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Analysis on Drill String Vibration Signal of Stick Slip and Bit Bouncing

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Abstract

In drilling engineering, drill string premature damage are frequently observed, resulting in drilling cost and cycle prolonged. Researches show that, the common phenomenon of drill string vibration is the main cause of premature damage, thus more and more attention is paid to research on drill string vibration. Real time monitor and analysis on drill string vibration has important implications for vibration control, complex prevention, downhole condition prediction and drilling parameter optimization. Cases of vibration signal of stick slip and bit bouncing are collected and analyzed with Fourier transform, and frequency spectrum characteristic of vibration signal is obtained. The results show that, the vibration signal can reflect bottom hole condition of drill string, thus to predict premature damage of drill string and decrease drilling cost.

Key words: Drill string vibration; Stick slip; Bit bouncing; Signal characteristic

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INTRODUCTION

Surrounded by drilling mud in deep wellbore and suffers from tension, stress, bending and torsion, the operation condition of drill string is quite harsh and complex. During drilling process, the working mode of drill string are mainly rotating and sliding, accompanied with various kinds of vibration. The vibration signal consists of three dimensional vibration of drill string, the vibration of bit when penetrating into formation and the vibration caused by friction and torque with wellbore. Different kinds of vibration signal reflect different working condition of drill string, as a rule of thumb, most downhole complex can be analyzed through drill string vibration and so it serves as a method to research on drill string work condition and downhole complex[1-2].

1. VIBRATION REGULARITY OF DRILL STRING SYSTEM

During drilling process, vibration can be categorized as axial, lateral and torsional according to vibration direction. On the surface, axial vibration behaves as bit bouncing, lateral as drill string eccentric and torsional as stick slip[3-4].

1.1 Axial Vibration

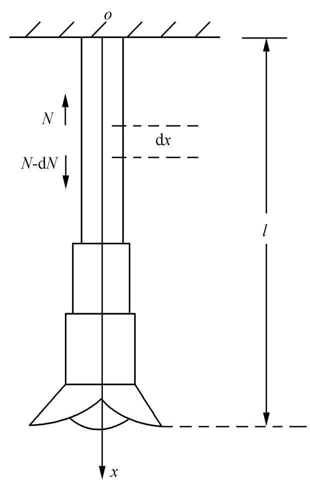

Figure 1
Model of Axial Vibration

During drilling process, axial vibration can results from unevenness of bottom hole, inconstant contact on bottom of roller bit and instable axial back force from formation. This kind of vibration exists during the whole drilling operation, with model shown in Figure 1 and analyzing equations followed.

$$\rho A(x)\,\mathrm{d}x\,\frac{\partial^2 y}{\partial t^2} = \frac{\partial N}{\partial x}\,\mathrm{d}x + \rho A(x)\,\mathrm{d}x \tag{1}$$

$$N = EA(x)\frac{\partial y}{\partial x} \tag{2}$$

From Equations (1) and (2):

$$\frac{\partial^2 y}{\partial t^2} = \frac{E}{\rho}\frac{\partial^2 y}{\partial x^2} + g \qquad y_{tt} = a^2 y_{xx} + g \tag{3}$$

Where: $a = \sqrt{E/\rho}$, is the velocity of compressional wave in drill string, m/s.

Equation (3) is the differential equation of drill string in axial direction[5].

1.2 Lateral Vibration

Lateral vibration, namely "strings" shaking[6], is a main behavior of drill string and affects its operation significantly, as shown in Figure 2. During the drilling process, downhole whirling of drill string and axial alternating force and displacement of drill bit are main factors of lateral vibration, which is affect by the wellbore quality and BHA type to much extent.

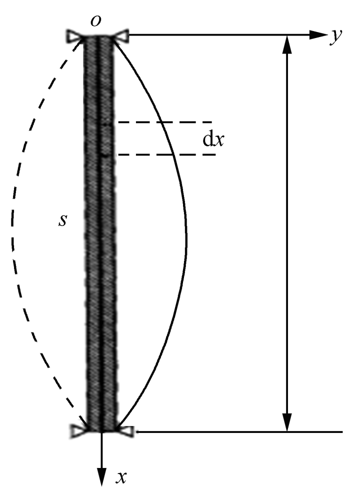

Figure 2
Model of Lateral Vibration

The characteristic of lateral vibration under axial load is summarized as following equation[7]:

$$\frac{\partial^2}{\partial x^2}\left[\left(EI\frac{\partial^2 y}{\partial x^2}\right) - (S + S_0 \sin\theta_t)y\right] + \rho A\frac{\partial^2 y}{\partial t^2} = 0 \tag{4}$$

1.3 Torsional Vibration

Torsional vibration is another important behavior of downhole drill string, which is manly induced by the change of RPM when drill bit penetrates into new formation. Especially when drilling into low ROP formation such as shale, torsional vibration became more obvious and the friction between drill string and wellbore is enforced, resulting in the so called stick slip[8], as shown in the following figure.

