Development Status of Hydraulic Hammers and Development Trends of Hydraulic hammers Used in Oil and Gas Well Drilling

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ABSTRACT

Hydraulic impact drilling technology is one of effective methods for improvement of rate of penetration in hard formations. This paper focuses on the summarization of the style, working principle, development status, advantages and disadvantages of current hydraulic hammers. In addition, this paper investigates development trends of hydraulic hammers used in oil and gas well drilling. The results are as follows: in the first place, direct-action type hydraulic hammers with small size were mainly used in shallow formations, and were extensively used in geological and mineral exploration engineering; moreover, double-action type and fluidic type hydraulic hammers with relatively large size were mainly used in deep formations, but they were in experiment period, and were not used extensively; finally, reverse-action type hydraulic hammers and fluidic-suction type hydraulic hammers were researched in early time, and little research were conducted in late time. Development trends of hydraulic hammers in oil and gas well drilling are high output power, high manufacture quality of key parts, and good adaptability to complicated downhole conditions. Double-action hydraulic hammers and fluidic hydraulic hammers have good application prospects in oil and gas well drilling.

KEYWORDS: Hydraulic hammer; Hard formation; Development condition; Application; Oil and gas well drilling

INTRODUCTION

In recent years, oil and gas exploration gradually develops into deep formation, and slow rate of penetration of hard formations has become more and more prominent[1,2]. Characteristics of conventional drilling technology with cone bit, PDC and jet drilling are slow rate of penetration, short life of bits, high drilling cost when drilling in hard formations. Impact drilling technology is one of the effective methods to improve rate of penetration in hard formations, which includes pneumatic impact drilling and hydraulic impact drilling. Pneumatic impact drilling technology is one kind of technology that high pressure gas drives an air hammer to generate high-frequency impact on a bit to break hard rocks[3]. When pneumatic percussion drilling technology is used in humid and water formations, it is easy to cause bit balling[4]. Hydraulic impact drilling is one kind of technology that high pressure fluid drives a hydraulic hammer to generate high-frequency impact on a bit to break hard rocks, which can be suit for humid and water formations. Compared with conventional drilling technology, hydraulic impact drilling technology can improve rate of penetration by a wide margin, prevent deviation and prolong service life of bits, etc.[5]. Since its birth, the technology has been well developed and applied in mine, quarry, geological exploration, hydrology and water well, oil drilling, geothermal drilling, engineering construction and engineering exploration, etc.[6]. Hydraulic hammers are key tools of hydraulic impact drilling technology. This paper focuses on the summarization of the style, working principle, development status, advantages and disadvantages of current hydraulic hammers. In addition, this paper investigates development trends of hydraulic hammers used in oil and gas well drilling.

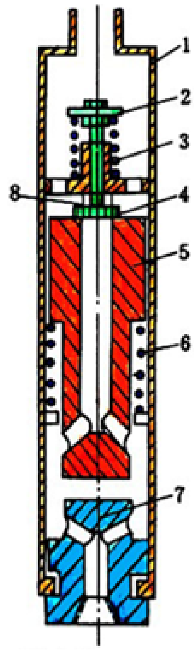
HYDRAULIC IMPACT DRILLING TECHNOLOGY

Hydraulic impact drilling is one kind of drilling technology that depends on high pressure fluid to drive a hydraulic hammer to generate high-frequency impact on a bit to crush hard rocks[7]. Hard rocks are weak resistance of shear and impact. Therefore, compared to traditional rotary drilling technology, hydraulic impact drilling technology can crush hard rocks more efficiently[8].Hydraulic hammers are key tools of hydraulic impact drilling technology. Scholars of china and other countries have developed several types of hydraulic hammers, which include direct-action type, reverse-action type, double-action type, fluidic type, fluidic-suction type [9].

DEVELOPMENT STATUS OF HYDRAULIC HAMMERS

Direct-action type hydraulic hammers

The working principle of direct-action type hydraulic hammers is that pistons are pushed to impact bits by high pressure fluid. At the same time, springs are compressed. When pressure of working chambers drops, springs relieve elastic energy and push pistons upward. The working principle of direct-action type hydraulic hammers is shown in Figure 1.



