Development of a Miniature Recorder for Drilling Motors

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Abstract. A recorder is designed to record the vibration data of the drilling motor for health assessment of the motor to improve the drilling efficiency. It is installed in the rotor catch of the drilling motor without increasing the length of the bottom hole assembly (BHA). The recorder is equipped with two triaxial vibration accelerometers with different ranges, a rate gyroscope, a temperature sensor, and an integrated circuit (IC) for timestamps. The recorder can measure and record the vibration data of the entire operation cycle of the ground transportation, rig-side handling and downhole operations of the motor. Vibration recorder does not require any configuration or intervention at rig sides so that it can be easily deployed to motor operations. The Python-based data analysis software was developed for the miniature vibration recorder. The analyzer can make statistics on the recorded data and display it with time plots and histogram. The vibration recorders provided adequate information of a drilling motor to maintenance shops and operator. These statistical data and charts can help users understand transportation, rig-side handling and downhole drilling.

1. Introduction
A drilling motor is a progressive cavity positive displacement pump installed in the drilling strings to provide torque to the drill bit. The drilling motor converts the energy of the drilling fluid into torque that drives the drill bit. The number of lobes and the length of the power section can be adjusted to optimize the performance of the motor to accommodate different drilling environments [1].

The main application of a motor is directional drilling. In drilling applications, drilling motors have been widely used because of their relatively cheap cost and high dogleg capacity. Due to the additional torque provided by the drilling motor, a sharper bit can be selected for a higher rate of penetration (ROP) [2]. However, actual drilling operations are often faced with inefficiency and planning delays. As the oil and gas industry's awareness of drilling efficiency improves, adverse drilling vibration is one of the most important reasons to reduce drilling efficiency. It is a well-known fact that harsh drilling conditions such as shock and vibration [3] are the main reasons that lead to the Bottom Hole Assembly (BHA) tool damages and reduce drilling quality [4], [5]. Drillstring shock and vibration (S&V) consist of three types: axial, lateral, and torsional [6], and they affect the quality and efficiency of drilling significantly.

Therefore, downhole drilling dynamics or vibration have become a research topic [7]–[9] in drilling domain. This study has focused on downhole measurement and impact of drilling vibration, and optimization of tools and operations to mitigate vibration hazards [10], [11]. Generally, drilling vibration is measured with sensors installed in MWD tools, logging-while-drilling (LWD) tools, rotary steerable systems, or specific BHA drilling dynamics measurement tools [4], [12]. This development work aims to study the effect of adverse vibration on the drilling motor. Because the drilling motor is a downhole non-intelligent tool, it does not contain measuring elements. The drilling motor's sensors, which are
usually installed in other tools above or below the motor, are measured the vibration of the motor indirectly. This type of measurement usually neither capture the vibration of the motor accurately nor provide operating data to understand adverse vibration on the motor.

A low-cost and miniature vibration measurement recorder was developed to measure and log the vibration of the drilling motor accurately, at the same time, the vibration recorder meets the needs of drilling motor maintenance and operation companies to obtain motor operation data. This paper introduces the primary information of the vibration recorder, including the shape and structure, sensor composition, working mode, and the post-job data analysis. One case study shows the transportation process, and downhole drilling vibration collected by the recorder and formulate an operation report.

2. The Vibration Recorder

The vibration recorder is a cylindrical device with a diameter of 1.9 cm and a height of 18 cm. It can be installed inside of a modified rotor catcher. The overall structure of the vibration recorder includes an AA size lithium battery, a tubular mounting chassis, and a print wire assembly(PWA) of 7.6cm long by 1.3cm wide. The PWA uses a digital signal processor (DSP) as the main control chip, the sensor includes two triaxial vibration accelerometers, a rate gyroscope, a timestamp IC and a temperature sensor. Both the accelerometer and the gyroscope on the vibration recorder are MEMS sensors, which have a wide operating temperature range and strong impact resistance. Therefore, it can work at a high temperature and high vibration environment underground. The lithium battery is still quite reliable, according to industry statistics, when the temperature is slightly higher than 150℃. The mounting chassis was designed according to the shape of the internal space of the rotor catcher so that it can be installed and removed. Figure 1 shows the installation location of the vibration recorder in the rotor catcher.

Figure 1. Schematic diagram of the recorder installed inside a motor

Figure 2 shows a block diagram of the sensor signal flow. The sensor measurements include vibration, temperature, timestamp, and rotation speed. Direct measurements and statistical data are stored in the memory of PWA and can be downloaded directly with the supporting software. The flash memory is about 8MB, and it can save about 30 days of data without filling the flash memory, including 200 hours of drilling data.

The right side of Figure 2 shows the coordinated system of sensors, where X is along the axial direction, the path of drill strings. The Y and Z are perpendicular to the direction of drill strings, which are the lateral directions. The lateral component is the vector sum of the Y-axis and Z-axis.
Sensors

| Vibration Acceleration |
|------------------------|
| X, Y, Z, Axial and lateral |
| Rate Gyro |
| X, Y and Z |
| Temperature |
| Timestamp |

Digital Signal Processing

| Multiple-channel sampling and filtering |
|----------------------------------------|
| ADC and scaling |
| Calculate Statistics |

Data Storage

| in on-board memory |

Figure 2. Block diagram of sensor signal processing and coordination system

Table 1 summarizes the sampling frequency of the sensor, direct measurement values and statistical methods. The direct measurement values of the sensor include three-axis acceleration, rotation speed, temperature and time. The recorder is installed in the rotor catcher, which is connected to the drill bit directly, the rotation speed can describe the bit status.

The working time of the vibration recorder depends significantly on the battery capacity, so the recorder has two working modes to extend the working time. In surface mode, the vibration data is statistically recorded every 6 minutes. In drilling mode, it is recorded every 10 seconds. The statistics consist of average acceleration (gn), peak acceleration (gn), shock counts in the bins of 5–100 gn and 100–200 gn.

