Design and field test of drilling composite impactor

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Abstract. When the PDC drill bit encounters the heterogeneous and highly abrasive formation, it comes up with problems such as serious stick-slip phenomenon, shallow depth of penetration and short service life, and meanwhile, the rapid drilling tool with a single impact function cannot meet the drilling acceleration demand of exploration and development in deeper and more complex formation. Therefore, as a complementary implement of the traditional percussion drilling tools, a efficient drilling composite impactor has been designed, which is capable of applying both the reciprocating torsional impact and the reciprocating axial impact. The impact characteristic parameters of the tool have been obtained through the ground performance test, which also verifying the reliability of the composite impact timing, in addition, the field application has been carried out in Tian17-Xie12 well. And the results show that the key drilling parameters, such as well inclination and azimuth, change stably, thus shortening the sliding drilling time, and compared with adjacent wells, the tool above-mentioned has improved the mechanical drilling rate by 38%.

1. Introduction
With the increase of drilling depth, formation development becomes more complex, rock drillability becomes worse, and the phenomenon of drillstring self-excited vibration, drilling tool twist off, and screw drilling tool hysteresis occurs from time to time, which seriously affects drilling efficiency and brings new challenges to drilling technology.

In recent years, torsional impactors have been developed and applied in China and abroad to suppress the stick-slip vibration of PDC bit [1, 2, 3, 4], and have achieved obvious speed-up effect in the application of some strata, but it cannot effectively solve the problem of low mechanical drilling rate caused by shallow depth of penetration and weak interaction between the bit and rock. Therefore, the axial impactor [5, 6, 7, 8] was developed and applied to further enhance the interaction, thus obtaining a certain speed-up effect. However, it has had a negative influence on the service life of the BHA and the bit, which limits its extension coverage [9, 10, 11].

Based on this, this paper has innovatively developed an efficient composite impactor, which can simultaneously generate two kinds of reciprocating impacts on the PDC bit, thus being easy to cause rock volumetric fracture [12], and then considerably improving the rock breaking efficiency. Furthermore, its regular composite impacts on the bit could effectively suppress axial runouts and stick-slip vibrations, so as to protect the bit and the BHA.
2. Structural design of the composite impactor

2.1. Overall concept design

According to the requirements of rapid drilling in field application, the overall design of the drilling composite impactor which is suitable for 8-1/2″ borehole has been carried out. The tool is intended to provide the driving energy by differential pressure of the nozzle, then to push the axial and torsional hammers alternately to generate the composite impact pulse by exchanging the high and low pressure fluid chamber repeatedly, and the driving torque of the upper string is transmitted to the bit through the casing insert. In addition, mounting a thrust bearing between the axial impact unit and the torsional impact unit can effectively reduce the energy loss of torsional impact.

Combined with the drilling process requirements of the target strata, the tool has been designed with allowable displacement from 0.8m³/min-2m³/min, and its maximum diameter is 178 millimeter, the throttling pressure shall not exceed 3MPa, the impact torque shall not be less than 800N.M, the axial impact force shall not exceed 2t, and the impact frequency shall range from 10 to 25Hz. The overall structure of the drilling composite impactor is shown in Fig.1.

![Figure 1. The overall structure of the drilling composite impactor.](image_url)

The drilling composite impactor is mainly composed of the housing and the body, and the latter includes the main parts such as torsional hammer, axial hammer, reversing hammer, thrust bearing, sand control casing, top base body, nozzle, safety block, bottom base body and so on. During normal drilling, a part of drilling fluid flows through the throttling nozzle, resulting in the differential pressure. The other part of drilling fluid enters the hydraulic chamber inside the tool through the side gap of the sand control casing, and pushes the reversing hammer to start the reciprocating motion of the torsional hammer and the axial hammer, thus transferring both the torque pulse and the axial impact pulse to the bottom base body.

2.2. Working mechanism

The torsional impact unit operates according to the running state transition diagram of internal hydraulic chamber as shown in Fig.2. The torsional hammer and the reversing hammer are driven by the differential pressure to rotate clockwise faster together, and the torsional hammer doesn’t stop running until it has hit the top base body, while the reversing hammer keeps running since the inertia before it impacts the inner edge of the torsional hammer, at this point, the high and low pressure chambers have finished switching as the change of flow channels, and vice versa. Therefore, when the impacter is started, the high and low pressure area of the internal hydraulic chamber will automatically switch back and forth, so as to drive the torsional hammer to hit top base body repeatedly, and then the torsional impact will be transferred to the drill bit, and a torque pulse will be superimposed on the normal drilling torque.
The axial impact unit operates according to the running state transition diagram of internal hydraulic chamber as shown in Fig.3. Due to the reciprocated relative rotation between the torsional hammer and the reversing hammer, the high and low pressure chambers in the axial impact unit are switched back and forth, thus pushing the axial hammer to impact on the upper sub and housing repeatedly, then the axial downward impact will be transmitted to the bit through the bottom base body, and an axial impact pulse will be superimposed on the bit during the normal drilling process.

