Post-job Data Analysis by Python for a Miniature Recorder in Drilling Motors

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Abstract. A vibration recorder has been deployed to capture the dynamics data of drilling motors for their operation and health evaluation. The recorder is usually inserted inside the rotor catcher of a conventional drilling motor in such a way that no extra length is introduced to the planned bottom hole assembly (BHA). The recorder can log data over the full operation cycle of a drilling motor, including vibration during surface activities and downhole operation. A post-job data analyzer was specifically designed based on Python. The analyzer processes the recorded data and generates statistics, time plots, and the various statistical plots such as histograms. These statistics and plots help the operators and maintenance technicians to gain insights into the motor operation and performance. The analyzer can provide adequate information on a drilling motor to asset owners for maintenance and operation optimization without analysis training or qualification from operators.

1. Introduction
Positive displacement motor (PDM) uses drilling fluid, which referred to as drilling mud, or just mud, to generate eccentric motion in a transmission section, which is then transferred to concentric torque and weight to drive drill bits. Drilling motors can be of different configurations of rotor and stator to provide optimal performance for the desired drilling operation. Typically the increase of the number of lobes and length of the power sections can produce higher output power [1].

The main application of a motor is directional drilling. During downhole operation, a drilling motor is typical of two operational modes, sliding (also called building) or rotating (also called drilling straight). Drilling motors are of high dogleg capacity and relatively cheap cost, and therefore, they have been widely used in the drilling industry. The additional torque provided by a downhole drilling motor allows for a more aggressive drill bit design to be selected and achieve a higher Rate of Penetration (ROP) [2].

However, drilling activities are often challenged with inefficiency and delays from original plans. The O&G (oil and gas) industry becomes more concerned with the understanding of drilling inefficiency and identifying factors that reduce drilling performance caused by adverse drilling dynamics, such as shock and vibration. It is well established that adverse dynamics, such as shock and vibration [3], is a major cause of the Bottom Hole Assembly (BHA) tool damages and undermines drilling performance [4]–[6]. Drillstring shock and vibration (S&V) can be categorized into three types: axial, lateral, and torsional [7], and they are destructive to drilling processes.

Downhole drilling dynamics or vibration have, therefore, become a subject of intensive research [8]–[10]. The study has focused on the downhole measurement of drilling vibration, its consequences, and tool and operation optimization processes for mitigation [11], [12]. Nowadays, drilling vibration can be measured by shock and vibration sensors in MWD tools, logging-while-drilling (LWD) tools, rotary

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steerable systems, or specific BHA drilling dynamics measurement tools [4], [13]. Dynamics of drilling motors are always indirectly measured from the sensors located either above or below them even though MWD or LWD tools in drilling motor bottom hole assemblies (BHAs) measure dynamics of drill collars, considerably above the motor, often without sufficient resolution to understand adverse drilling dynamics on the motor and to design remedial actions for the operations.

A low-cost and miniature vibration measurement recorder was developed to meet the needs of providing data to motor maintenance and operation companies. This paper presents the development and specifications of the vibration recorder, followed by the post-job data analysis. One case study is presented to show the downhole drilling vibration of drilling motors captured by the recorder.

2. The Vibration Recorder
The vibration recorder is designed approximately 7-in long and 0.75-in in diameter cylindrically, and capable of being easily installed inside of a modified rotor catcher. The vibration recorder consists of a print wire assembly (PWA) of 3-in long by 0.5-in wide, a tubular mounting chassis, and an AA size battery. The PWA consists of a three-axis vibration accelerometer, a three-axis shock accelerometer, a rotation gyroscope, a temperature sensor, and a timestamp IC besides a digital signal processor (DSP). The PWA has been qualified for downhole environments in terms of temperature ratings and shock conditions. The mounting chassis was designed to fit inside a rotor catcher of a drilling motor, and it can be quickly taken out for services. The lithium battery of AA size was qualified for the temperature profile of drilling applications. Figure 1 shows how the vibration recorder is installed in a rotor catcher.