1-shell; 2-washer of movable valve seat; 3-valve spring; 4-movable valve;
5-piston; 6-spring of hammer; 7-anvil; 8-buffer washer

Figure 1: Working principle of direct-action type hydraulic hammers

Direct-action type hydraulic hammers were studied intensively by scholars in early time[10]. The Geology Ministry of former Soviet Union systematically popularized direct-action type hydraulic hammers which were widely used in geological and mineral exploration engineering. The main models of hydraulic hammers wereΓB-5、ΓB-6、Γ-7、Γ-9. Outside diameter of the hydraulic hammers was 54 ~ 73 mm, and weight of the hydraulic hammers was 25 to 50 kg. From 1970 to 1980, the cumulative footage was 8.9 million meters. In 1983, Chinese Academy of Geological Sciences Exploration Technology Research Institute developed YZ series of direct-action type hydraulic hammers which were mainly used in the field of core exploration drilling. The result of test indicates that rate of penetration was improved by 20%~40%. Especially, combining with man-made impregnated diamond bits in slipping formation, rate of penetration was improved by several times. The Comprehensive Study Geology Group of Hebei Geology and Mineral Resources Bureau developed ZF series of direct-action type hydraulic hammers, parameters of which were as follows: first, outside diameter was 54 mm ~56 mm; second, weight was 18 kg ~20 kg; third, single impact energy was 8 J ~15 J; finally, impact frequency was 42 Hz ~57 Hz. In 1983, the footage was 4056 m. The average rate of penetration was improved by 46%, and round trip footage was improved by 62%. ZG series of hydraulic hammers was improved on the basis of ZF series, mainly to reduce single impact energy and increase impact frequency[11].

Direct-action type hydraulic hammers are widely used in shallow formations, and were extensively used in geological and mineral exploration engineering. However, they have not been fully used in oil and gas well drilling industry. The reasons are as follows:

(1) Size and displacement of direct-action type hydraulic hammers are small.

(2) Working spring is short service life caused by high frequency impact of pistons.

(3) Direct-action type hydraulic hammers are sensitive to well depth, and they are affected obviously by back pressure. Therefore, direct-action type hydraulic hammers are suitable for holes, depth of which is with less than 1000 m.

(4) When the operation is abnormal, fluid flow channel will be cut off to inspect drill strings. Hence, mud can not be circulated, which is not permitted in oil and gas well drilling.

Reverse-action type hydraulic hammers

Reverse-action type hydraulic hammers are adverse to direct-action type. Springs of reverse-action type are set on upper chambers. The principle of reverse-action type hydraulic hammers is that pistons are pushed upward by high pressure fluid. In the same time, springs are compressed. When pressure of working chambers drops, springs relieve elastic energy and push pistons to impact bits. The working principle of reverse-action type hydraulic hammers is shown in Figure 2.

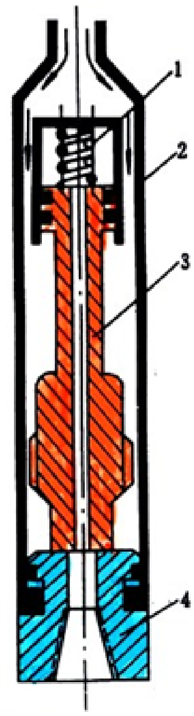
Reverse-action type hydraulic hammers were studied in early stage, but were seldom used in later time[10]. ГВМС-5M model hydraulic hammer developed by the former Soviet Union and 79-3 model hydraulic hammer developed by China were with complicated structures and easily damaged parts, so they were rarely used. Reverse-action type hydraulic hammers developed by Gulf Petroleum Company and Shell were mainly used in oil well drilling and elimination of sticking. Therefore, the diameter of hydraulic hammers was large to drill into borehole diameter of 222 mm. The weight was 300kg, and impact frequency was 10 Hz.

It is very difficult to apply reverse-action type hydraulic hammers in oil and gas well drilling industry. The main reasons are as follows:

(1) Structure of reverse-action type hydraulic hammers is complicated.

(2) Damageable parts are much in quantity.

(3) Service life of springs is short, and it is relatively strict with manufacturing process of springs.



1- spring of hammer; 2-shell; 3-piston; 4-anvil

Figure 2: Working principle of reverse-action type hydraulic hammers

Double-action type hydraulic hammers

The main characteristic of double-action type hydraulic hammers is that upward stroke and downward stroke of pistons are both driven by high pressure fluid, but not springs. The principle of double-action type hydraulic hammers is that pistons are pushed upward by different pressure of top and bottom faces of pistons. When pistons move upward to touch movable valves, center fluid flow channels of pistons are closed. Then, high pressure fluid pushes pistons to move down to impact bits.

In 1960, the former Soviet Union developed series of double-action type hydraulic hammers, including non-springs type and movable valve type with reverse springs[10]. Although double-action type hydraulic hammers were not less effective than direct-action type hydraulic hammers, the application of double-action type hydraulic hammers was much less than that of direct-action type. Pan American Oil Company developed a kind of double-action type hydraulic hammers used in oil and gas well drilling. Diameters of hydraulic hammers were 200 mm and 311 mm, and single impact energy of hydraulic hammers was respectively 397 J and 794 J. The hydraulic hammers were tested in well section of 30 m~2 400 m of 15 wells. The result indicates that rate of penetration was improved by 96%~350% in limestone. Smith Tool Company cooperated with Britain and Germany to develop a kind of double-action type hydraulic hammers with non-springs. Single impact energy of the hydraulic hammers was more than 1 000 J because of high weight of the hammers and high pressure of fluid[12].

