MEASUREMENT OF VIBRATION DISPLACEMENT IN NMR LOGGING WHILE DRILLING

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Abstract − The random vibration of the drill collar results in the additional attenuation to the NMR LWD signals, which will bring additional error in the process of T2 spectrum inversion. The determination of the displacement will help to recuperate the signals. This paper studied the property of the drill collar and proposed a scheme to determine the random vibration displacement which used two tri-axis vibration accelerometers and a two axis magnetometer. The simulation results and the shaking table test demonstrate that this scheme is effective and can be implemented in the instrument.

Keywords: Measurement, Random vibration, Displacement, NMR LWD

1. INTRODUCTION

NMR is one of the most useful non-destructive techniques of material analysis since it has been invented in 1946. It was successfully used for well logging when the inside-out permanent magnet version is first proposed in 1980 [1-3], and a large number of the NMR well logging applications illustrated that it not only improved the determination of the porosity and fractional fluid saturation of the formations, but provides a systematic estimate of permeability also. So it is one of the routine methods for well logging in petrophysical industry nowadays.

The idea of logging while drilling (LWD) is to put the logging instrument in the drill collar, therefore the measurement is done while the drilling system is working, and consequently the information of the formation is obtained in real time. This conception is almost aroused together with wireline logging, which is only used to measure the well those have finished. However, it is until about 2000's the practical LWD instruments have been commercially used because the restriction of the electric technology.

Compared with wireline logging, LWD has the obvious advantage: it can provide the information in real time, therefore helps petrophysicists, geologists and drillers achieve optimal wellbore placement within a reservoir, resulting in reducing the drilling cost significantly. The other advantage is it can measure the high dip well even within the horizontal well, where it is almost impossible for the wireline logging instruments. So the LWD instruments is replacing the conventional wireline logging instruments more and more, especially in the new well exploring.

The LWD instruments must work under the temperature up to 150 Celsius degree, and the pressure up to 20000 psi, which brings the great challenge to the electronic technology, in addition, the most difficulty to study the instruments, is the influence of the vibration of the drill collar when the drill system is working. As we know that the NMR measurement is not instantaneous, it needs continuous excites and detects the echo signals according to the CPMG series. When it happens in NMR LWD, the measured resonance region will change, and bring the additional attenuation to the echo signals.

The general procession method is to monitor the vibration acceleration, and give up the measurement results when the acceleration is too large. Therefor this method is just the expedient because there is not the suite scheme to measure the displacement of the drill collar precisely.

The harsh environment in the well makes the general displacement sensor is not suitable. Although there are some type of vibration sensor can be used in the well, but when we measure the displacement by the acceleration, the first problem is how to estimate the initial displacement and the initial velocity of the object. By the reason of the collar's vibration is restricted in the range of the well and the random property of the vibration, so the average displacement is zero, under this condition, our study proposed a solution to estimate the initial displacement and the initial velocity, then the displacement may be obtained.

Another problem to measure the displacement is the rotation of the drill collar when it is working. It makes the direction of the accelerometers will change accordingly, to determine the absolute acceleration of the displacement, it is necessary to measure the rotation velocity of the drill collar and find the relationship of the local coordinate system and the fixed coordinate system. The method in this scheme used a two axis magnetometer which is installed on the instrument to measure the geomagnetisms in the well, and then a relationship of the local coordinate and the fixed coordinate was created.

2. ERECTION SCHEME OF THE SENSORS AND THE MEASURE PRINCIPLE

2.1. The assembly of the sensors and the drill collar

As showing in Fig. 1, the drill collar is a cylindrical steel structure, and its cross section is a circular ring, and the hole in the centre of it was used for mud flowing. The scheme proposed in this paper include two tri-axis vibration

