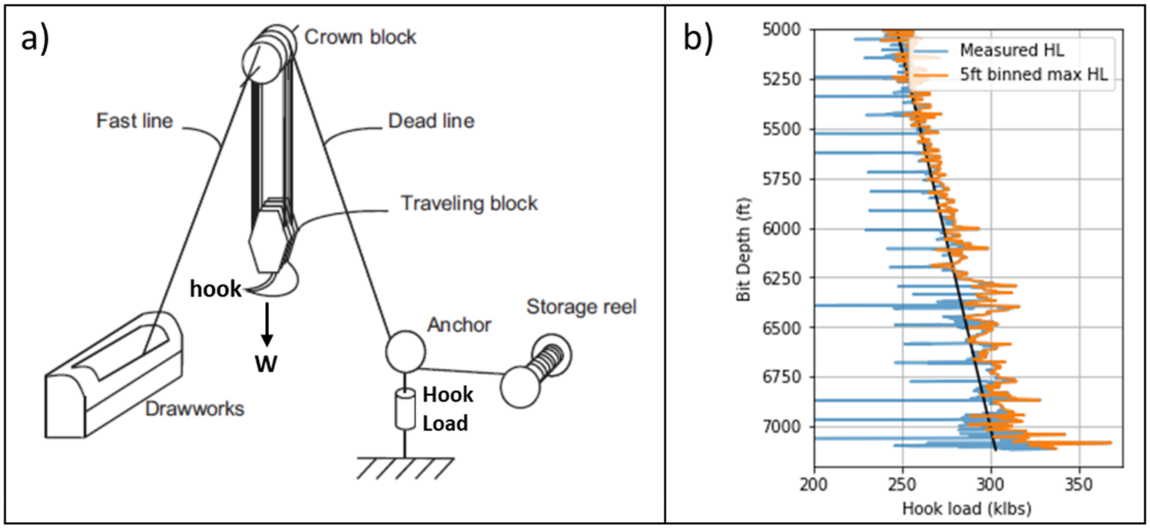

FIG. 3. a) A simplified schematic shows the location of the Hook Load measurement in the hoisting system (modified from Bourgoyne et al., 1986). The weight suspended on the hook (W) is measured and monitored to estimate dynamic and static forces in the borehole including buoyancy, friction, and weight on bit. b) An example HL measurement during tripping operations (blue) as a function of bit depth and the maximum HL value for binned 5ft intervals (orange). The baseline trend (black) is considered to be correct for this example. Overpull is observed primarily in the bit depths between 6250 ft and 7100ft.

OVERPULL MODELLING

The focus of this study is not modelling the expected HL or friction values, but instead modelling the overpull HL values. The overpull is calculated by subtracting the expected HL, H^, from the observed maximum HL measurements with binned depth intervals. Referring to Figure 3b again, the overpull value would be the orange curve minus the black trend curve. By separating the overpull from the HL measurements, a model of resistance due to dysfunctions can be created for various causes of overpull. Taking a signal processing approach, the overpull signal will be considered as the combination of a source signal and a resistance signal. A mathematical representation of the overpull signal (OP) as a function of depth (z) is the convolution of the BHA source signal (S) with the resistance signal (R) in Equation 1.

$$OP(z) = S(z) * R(z) \qquad (1)$$

The source signal is based on the makeup of the BHA, where components of the BHA that are close to hole gauge are considered square waves (e.g. at the bit, stabilizers, or roller reamers). To demonstrate, a source signal is created for a BHA with two stabilizers located roughly around 60ft and 120ft from the drill bit (Figure 4). The stabilizer and bit locations along the BHA are assigned values of 1, while the other sections that are smaller gauge are assigned zero values.