However, in oil well drilling test, when well depth is more than 3 000 m, the hydraulic hammer can not work normally. In 1993, the Deep Drilling Research Institute of Germany, TU Clausthal designed a valve type double-action hydraulic hammer with a diameter of 140 mm[12], which adopts two springs. After a preliminary test, the single impact power was up to 800 J ~ 900 J. Originally, the hammer was intended to be used in KTB ultra deep drilling science drilling. However, the hammer worked unsteadily, and did not work under high confining pressure. Finally, the hammer was not used.

In 2005, YZX series hydraulic hammer were developed by the Exploration Institute of Chinese Academy of Geological Sciences. Structures of the hammers were improved as follows: first, seal components were reduced to 2 units, so the blocking rate of movable parts was reduced; second, the fixed throttling ring was canceled, so the impact energy was improved by 25%~50%; finally, adjustable and perforated diffluent structures resolved the unmatched contradiction of working displacement of hammers and displacement used in drilling sites[13]. From 2001 to 2005, the YZX127 style hydraulic hammer had been used in the Chinese Continental Scientific Drilling CCSD1 well construction. Cumulative footage of the hammer was 3 526.3 m, and maximum hole depth was 5 118.2 m. In drilling of eclogite and gneiss with 8 to 9 level drillability, rate of penetration was improved by nearly 100%, and full pipe rate of round trip reached more than 95%, and core harvest rate was more than 90%. In 1998, in order to meet the need of drilling deep holes in hard formations, Daqing Petroleum Administration Drilling Research Institute developed XC-82 model hydraulic hammer. The main characteristics of the hammer were as follows: first, long service life because of adopting piston ring seal with high reliability and small frictional resistance; second, simple structure with only 8 components in the whole hammer[14]. University of Petroleum in China developed SYZJ model double-action type hydraulic hammer. The hammer relied on two movable valves with water distribution to push upward stroke and downward stroke of the piston[15]. When the hammer was tested in the section of 2 308 m~2 351 m in YiNan 5 well Jidike group, rate of penetration was improved only by 21% in mudstone formations, and rate of penetration was improved by 63% in hard and brittle formations. In addition, the deviation was kept in 2 degrees.

Double-action type hydraulic hammers have been developed in deep well of oil and gas well drilling industry, but further research is needed. The main reasons are as follows:

(1) High quantity of dynamic sealing lead to high dynamic blocking rate and high performance requirements of drilling fluid.

(2) Double-action hydraulic hammers are relatively sensitive to the adaptability of well depth, and are affected relatively obviously by back pressure.

(3) Fixed throttle rings of double-action hydraulic hammers produce some damping effect toward downward stroke of pistons.

Fluidic type hydraulic hammers

The principle of fluidic type hydraulic hammers is that bistable fluidic elements control fluid to regularly push pistons up and down to impact bits[16].

Fluidic type hydraulic hammers are first developed by Chinese scholars[10]. In the early stage, fluidic type hydraulic hammers were with small size and small output power, so they were mainly used in shallow drilling industry. Until the 1980s, cumulative footage of fluidic type hydraulic hammers was about 100,000 m, and the maximum wells depth was 835.56 m. DGSC-203 type fluidic hydraulic hammer was designed for wells with diameter of 311.15 mm (12 $^1/_4$ inch) and well section of 3 000 m~4 500 m in oil well drilling. To adapt for oil and gas well drilling, diffluent component was added in the hammer to match with large displacement. Flow section of fluidic element was enlarged and coated with hard alloy material, so service life was improved. In addition, single impact energy was improved to achieve volume crushing of rocks working in with ball tooth bits. In 2002, the first experiment of the hammer was developed in a geothermal well in Huairou. In drilling of tuff and andesite, rate of penetration was improved respectively by 17% and 41%. After the experiment, the hydraulic hammer was disassembled for inspection. It was found that the fluidic element with micro erosion, the interior of cylinder block with erosion, and some seal components with damage[17]. YSC-178 model fluidic hydraulic hammer developed by Jilin University was tested in Sinopec Songnan gas field Yaoshen 7 well. Maximum well depth was 3 624 m, and rate of penetration was improved by 463%. After the experiment, appearance of the hydraulic hammer was intact. However, fluorine rubber seal components between the fluidic element and cover surface were failure caused by poor low temperature resistance of fluorine rubber[18,19].