accelerometers *A* and *B* mounted in the collar symmetrically, their sensitive axis's direction is depicted in the figure, marked as *Ax, A$_y$, A$_z$, B$_x$, B$_y$* and *B$_z$*. Then the local coordinate system o-xyz is created as shown in the figure. Meanwhile a two axis magnetometer *M* mounted in the collar also, the magnetometer's sensitive axis is marker as *Mx* and *My*. Finally a fixed coordinate system *o'-x'y'z'* is created simultaneously, which the *plane x'y'* is the cross section of the drill collar, and the *x'* axis points to east of the geomagnetism, *y'* points to north of the geomagnetism, *z'* was determined by right-hand rule and point to the axis of the drill collar.
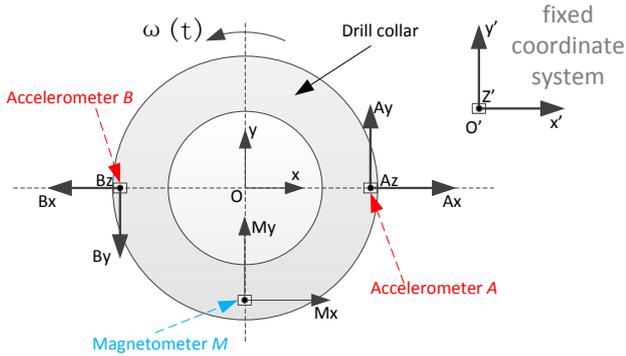

Fig. 1 Assembly drawing of sensors and collar

2.2. Acceleration under fixed coordinate system

With the assemble of the vibration sensors, then in the local coordinate system the longitudinal, lateral and torsional vibration acceleration of the drill collar can be described as

$$\begin{cases} a_x(t)=(A_x(t)-B_x(t))/2 \\ a_y(t)=(A_y(t)-B_y(t))/2 \\ a_z(t)=(A_z(t)+B_z(t))/2 \\ a_T(t)=(A_y+B_y)/2 \end{cases} \tag{1}$$

At same time, an angle between axis *x* and axis *x'* was determined

$$\phi(t) = \arctan(M_y(t)/M_x(t)) \tag{2}$$

Then through the relation of the local coordinate system and the fixed coordinate system, lateral acceleration can be transfer to fixed coordinate system

$$\begin{cases} \begin{bmatrix} a_{x'}(t) \\ a_{y'}(t) \end{bmatrix} = \begin{bmatrix} \cos(\phi(t)) & -\sin(\phi(t)) \\ \sin(\phi(t)) & \cos(\phi(t)) \end{bmatrix} \begin{bmatrix} a_x(t) \\ a_y(t) \end{bmatrix} \\ a_{z'}(t)=a_z(t) \end{cases} \tag{3}$$

2.3. Displacement calculation

After the acceleration is measured, an integral operation of the acceleration can obtain the displacement; take $a_{x'}$ for example, first to transfer it with discrete Fourier transform

$$a_{x'}(k) = DFT(a_{x'n}) = \sum_{n=0}^{N-1} a_{x'n} e^{-(j\frac{2\pi}{N})nk}, \tag{4}$$

$$(n, k = 0, 1, 2, \cdots, (N-1))$$

Where *n* represent discrete point of the acceleration which was obtained at time t_n, *k* represent the discrete point after the transform, and N is the coefficient of the Fourier transform.

After rearrangement of $a_{x'}(k)$, it can be wrote as

$$a_{x'}(k)=((a_{x0},jb_{x0}),(a_{x1},jb_{x1}),\cdots,(a_{x(N-1)},jb_{x(N-1)})) \tag{5}$$

Then in frequency domain, the amplitude, the frequency, and the phase can be calculate

$$\begin{cases} A_k=\sqrt{a_k^2+b_k^2} \\ \omega_k=2\pi\dfrac{k}{T} \\ \varphi_k=\arctan\dfrac{b_k}{a_k} \end{cases}, (k = 0, 1, 2, \cdots, (N-1)) \tag{7}$$

Finally the acceleration $a_{x'}$ can be wrote as a sum of series of simple harmonic vibrations

$$a_{x'}= \sum_{k=0}^{N-1} A_k \cos(\omega_k t+\varphi_k) \tag{8}$$

After two times integral operation of $a_{x'}$ represented by (8), the displacement is obtained

$$d_{x'}(t)= \sum_{k=0}^{N-1} A_{dk}\left(\cos\omega_k t+\varphi_{dk}\right)+C_1 t+C_2 \tag{9}$$

Where

$$\begin{cases} A_{dk}=\dfrac{A_k}{\omega_k^2} \\ \varphi_{dk}=\varphi_k-\pi \end{cases} \tag{10}$$

Was determined by (7), and the constant C_1 and C_2 in (9) are the initial velocity and the initial displacement of the object respectively.