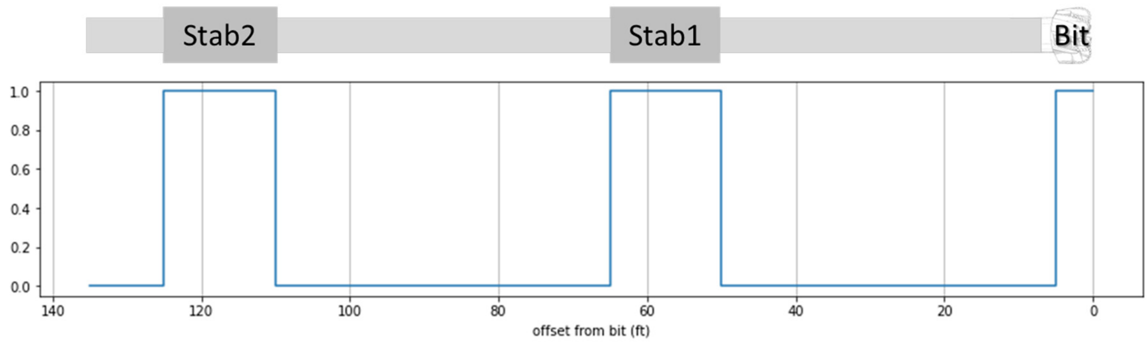

FIG. 4. The BHA source signal is created as sequence of square waves aligned with the components of the BHA that are near the same gauge as the borehole. For this example BHA, there are 2 stabilizers, denoted as Stab1 and Stab2, and the drill bit (denoted in the BHA schematic at the top) used to create the BHA source signal.

A resistance signal is created with a selection of hypothetical resistance signatures along a depth profile of a wellbore that is 3000ft deep (Figure 5). The resistance signatures have varying thickness and edge profiles (i.e. tapered edges versus abrupt edges). The maximum resistance for each signature is the same at 8 klbs. To model the overpull during tripping, the BHA source signal from Figure 4 is convolved with the resistance depth profile starting from the maximum borehole depth. The overpull signal is the combined resistance of the 2 stabilizers and the bit sliding past the resistive zones (Figure 5). Overpull measurements are referenced to borehole depth of the bit, thus explaining the "depth stretching" of the overpull signature compared to the resistance signature. Distinct responses in the overpull signatures are created due to the variations in thickness and edge profile of the hypothetical resistance signatures. Thick resistance zones appear as a lower frequency response with higher overpull due to the combined effect of multiple parts of the BHA (signatures 2,4,7). Thin zones result in a higher frequency appearing response with lower overpull as each component of the BHA passes through the resistive zone separately (signatures 1,3,5,6). The tapered and abrupt edges of the resistance signatures are also translated to the overpull signatures.

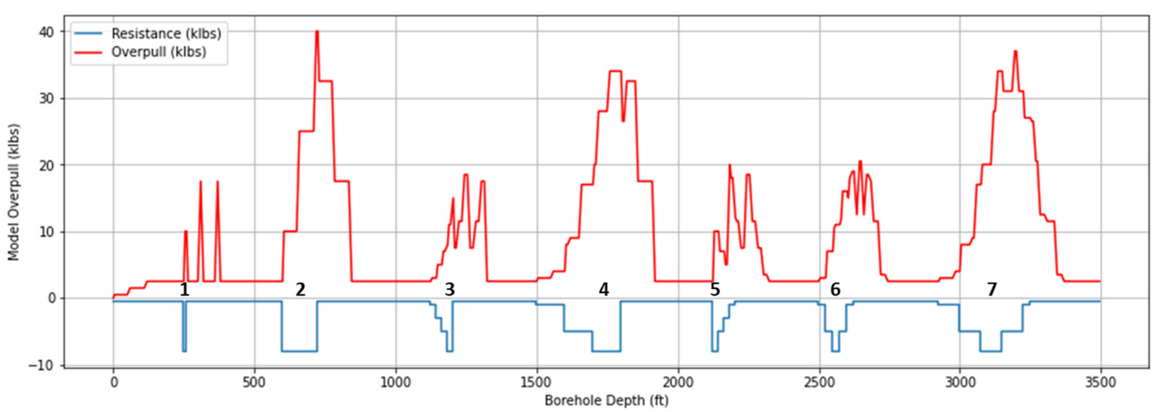

FIG. 5. The synthetic resistance depth profile for a 3000ft borehole has hypothetical resistance signatures to represent constrictions with varying characteristics (blue) plotted here as negative values for visualization purposes. The corresponding overpull (red) from the convolution with the BHA signal shows unique character for each resistance profile.