![Vibration Recorder Installation](image)

Figure 1. A vibration recorder installed in a motor

In Figure 2, on the left-hand side, a block diagram of digital signal processing, the sensors, and data recording within the vibration recorder is shown. The sensor measurements include vibration (amplitude $< 5$ gn) and (amplitude $\geq 5$ gn), rotation speed, temperature, and timestamp. These measurements are filtered and sampled, and then the corresponding parameters are calculated; direct measurements and statistical data are stored to the memory on the PWA for the post-job analysis.

The coordinating system of the measurement sensors is shown on the right-hand side in Figure 2, where $X$ is the axial direction, which is along the path of drill strings, and $Y$ and $Z$ are the lateral directions, which is perpendicular to the direction of drill strings.

Table 1 summarizes the sensors, direct parameter measurements, and statistics, and memory recording of the vibration recorder. Because the recorder is installed on a rotor catcher, which is directly connected to the drill bit through the rotor of a drilling motor, the bit status (bit rotation speed and stalling) can
also be measured. Direct measurements of the sensors include 3-axis shock and vibration, 3-axis rotation speeds, temperatures, and timestamps.

Figure 2. Block diagram of the processing of the sensors and coordinating system

Based on measurements, statistical vibration information is computed at the rate of every 6 minutes for surface data and at the rate of every 10 seconds for downhole data. The statistics information consists of peak axial acceleration (gn), average axial acceleration (gn), and peak lateral acceleration (gn), axial shock counts in the bin from 5–100 gn, axial shock counts in the bin from 100–200 gn, lateral shock counts in the bin from 5–100 gn and shock counts in the bin from 100–200 gn. Based on shock counts, one can compute shock frequency based on the logging frequency of the shock count channel, which can be vital to the understanding of downhole vibration. Based on measurements, statistical rotation speed information consists of minimum rotation speed (rpm), maximum rotation speed (rpm), average rotation speed (rpm), bit stick-slip severity (%), and bit stalling. The stick-slip severity is calculated by equation (1).

\[
\text{stick slip severity} = \frac{v_{\text{max}} - v_{\text{min}}}{2 \times v_{\text{average}}} \times 100\% 
\]

Table 1. The sensors, direct measurements, and statistics and memory recording

| Sensors            | Direct Measurement                      | Statistics and Memory Recording |
|--------------------|----------------------------------------|--------------------------------|
| Data and Time      | Real-time Clock and Calendar           | Not Available (N/A)            |
| Vibration (X, Y, and Z) | Shock and vibration (X, Y, and Z) @ 800 Hz | Peak axial, average axial, and peak lateral, Shock Bins (5–100,100–200 gn), Inclination |
| Rotation (X, Y, and Z) | Rotation speed @ 20 Hz | Minimum rpm, maximum rpm, mean rpm, bit stick-slip severity, and bit stalling |
| Temperature        | Temperature                             | N/A                            |

3. Post-job Data Analyzer

As a part of the post-job analysis, a Python data analyzer is used to process the data and provide a detailed report for users. As Figure 3 shows, the process of the Python data analyzer is demonstrated. Firstly, the libraries of pandas, numpy, and matplotlib are imported. Pandas is the main library for data processing; Numpy is a multidimensional matrix operation library, and Matplotlib is a python plotting library. Then, the data from the recorder is read into the memory. When a data entry is empty, it will be marked as NAN in the Pandas format. The NAN values in the data are processed accordingly. As there are two sampling frequencies used, the time difference between two adjacent rows is obtained to determine the time duration in each operation mode.

Once installed to a motor in a maintenance shop, the vibration recorder starts sampling and recording, and it does not require any initialization or configuration again at rig sides. The recorder does not affect the downhole drilling operation of motors, and no extra or additional work is required from rig crews. The recorder measures, processes, and logs surface and downhole dynamics data continuously. As soon as a drilling motor is back to a maintenance shop, the recorder is removed from the tool. Once the data
is downloaded by using a UI (User Interface) program, a python analyzer can be run to produce a job summary report containing the usage of drilling motors and actual downhole conditions. This report provides essential data for maintenance teams to understand the operating conditions of drilling motors quickly and make the right decision to perform appropriate levels of services and preventative actions accordingly. Moreover, the analyzer can generate more statistics on temperatures, axial vibration, lateral vibration, rotation speed, and stick-slips. The statistics are presented in different viewing formats, such as time plots, histograms, etc.