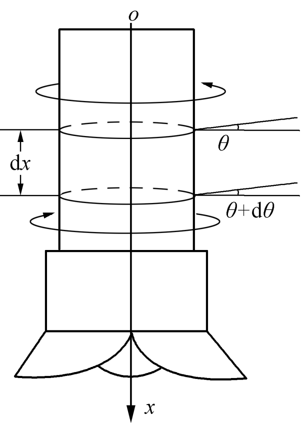

Figure 3
Model of Torsional Vibration

2. SAMPLING SYSTEM OF DRILL STRING VIBRATION

Vibration of drill string is a complicated behavior, and vibration sampling is the fundamental and most important part of its analysis. The quality of sampling determines whether it can reflect the working condition of drill string.

2.1 Acquisition Device

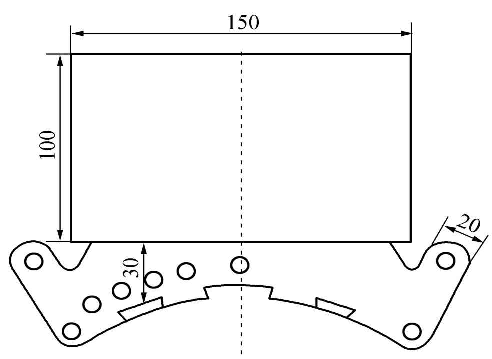

Figure 4
Design of Acquisition Device

In-field application is carried out with above device, results shows that this wireless sensor works functionally and vibration signals can be sampled and transported as long as 150 m, whether on mechanical drilling rig or electric. The vibration sample is wirelessly transmitted and received by the PC, which is connected with comprehensive logging unit, and further analyzed via the processing software together with logging data. In field application shows that the hardware of the vibration sampling system can meet the requirement of signal sampling as designed.

2.2 Design of Software

Acceleration and other vibration data can be retrieved after Fourier transform via above data processing software, and in field application has proved its accuracy, reliability and stability.

3. ANALYSIS ON VIBRATION SIGNAL OF STICK SLIP

During the application of well XC26, more than 500 samples of slight stick slip at 9:45 AM September 25th were analyzed with following drilling parameters: 3,466.51 m MD, WOB 96 - 100 KN, RPM 71 - 76 rpm, Torque 5.7 - 12.3 KN·m.

The relationship between three dimensional acceleration and drilling parameters were analyzed based time domain analysis (Figure 5). Conclusion comes to that, three dimensional acceleration fluctuated significantly with the change of WOB, RPM and torque, especially the torsional vibration which is significantly affected even with slight stick slip.

