Simulation of impact load modulation device based on drill string vibration

Xiaopeng Lu \textsuperscript{1a*}, Hualin Liao \textsuperscript{1b}, Huajian Wang \textsuperscript{1c}, Wenlong Niu \textsuperscript{1d}, Jiansheng Liu \textsuperscript{1e}

\textsuperscript{1}Oil and gas well engineering, China University of Petroleum (East China), Qingdao, 266580, China.

\textsuperscript{*}904537930@qq.com, \textsuperscript{b}liaohualin2003@126.com, \textsuperscript{c}Huajian_WANG@163.com, \textsuperscript{d}453726950@qq.com, \textsuperscript{e}liujiansheng2019@163.com

Abstract—The longitudinal vibration of the bottom drill string is violent and the law is complex during the deep well drilling. The vibration of the drill string brings many adverse effects on the drilling pipe fracture and bit trampoling. Generally speaking, the effective way to control the vibration of drill string is to install damping device in bottom hole. The research group proposes a device that uses the longitudinal vibration energy of the deep well drill string to modulate the impact dynamic load, which converts the vibration energy of the downhole drill string that is not conducive to drilling into the mechanical impact energy that improves the rock breaking capacity of the bit. The impact load modulation device can use the drill string to apply the "mechanical WOB" and the differential pressure between the upper and lower piston to produce the "hydraulic WOB". The simulation results show that the adjustable range of output load is $2 ~ 7T$, and the change of each time is about $2T$. The modulation law of impact load under the influence of longitudinal vibration of drill string and different parameters is analyzed. Through ground experiment and simulation, the damping performance and speed-up effect of the modulation device are compared and analyzed, and the impact load output characteristics of the device are analyzed, which provides a thinking for the design of damping and pressurization tools.

1. Introduction

Drill column vibration is the main factor leading to drill column failure and fatigue damage, which is generally divided into transverse vibration, longitudinal vibration and torsional vibration. Studies have shown that longitudinal vibration has the greatest impact on the life of the drill column, and the resulting longitudinal impact force can be as high as 840 kN\textsuperscript{[1]}; the situation is complicated during the drilling of deep wells, where the longitudinal vibration of the bottom drilling column is intense and accompanied by large and violent fluctuations in the drilling pressure at the bottom of the well. In order to reduce the harm caused by drill string vibration, the conventional method is to use mechanical or hydraulic shock absorber in BHA to buffer the longitudinal vibration of drill string\textsuperscript{[2]}.

How to be able to use the longitudinal vibration of the drill column and transform it into drill bit energy to break the hard formation rocks, so as to obtain a higher mechanical drilling speed, reduce the cost of hard formation drilling and improve the economic efficiency is a breakthrough point of the current research\textsuperscript{[3]}. The research group proposed an impact load modulation device, which can convert the actual drill string vibration energy into rock breaking energy under the existing energy conditions. In this paper, the simulation and experimental test are carried out based on the modulation device\textsuperscript{[4]}, and the data are analyzed and compared and supplemented from the perspectives of theoretical analysis, simulation and ground experiment. Explore the law and waveform characteristics of drill string vibration.
longitudinal vibration, and analyze the output load characteristics of the modulation device to ensure the feasibility of the idea\[5\][6].

2. Analysis of the structure principle of the modulation device

The structure of the impact load modulation device is shown in Figure 1. This modulation device is capable of transforming the downhole drilling column vibration energy, which is not conducive to drilling, into mechanical impact energy to improve the rock breaking ability of the drill bit. Working principle: The "mechanical drilling pressure" is applied by the drill column and the "hydraulic drilling pressure" is generated by the pressure difference between the upper and lower piston. When the drill column vibrates axially, the gap between the pressure-bearing head and the pressure-bearing seat is changed, the continuous jet is modulated into a pulsating jet, the pressure fluctuation is generated in the drill column, and the "hydraulic drilling pressure" is changed into the impact dynamic load, so that the drill bit is under the combined action of dynamic and static loads to break the rock and improve the rock-breaking efficiency\[7\][8].

![Figure 1 Structure schematic of impact load modulation device](image)

3. Analysis of the structure principle of the modulation device

3.1 Model construction for Ansys simulation

The numerical analysis method of liquid-solid coupling is used to establish a simulation and analysis model of the drilling column vibration impact load conversion mechanism and explore the output pressure fluctuation characteristics of the modulation device\[9\].

The mechanical drilling pressure of the drill column is transmitted downward through the outer casing and adjusted by the intermediate spring for buffering, which makes the loading characteristics of the mechanical drilling pressure change from violent fluctuation to relative stability. Another part of hydraulic impact energy acts on the pressure-bearing head to apply hydraulic drilling pressure to the lower bit, and the outer casing generates longitudinal movement due to the vibration of the drill column, which causes the volume of the pressurization chamber to change and the volume of fluid to change, and then the impact force on the piston to change, and finally the hydraulic drilling pressure generates cyclic fluctuations, so that the drill bit is subject to fluctuating impact while rotating to improve the rock-breaking efficiency.
3.2 Simulation analysis of Ansys simulation

The simulation was carried out by fluent in Ansys, setting the state as turbulent and transient, setting the velocity of the moving surface by udf file, choosing the sine function, taking the frequency as 8 Hz and the amplitude as 10 mm. the simulation result output load versus velocity itself is shown in Fig.2, it can be seen that when the input is standard sine velocity, the waveform of the drilling column vibration after modulation device adjustment is also similar to sine 10.