Because of the constant C1 and C2, the displacement determined by (9) will fluctuate about a line. It was showed in Figure 2. And the line is determined by:
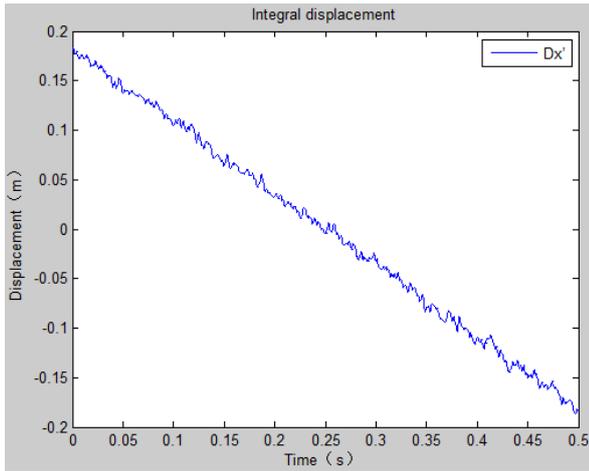
$$L=C1\times t+C2 \tag{11}$$

Fig. 2 The result of two times integral of the acceleration

Here we proposed an algorithm to evaluate the line, that is we fit the displacement with a line, and then let the revised displacement is:

$$D_{x},(t) = \sum_{k=0}^{N-1} A_{dk}\left(\cos\omega_k t + \varphi_{d_k}\right) - P_1 t - P_2 \qquad (12)$$

Where the $D_{x},(t)$ is the revised displacement of the random vibration, $P1$ and $P2$ is the coefficients of the fitted line.

Actually, because the measure error exists, the $C1$ and $C2$ will change with time t, so an improved algorithm is to fit the displacement with a higher order polynomial, generally 5 orders is needed.

3. NUMERICAL SIMULATION

To test the effective of the algorithm above, a set of random vibration is constructed, and the displacement is calculated.

The constructed acceleration, the frequency spectral of the acceleration, the comparison of the real and the calculated displacement are shown in Fig. 3 to Fig. 5.

To illustrate the effect of the measuring error, a random noise has added to the signals which is range from 0.1% to 0.5% of the measured value, and the analysis result can be found in Table 1.
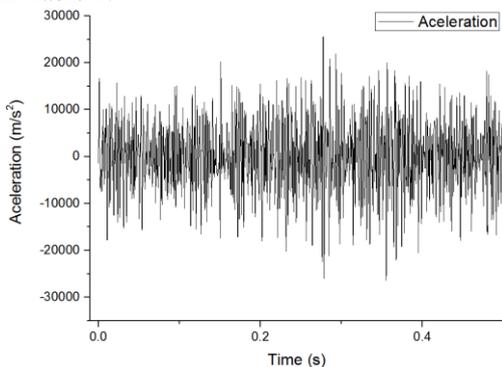

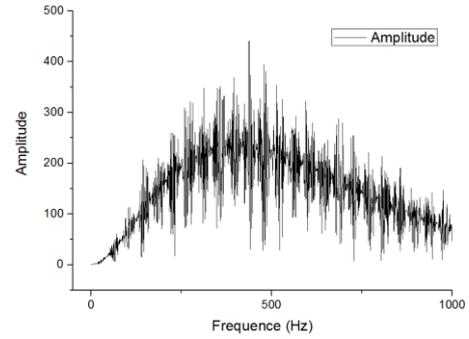Fig. 3 The constructed acceleration

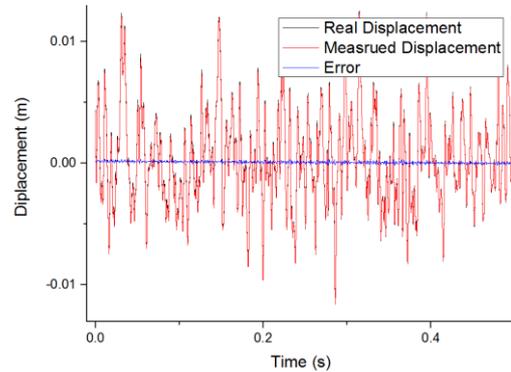Fig. 4 Frequency Spectral of the constructed acceleration