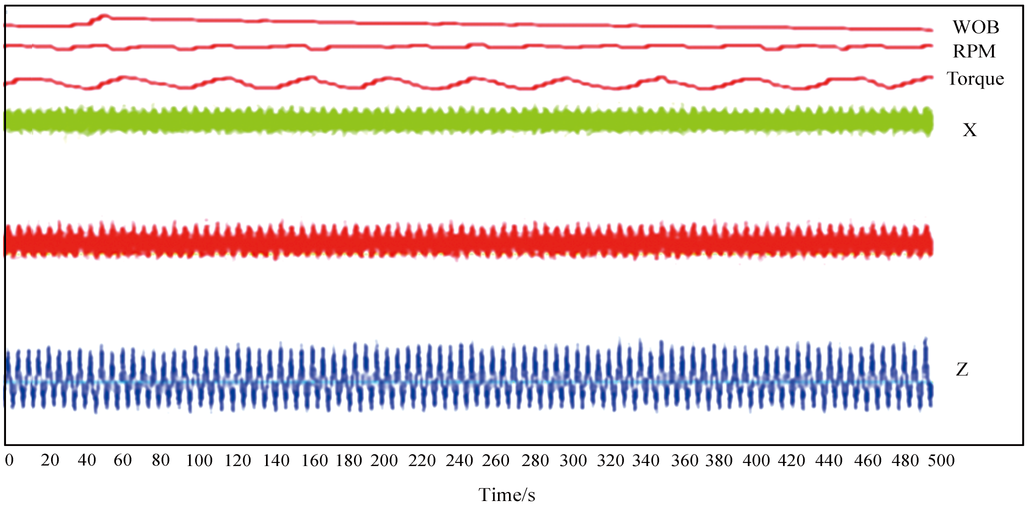

Figure 5
Time Domain Analysis on Vibration Signal of Stick Slip in Well XC26

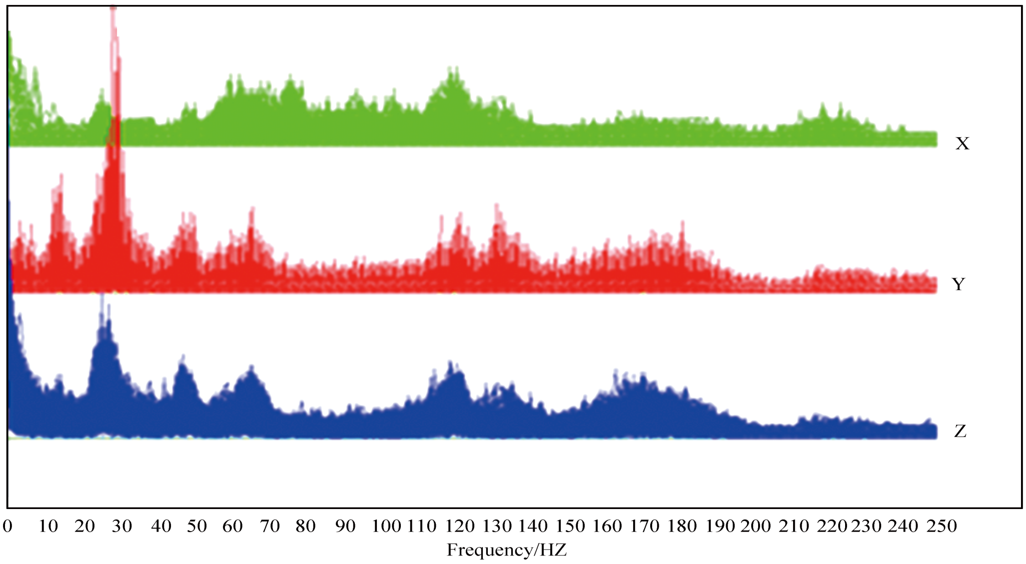

Figure 6
Frequency Spectrum Analysis on Vibration Signal of Stick Slip in Well XC26

Conclusion from frequency spectrum analysis (Figure 6) comes to that: Axial vibration is most susceptible at frequency of 0 - 10 Hz and 60 - 130 Hz while lateral vibration at low frequency and 120 - 180 Hz and torsional vibration at low frequency, 110 - 140 Hz and 160 - 190 Hz. Stick slip vibration is also analyzed in well XC26 with the following samples: 9:56 AM - 10:04 AM October 5th, 3,628 m MD, sandstone; 02:37 AM - 02:45 AM October 15th, 3,817 m MD, conglomerate; 9:35 AM - 9:42 AM September 25th, 3,466 m MD, shale, and the conclusion comes to amplified amplitude of torsional vibration at low frequency with stick slip.

4. ANALYSIS ON VIBRATION SIGNAL OF BIT BOUNCING

At 12:00 AM September 14th, the phenomenon of bit bouncing is observed obviously and frequently at the depth of 2,937.2 m MD, accompanied with mass of falling cutting. With WOB 97 - 106 KN, RPM 107 - 112 rpm and torque 9.7 - 17 KN·m, vibration in three dimensions is obviously amplified, especially axial vibration at the frequency of 0 - 30 Hz, and drill bit is verified to be damaged after POOH. Vibration signal under that condition is sampled more than 500 times for further analysis.

As shown in Figure 7, acceleration in three dimensions fluctuates significantly with different features. Axial vibration shows obvious un-uniformity while lateral and torsional vibration is almost uniform with little exception of lateral vibration. Drilling parameters changed to large extend when bit bouncing occurred, including WOB, RPM and torque, especially WOB which goes up and down irregularly. Analysis on vibration shows that vibration in three dimensions fluctuated significantly and irregularly, extremely in axial.

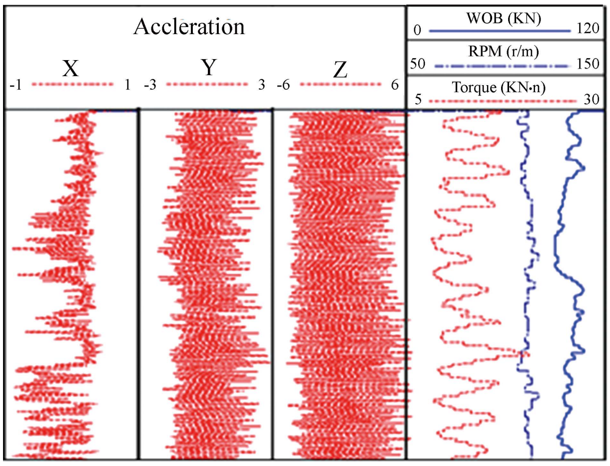

Figure 7
Mean Vibration and Drilling Parameters Change With Bit Bouncing in Well XC26

Frequency domain analysis is shown in Figure 8, conclusion comes to that the frequency of three dimensions vibration covers a large range extend of 50 - 250 Hz with the exception of concentration at low frequency, indicating the irregularity of vibration signal and amplification of amplitude at low frequency.