Start

Import the library of numpy, panda, Matplotlib and pyplot

Read all data

Check the integrity of the data

Y

Fill all value for NULL

N

Time Difference

Correct timestamps

Output time statistics including starting time, ending time and duration

Output lowest and highest temperatures, and temperature plots

Temperature statistics and temperature histogram

Highest vibration, statistics and histogram

Rotation speed, statistics and stick_slip

End

Figure 3. The data processing flowchart of Python data analyzer

4. Case Study
The field case study relates to a well located in Texas, US. In Figure 4, the recorder data captured the overall operation cycle of the drilling motor throughout 31 days from 29th September to 31st October. From temperature and vibration, the downhole drilling time can be easily differentiated from its surface activities.

In Figure 4, the plot (a) shows peak axial shock, mean axial shock, and shock counts in the bins of from 5 gn to 10 gn and from 100 gn to 200 gn. During downhole operation, peak axial shock values were
around 40 gn; during the time when the tool on surface, several high-amplitude axial shock events were observed at around 35 gn, and these may relate to transportation activities or rig-side tool movements. The plot (b) shows peak lateral shock, and shock counts in the bins from 5 gn to 100 gn and from 100 gn to 200 gn. During downhole operation, peak lateral shock values were of 100 gn amplitude with the maximum shock of 180 gn amplitude; on the surface, several high-amplitude lateral shock events were observed at around 70 gn, and these shocks coincided with the high-amplitude axial shock events; therefore, these may also occur due to transportation activities or rig-side movements. For example, on October 17th, a peak lateral shock of 91 gn and a coincided peak axial shock of 31 gn were observed. The plot (c) shows rotation speed and temperature statistics, including maximum, mean, and minimum values. The temperature data has day-and-night patterns when the motor was on the surface. When the drilling motor was tripped into the well, the temperature gradually increased to 50⁰C and then rose to around 56⁰C when drilling to a deeper depth.

5. Analysis by Python Analyzer
By using Python Analyzer, the post-job analysis is further performed. Figure 5 shows all the data channels of the recorder. From top to bottom, the plots are temperatures, peak axial acceleration, peak axial acceleration, average axial acceleration, rotation speed, and stick-slip values.

![Figure 5. Overview of Data in the Recorder in the Time Plot Format](image)

Table 2 presents the statistical information of the run generated by the Python Analyzer. Figures 6, 7, and 8, show the histogram plots of statistical data, including temperature, peak axial acceleration, and peak lateral acceleration.

| Parameters          | Statistical results       | Parameters          | Statistical results       |
|---------------------|----------------------------|---------------------|----------------------------|
| Starting time       | 2016-09-28 10:18:27        | Pk_lateral_max      | 189.27g                    |
| Ending time         | 2016-10-30 06:49:45        | Pk_axial_min        | -38.7805g                  |
| Running time        | 31 days 20 hours 31 minutes 18 seconds | GAxShkCnt_5_100g  | 3037873                    |
| Max. temperature    | 56℃                        | GAxShkCnt_100_200g  | 0                          |
| Lowest temperature  | 0℃                         | GLShkCnt_5_100g     | 20432028                   |
| Pk_axial_max        | 39.4146g                   | GLShkCnt_100_200g   | 25873                      |
6. Conclusions
The vibration recorder is a small battery-powered data-logger device, which can be installed in motor rotors at a maintenance shop. The recorder can log more than tens of days covering shipment, rig-side handling, and downhole operation. Surface data can witness any potential damages caused during surface activities. Besides, the data that the recorder collects have been shown to enable characterizing downhole vibration measurements and statistics, bit rotation speeds, stick-slip and stall occurrences, temperature readings, and timestamps.

A data analyzer has been developed to provide post-job data analysis. These measurements and statistics provide valuable insights into the vibration of drilling motors. One case study was presented, and data from the vibration recorder was presented in different plots and statistical values. These data can help asset owners better understand the working condition of the motor with the installed recorder.

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