DISCUSSION

Using the model described above, the overpull measurements are forward modelled as a convolution of the BHA signal and a resistance depth profile. To evaluate the validity of the forward model, real overpull data from a tripping operation is compared to a modelled overpull response. Figure 6 shows the model inputs and modelled overpull. The BHA signal corresponds to the representative BHA for this tripping run. A manual fit of the overpull data was produced by adjusting the resistance profile to create an approximate visual fit to the real overpull measurements. Although there are variations in how well the model fits the data, the results are encouraging as a demonstration of the validity of the forward model.

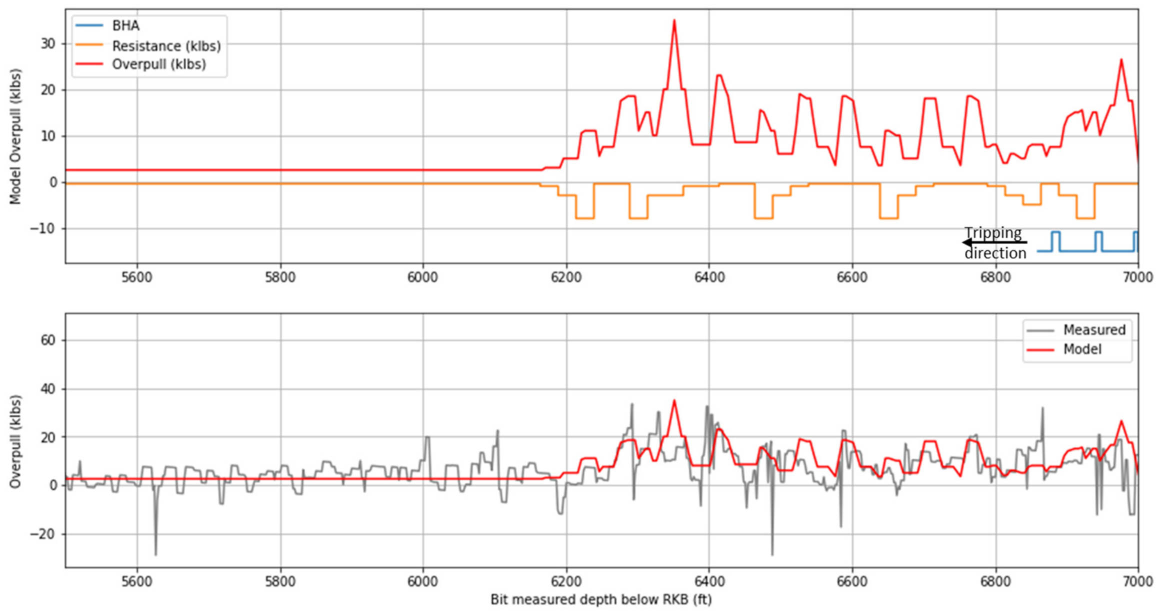

FIG. 6. The model overpull (green) is calculated by convolving the BHA source signal (blue) with the resistance signal (orange) starting from the maximum depth of the borehole. Similar overpull signatures can be observed in the model and a real dataset (red), specifically the overpull between approximately 6300ft and 7150ft.

SUMMARY

The proposed method of forward modelling the overpull during tripping shows encouraging similarities to real data. The ultimate goal of this method is to recover the resistance signal. In order to retrieve the resistance signal, the inverse problem will need to be solved by deconvolving the measured overpull signal using the BHA source signal. The estimated resistance signal will provide a depth reference for borehole dysfunctions and potentially insight into the specific type of dysfunction. This will allow targeted mitigating operations to avoid further complications and potential decreases to the drilling operation efficiency. Future work for this study includes: 1) continued testing of different BHA source signals, 2) deconvolution testing of synthetic overpull data, 3) comparing other real data examples to the forward modelled data, 4) application of the deconvolution method on the real data sets, and 5) comparison to drilling reports, drilling data, and wireline data to confirm borehole dysfunctions and investigate correlation of resistance profiles with types of borehole dysfunctions.

ACKNOWLEDGEMENTS

We thank the sponsors of CREWES for continued support. This work was funded by CREWES industrial sponsors, NSERC (Natural Science and Engineering Research Council of Canada) through the CRSNG 561118-20, and Alberta Innovates through the grant 212200496. We also thank Eavor Technologies for the technical discussions and providing drilling data.

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