The principle of the vibration counting function is that when the vibration amplitude exceeds the threshold, the maximum value in the data after this time is taken as the peak value of vibration. Under normal circumstances, the pulse of downhole vibration is 1-2ms, and the 16 points after the threshold are exceeded. In the window, the sampling frequency of acceleration is 800Hz, and the period of 16 points is 20ms. The window can completely capture a downhole vibration. As shown in Figure 3, the 16 points starting from the point exceeding the threshold, the highest point data is a vibration peak. If the peak value of vibration is less than 100gn, the counter of 5-100gn is increased by one; if the peak value is higher than 100gn, the counter of 100-200gn is increased by one.

Table 1. Data introduction

| Sensors | Direct Measurement | Statistics and Memory Recording |
|---------|-------------------|---------------------------------|
| Data and Time | Real-time Clock and Calendar | N/A |
| Vibration (X, Y, and Z) | Shock and vibration (X, Y, and Z) @ 800 Hz | Peak axial vibration, average axial vibration, and Lateral peak vibration, Shock Bin Qty (5–100 g, 100–200 g), Inclination |
| Rotation (X, Y, and Z) | Rotation speed @ 20 Hz | Minimum speed, maximum speed, mean speed, bit stick-slip severity, and bit stalling |
| Temperature | Temperature | N/A |

From the recorder, the statistical rotation speed information includes maximum, minimum, average rotation speed (rpm), bit stick-slip severity (%), and bit stalling. The stick-slip severity can be calculated by the following formula.

\[
stick\ slip\ severity = \frac{v_{\text{max}} - v_{\text{min}}}{2 \times v_{\text{average}}} \times 100\% \tag{1}
\]
3. Post-job Data Analyzer

A data analyzer based on Python performs detailed statistics on the data and provides users with a detailed report. Figure 4 shows the process of the post-job data analyzer.

The recorder has supporting software, which can be initialized with one key when connected to the host computer, and enter the vibration collection state. Then it can be installed to a motor. The recorder does not require additional operations and does not affect the downhole work of the drilling motor. The recorder follows the drilling motor and drills downhole, continuously measuring and processing the vibration data of the drilling motor. When drilling motor is finished and returned to a maintenance workshop, the vibration recorder is removed from rotor catcher. Using the supporting software to download the data, generate operation reports and data files. The vibration recorder performs basic statistics on the data, such as the number of axial and lateral vibrations. This report provides essential information for the motor maintenance team to quickly understand the operating conditions so that they can perform appropriate maintenance measures.

![Flowchart of Data Processing](image)

**Figure 4. The data processing flowchart**

4. Case Study

Figure 5 is a vibration recorder installed on a directional drilling motor for data collection. The recorder data recorded the overall operation of the drilling motor from September 29, 2016, to October 31, 2016, for a total of 31 days. According to the law of temperature and vibration data, it can be seen that there is a considerable difference between surface activity and drilling activity.

In Figure 5, the plot (a) shows axial vibration information, including peak values, mean values, and count statistics in the bins of 5–100 gn and 100–200 gn. During downhole operations, the axial impact is mostly less than 25 gn, with the maximum value is 40 gn; on the surface, individual higher impacts can reach 35 gn.

The plot (b) shows lateral vibration information, including peak values, and count statistics in the bins of 5–100 gn and 100–200 gn. During the drilling operation, the lateral shock peak values are mostly less than 80 gn, with a maximum of 180 gn; on the surface, individual higher impacts can reach 70 gn, and these events occur almost simultaneously with high-level axial shock events; it may be caused by transportation activities or rig-side movements. For example, on October 17, both axial and lateral impacts were observed, which may be transported or on-site handling.
The plot (c) shows temperature and rotation speed information. When the motor was on the surface, the temperature curve showed day-and-night patterns. When the drilling motor started to work, the temperature gradually increased to 50°C, and when drilling deeper, the temperature gradually increased to 56°C. The RPM line started to oscillate, due to the connection during the drilling process, there is a dramatic change in the RPM line.

Table 2 calculated the statistical information of the drilling job and the information is generated by the Python Analyzer. Figures 6, 7, and 8 demonstrated the histograms of peak axial acceleration, temperature, and peak lateral acceleration, respectively.

Table 2. Statistical results

| Projects                  | Statistical results       |
|---------------------------|--------------------------|
| Starting time             | 2016-09-28 10:18:27      |
| Ending time               | 2016-10-30 06:49:45      |
| Running time              | 31 days 20 hours 31 minutes 18 seconds |
| Maximum temperature       | 56°C                     |
| Lowest temperature        | 0°C                      |
| Pk_axial_max              | 39.4146g                 |
| Pk_axial_min              | -38.7805g                |
| Pk_axial_max              | 189.27g                  |
| GAxShkCnt_5_100g          | 3037873                  |
| GAxShkCnt_100_200g        | 0                        |
| GLShkCnt_5_100g           | 20432028                 |
| GLShkCnt_100_200g         | 25873                    |
5. Conclusions
The miniature vibration recorder is a low-cost data recording device powered by a lithium battery that can be installed in the motor rotor. The device can record device vibration data for more than 30 days. The data collected by the recorder can show the bit rotation speed, stick-slip and stall occurrences, temperature and timestamps. The recorded vibration data provides a rich database for downhole dynamics.

A data analyzer can automatically analyze the data to form a statistical report. This provides great convenience for the manual analysis of the poor performance of the drilling motor and the failure of the drilling motor. A case is shown, the data of the vibration recorder is displayed in the form of statistical tables and histograms. These data and statistical information can help the motor maintainer understand the working condition of the drilling motor.

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