Figure 3 shows the presence of a fast and small random disturbance at the same time as the sinusoidal velocity, and it can be seen that the high-frequency small-amplitude disturbance has a greater impact on the original waveform, so it is important to analyze the high-frequency component of the longitudinal vibration of the drill column, in which the disturbance of 3 times the frequency can reduce the output load, but there will be a certain impact mutation, and the disturbance of 10 times the frequency can increase the fluctuation difference of the output load, and can form a high-frequency, cyclic impact, which is good for the drill to break the rock. One tenth of the amplitude of the velocity perturbation at 10 times the frequency can increase the peak output load by 20%, so it can be seen that the high frequency small amplitude vibration can also help us to improve the rock breaking efficiency. At the same time, the output load waveform reflects that it can still maintain a relatively stable impact load capacity under the combined action, and the average impact capacity can reach 4t action, which meets the impact design requirements.

Figure 2 Ansys simulation simulation of different amplitude and frequency output load graph

Figure 3 Load output diagram of different speed disturbance modulation devices
The results of changing the size of the main flow hole diameter on the output load are shown in the left panel of Figure 5 below, with the increase of the main flow hole diameter, the output load of the modulation device decreases, and is the overall waveform complete downward shift, whenever increasing the diameter of the main flow hole by 5 mm, the overall result decreases by 10 MPa. the effect of different diameters of the side flow hole on the output load is shown in the right panel of Figure 4, it can be seen that the different diameters of the side flow hole do not affect the results to a large extent, the degree of influence of the side flow hole diameter on the output load can be ignored.

4. Field experiments and analysis of results

4.1 Experimental principle and scheme layout
In order to study the actual vibration law of drill string vibration, ground experiments were carried out. Taking the near bit parameter measuring nipple and pressure and acceleration sensor as the measuring instrument, the oscillator is used to generate the longitudinal vibration of the drill string, monitor the inlet and outlet pressure change, acceleration and displacement change of the modulation device, analyze the vibration law of the actual ground experimental drill string, and compare it with the simulation results to improve the reliability of the conclusion.

Experiments are conducted using a double pump truck, which can reach a maximum pump-in fluid speed of 2.0 m³/min. The complete set of experimental equipment and modulation device is arranged as
shown in Figure 5, with pressure sensors designed at the entrance and exit to monitor pressure fluctuations; wireless acceleration sensors are arranged at the tool output to monitor acceleration changes.

The experimental scheme is to increase the displacement of the pump truck pumping in, monitor the fluctuation of pressure and acceleration changes, and explore the vibration characteristics of the drilling column under different displacements. The displacement starts from 0.5 m³/min, and the displacement is gradually increased after the pressure is stabilized, so that the modulation device can work stably at all displacements and ensure the reliability and stability of the monitoring results.

4.2 Analysis of the displacement output characteristics of the modulation device

Fig.6,7 shows the acceleration data measured by the modulation device under different displacement. The acquisition frequency is 640Hz. It can be seen that under the displacement of 0.5m³/min, the maximum acceleration can reach 1g and the period is about 4Hz, in which the peak value of disturbance is 1/3g and the period is about 12Hz; At the displacement of 1.0m³/min, the vibration amplitude is significantly increased to about 4g, the period is almost unchanged, and the disturbance is equally expanded, which is 1/3 of the existing peak value, and the period is 3 times; At the displacement of 1.5m³/min, the peak value reaches about 10g and the period is 4.5Hz, and the disturbance still exists; At the displacement of 1.8m³/min, the peak value reaches about 30g, the period is 5Hz, and the disturbance also exists.

It can be seen that in the actual ground experiment, the output vibration amplitude of the modulating device increased continuously and exponentially with the increasing displacement, which shows that during normal drilling, the amplitude of the drill column vibration is large and the effect is drastic is feasible and necessary to perform vibration analysis on the drill column.
4.3 Analysis of the pressure output characteristics of the modulation device

Figure 8 below shows the output pressure fluctuation of the modulating device at a displacement of 1.0 m³/min. After the fluid passes through the device, there is some pressure loss and the whole waveform shifts downward.

After the modulation device, the peak and frequency of pressure fluctuations do not change much, while the minimum value of pressure is increased, and more importantly, the whole waveform becomes more stable, the sharpness of pressure fluctuations is alleviated, and the overall effective pressure is increased, which realizes the pressure boosting function of the modulation device, so that after the fluid passes through the modulation device, the pressure is enhanced, the waveform is more stable, and the desired effect can be achieved.

5. Conclusion

In the case of longitudinal vibration of the drill column, the modulation device can slow down the intensity of the vibration of the drill column, transform the unstable irregular vibration of the drill column at the bottom of the well into a more stable sinusoidal vibration, and then use the displacement provided by the vibration energy to change the volume of the pressurization chamber, which compresses the fluid and generates variable hydraulic drilling pressure, and cooperate with the mechanical drilling pressure generated by the drill collar and the drill column to break the rock.

The combination of the mechanical drilling pressure generated by the drill collar and the drill column enables the drill bit to break the rock under the combined dynamic and static action, which improves the rock breaking efficiency.

The structural parameters of the modulation device are determined, the simulation scheme is designed, and the sinusoidal velocity loading is preliminarily given. The modulation device can produce about 4 ~ 5T output load impact, which can meet the actual drilling requirements; And continuously improve the structural parameters to determine the influence law of different structural parameters on the output load waveform; Finally, by changing the loading waveform and taking the parameters collected from the ground experiment as a reference, the velocity loading conditions with disturbance are designed. In this case, the modulation device can still stably output the impact load, and the output load of the modulation device can also increase with the increase of vibration.

Ground drilling column vibration experiments were conducted, using pressure sensors to measure the pressure change waveforms before and after the modulation device, and acceleration sensors to measure the output displacement characteristics of the modulation device. The experimental data show that the modulation device can achieve better damping effect under effective operation, and the vibration of the drill column is transformed into a more stable sinusoidal vibration condition after the modulation device.
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