Fig. 5 Comparison of the real and the measured displacement without noise

Table 1. Error analysis

Measuring error	0.1%	0.2%	0.3%	0.4%	0.5%
Average displacement	0.031 (m)	0.031 (m)	0.031 (m)	0.031 (m)	0.031 (m)
Average error	5.5e-4 (m)	7.9e-4 (m)	8.4e-4 (m)	1.1e-3 (m)	2.9e-3 (m)

4. CIRCUIT DESIGN AND SHAKING TABLE TEST

The schematic circuit diagram is shown as Fig. 6, and the PCB is designed. After the circuit is finished, we put it on a shaking table to test it performance. Fig.7 is the power spectrum curve of the random vibration, and Fig. 8 is the displacement calculated with the acceleration that installed on the circuit.
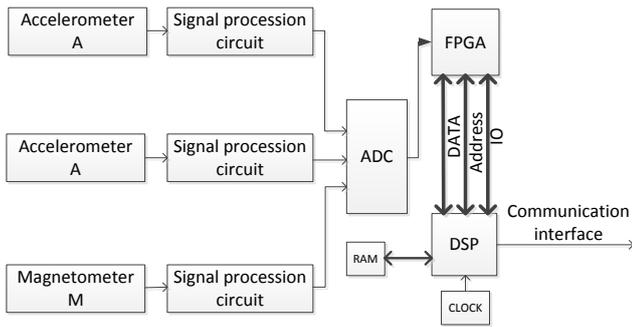
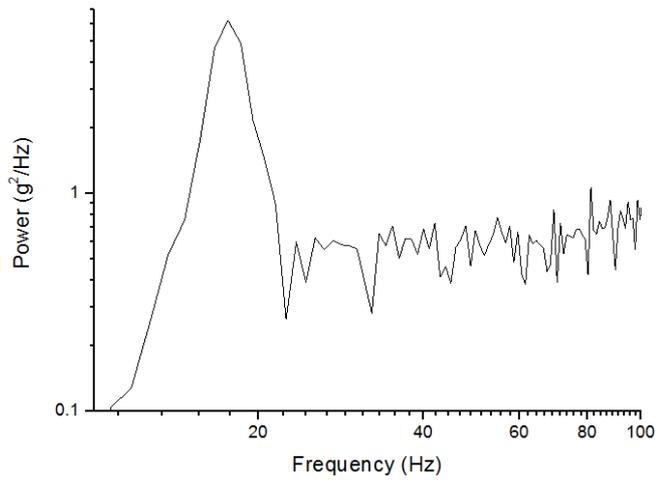Fig. 6 Schematic circuit diagram
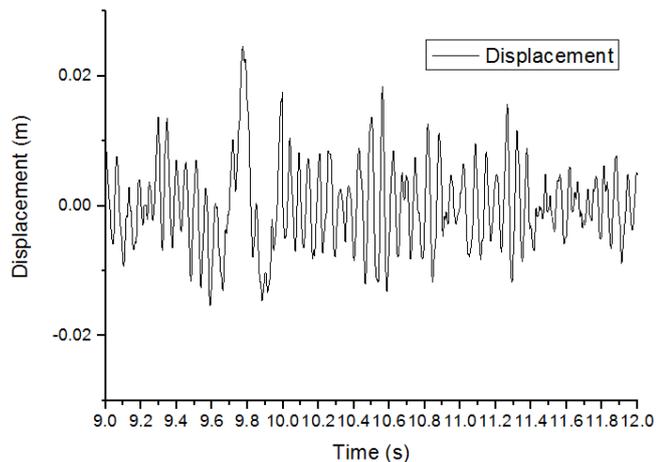

Fig. 7 Power spectrum

Fig. 8 Displacement of the shaking table.

5. CONCLUSIONS

It is necessary to take the vibration displacement into account for NMR LWD instruments, but the hostile environment downhole restricted the selection of the displacement sensors. Through the acceleration to calculate the displacement should meet the problem evaluating the initial displacement and the velocity. Because the average displacement of the vibration is zero, then after the integration with the acceleration, a polynomial fitting algorithm was employed with the result, after the result minus the fitted curve, the approximate displacement was determined. And then it can be used as the displacement of

the drill collar. Finally, the experimental results show that it has a small average error rate and good unbiasedness.

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