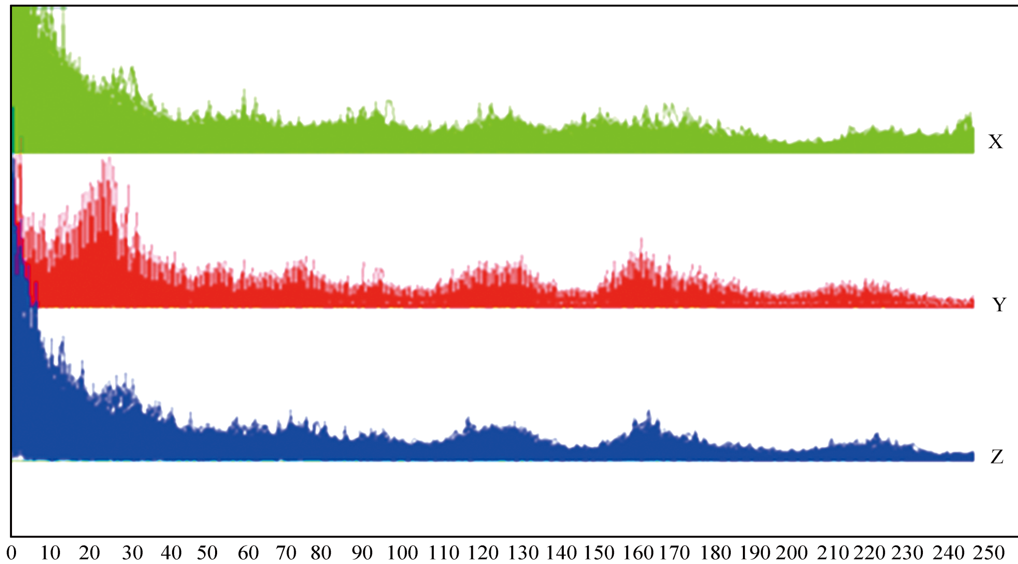

Figure 8
Vibration Frequency Distribution With Bit Bouncing in Well XC26

Conclusions from above analysis come to that, recognition on downhole complex through time domain vibration is not easy for the affection of drilling parameters, so more attention is paid to frequency domain. As analyzed in above well XC26, the amplitude of 1 - 10 Hz stick slip vibration overrides any other frequency, while the amplitude of 0 - 50 Hz three dimensional bit bouncing vibration is also distinguished from other frequencies, as shown in the following table.

Table 1
Stick Slip Vibration Analysis on Well XC26

Operation	Vibration	Amplitude 0 - 10 Hz	Average amplitude	Times
	Axial	0.015	0.017	0.88
Normal drilling	Lateral	0.055	0.050	1.10
	Torsional	0.059	0.042	1.40
	Axial	0.011	0.014	0.79
Stick slip	Lateral	0.074	0.048	1.54
	Torsional	0.243	0.051	4.76

From analysis in Table 1, the amplitude of 0 - 10 Hz torsional vibration signal is 4.76 times of the average and 1.4 times of normal drilling, and thus stick slip condition can be recognized from the 0 - 10 Hz torsional vibration signal.

Table 2
Bit Bouncing Data Analysis on Well XC26

Operation	Vibration	Distribution		
		0 - 50 Hz	50 - 100 Hz	100 - 200 Hz
	Axial	17.04%	29.83%	38.19%
Normal drilling	Lateral	33.06%	22.54%	33.11%
	Torsional	27.59%	24.32%	36.50%
	Axial	39.61%	20.90%	29.16%
Bit bouncing	Lateral	37.54%	19.17%	34.62%
	Torsional	50.49%	18.06%	25.49%

As we can see from Table 2, axial and torsional vibration signal between 0 - 50 Hz is increased obviously while lateral vibration barely changed, thus bit bouncing can be predicted from the change of axial and torsional vibration between the frequencies of 0 - 50 Hz.

CONCLUSION

(a) During the process of drilling, downhole vibration suffers from different factors and reflects different operation conditions. Special vibration signal monitored on surface can reflect different kinds of downhole vibration, real time monitor and analysis on this vibration signal can predict downhole tool work condition at the very moment and prevent downhole complex caused by premature damage of drill string.

(b) By study of vibration signal of stick slip and bit bouncing, conclusions come to high amplitude of low frequency torsional vibration with stick slip and high amplitude of low frequency of axial and torsional vibration with bit bouncing. Operation condition of downhole tools such as stick slip and bit bouncing can be predicted from this different characteristic of vibration signal.

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