3. Ground performance test
In order to test the impact characteristics of the composite impactor, a ground performance test platform was designed, as shown in Fig.4. When the mud pump is turned on, the fluid inside the tool drives the hammers to impact on both the top base body and the housing repeatedly, and the impact force and impact torque are transmitted to the corresponding sensor. Finally, the composite impact characteristic curves are obtained by the signal acquisition and processing software.

Figure 2. The running state transition diagram of torsional impact unit.

Figure 3. The running state transition diagram of axial impact unit.

Figure 4. The schematic diagram of the ground performance test platform.
Based on the schematic diagram of the ground performance test platform, the test apparatus has been set up, as shown in Fig.5, nozzles with different diameter have been selected, then the differential pressures under different displacement were recorded by the pressure transmitter, in addition, the signals from both the force sensor and the torque sensor were acquired by the oscilloscope, thus obtaining impact characteristic values by signal processing.

Figure 5. The physical map of the test apparatus.

The relation curves that differential pressure varies with displacement have been obtained, as shown in Fig.6. It can be seen that with the increase of displacement, so does the differential pressure, and it has a quadratic relationship with displacement. Moreover, as the nozzle diameter gets larger, a larger displacement is needed for the differential pressure reaching 3MPa. Taking the nozzle diameter of 12mm as an example, the history of the impact torque, the differential pressure and the impact frequency that varies with displacement was recorded and analyzed, as shown in Fig.7. It can be seen that the impact torque reached 820N.M and the impact frequency reached 13Hz under the differential pressure of 3MPa. Furthermore, the axial impact force of the composite impactor was tested separately, and the test results were shown in Fig.8. It can be seen that the axial impact force increased from 1.1t to 1.9t with the increase of displacement. Therefore, the results above meet the requirements of the tool design.

Figure 6. Curves of the differential pressure.  
Figure 7. Torsional impact characteristic curves.

Figure 8. Curves of the axial impact force.  
Figure 9. Field application photo.
4. Field application
The drilling composite impactor has been applied in well Tian17-Xie12, as shown in Fig.9. The drilling assembly is Φ215.9mm PDC bit + Φ186mm composite impactor + Φ171.5mm 1.25° screw + check valve + one Φ158.8mm non-magnetic drill collar + MWD + fifteen Φ127mm heavy weight drill pipes + Φ165mm vibration isolator + several Φ127mm drill pipes.

After connecting the upper drilling tool and the screw, the pump circulation was built up with the pump pressure 5MPa, then the impactor was placed under the screw, confirming that the pump pressure was 7MPa as rebuilding the pump circulation, thus indicating that the differential pressure generated by the tool was 2MPa, which was basically consistent with the test results, meaning that worked properly. Then, the tool string was lowered with a PDC bit connected at the bottom of the impactor. The pump wasn’t turned on to circulate until the bit had been about 50 meters away from the bottom of the well, the pump pressure was measured to be 7MPa, which meant everything was going well, later, two tons of WOB was applied to start drilling when the bit had touched the bottom of the well.

From the depth of 258 meters to the depth of 2223 meters, it took 104 hours to finish the second section of the well, and the pure drilling time was 74 hours, the formations encountered were Minghuazhen formation, Guantao formation and Dongying formation. According to the well bore configuration, from 258 meters to 400 meters was a vertical section, the composite drilling method had been adopted, two to four tons of WOB was applied, from 422 meters to 603 meters was a deflecting section, the sliding drilling method had been adopted, two to three tons of WOB was applied, from 603 m to 1892 m was a holding section, the composite drilling method had been adopted, three to four tons of WOB was applied, from 1892 meters to 2124 meters was a drop-off section, the sliding drilling method had been adopted, two to three tons of WOB was applied, from 2124 meters to 2223 meters was a holding section, the composite drilling method had been adopted, three to four tons of WOB was applied.

The adjacent well Tian17-Xie11 with the similar formation and well bore configuration as the well Tian17-Xie12 was an injection well of the same platform, according to the comparison of the two Wells’ drilling rate with the same well section, the average drilling rate in well Tian17-Xie12 was 29.23 meters per hour, and the average drilling rate in well Tian17-Xie11 was 21.22 meters per hour, which increased the mechanical drilling rate by 38%. In the process of the well construction, the inclination index of the holding section was very stable all the time, which had reduced the time of sliding drilling, and meanwhile improving the drilling efficiency.

5. Conclusion
Combined with the technical advantages of the existing drilling impactors, a drilling composite impactor has been designed, which is able to generate both the torsional impact and the axial impact back and forth, thus improving the drilling efficiency.

Based on the ground test platform, the performance test has been carried out for the composite impactor, the results show that characteristics including impact torque, axial impact force and impact frequency all meet the design requirements.

The drilling composite impactor has been applied in well Tian17-Xie12, and the mechanical drilling rate was increased by 38% compared with that in the adjacent well. When drilling in the holding section, the inclination index was relatively stable, which reduced the time of sliding drilling and improved the drilling efficiency. Therefore, this tool can provide technical support for high efficiency rapid drilling in deep hard formation in China.

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