Further research is needed for application of fluidic type hydraulic hammers in oil and gas well drilling industry. The main reasons are as follows:

(1) Fluidic elements are eroded seriously, so the service life of fluidic type hydraulic hammers is short.

(2) Wall-attachment changing-over performance is easy to be affected by the performance of the drilling fluid, so fluidic type hydraulic hammers are strict with the performance of the drilling fluid.

(3) Dynamic seal components are prone to be failure in a short time.

Fluidic-suction type hydraulic hammers

The principle of fluidic-suction type hydraulic hammers is that pistons are pushed up and down by roll-suction of high speed of fluidic fluid and comprehensive feedback between valves and pistons[10].

Fluidic-suction type hydraulic hammers are also first developed by Chinese scholars[10]. Fluidic-suction type hydraulic hammers were studied in early time, but were seldom used in later time. SX-54III model fluidic-suction hydraulic hammer was developed by Yunnan Bureau of Geology and

Mineral Resources. Diameter of the hammer was 54 mm, and weight of the hammer was 6 kg~10 kg. From 1983 to 1984, accumulative footage of SX-54Ⅲ model hammers was 3 521.47 m, and rate of penetration was improved by 15%~155%. Working fluid of SX-54Ⅲ model hammers mainly used water. CQS model fluidic-suction hydraulic hammer was designed and applied in Changqing Oilfield. Diameter of the hammer was 156 mm~178 mm, and weight of the hammer was 35 kg. The hammer was tested in 8 wells including wa 6-8, North 95-1, Hua 173, Ping 29-23, Ping 32-19, Xinbai 9-7, Shan 186, Shan 195 in Changqing Oilfield. Maximum depth of CQS model hammer was 2 350 m, and accumulative footage was 3 521.47 m. Rate of penetration was respectively improved by 20%~30% and 40% in upper and nether well section[20]. Xi'an Petroleum University developed fluidic-suction model hydraulic hammers to meet the need of drilling deep well with 4 000 m to 5 000 m. Wear resistance was improved by further optimization design of valves, seal components, nozzles and anvils, laser cladding on important parts. However, application reports were not seen[21].

Fluidic-suction type hydraulic hammers rely on roll-suction force to lift pistons. Hence, weight of pistons cannot be too large. Fluidic-suction type hydraulic hammers are difficult to be applied in oil and gas well drilling. The main reasons are as follows:

(1) Weight of pistons used in oil and gas well drilling is high, so pistons need relatively high lift forces.

(2) Pressure drop of nozzles used in oil and gas well drilling is high, so wear rate of nozzles is fast.

DEVELOPMENT TRENDS OF HYDRAULIC HAMMERS USED IN OIL AND GAS WELL DRILLING INDUSTRY

Hydraulic hammers have been used in geological exploration industry, and gradually develop into oil and gas well drilling industry. There are great differences between geological exploration drilling and oil and gas well drilling. In addition, in recent years, oil and gas well drilling gradually develops into hard formations. Hence, it is necessary to research development trends of hydraulic hammers used in oil and gas well drilling industry.

High output power

Output power of hydraulic hammers is usually less than 10 kW, and improvement rang of rate of penetration is ordinarily less than 100% combined with conventional cone or PDC bits. Hydraulic hammers mainly depend on impact to break rock. Small output power is not conducive to volume fragmentation of rocks, so rate of penetration is not improved effectively. Energy consumption model of rock fragmentation presents minimum energy consumption for crushing unit volume of rock under real drilling conditions[22]. The result indicates that bottom pressure environment exerts a tremendous influence on the rock crushing energy consumption. The rock crushing energy consumption of overbalanced drilling is much higher than underbalanced drilling. Rock crushing energy consumption is proportional to rate of penetration, and is inversely proportional to output power. Air hammers are underbalanced drilling, and hydraulic hammers are overbalanced drilling. In order to obtain the same rate of penetration, output power of hydraulic hammers should be higher than air hammers. According to statistics, output power of hydraulic hammers is usually less than 10 kW caused by working principle, working medium and structure design, etc. However, output power of air hammers reached 25 kW. Small output power of hydraulic hammers leads to unobvious improvement of rate of penetration. Therefore, hydraulic hammers used in oil and gas well drilling should have high output power.

High manufacture quality of key components

The key components of hydraulic hammers include springs, seal components, valves and fluidic elements. Direct-action type and reverse-action type hydraulic hammers mainly use springs to finish restoration or impact process. The springs are prone to be damaged by high output power and high frequency impact. Seal components of hydraulic hammers are more than 4, and most of seal components are dynamic. Seal components are prone to be worn by solid particles of drilling fluid, and fluid comes up and down along pistons. Thus, pressure drop is reduced seriously to cause failure of hydraulic hammers. In addition, seal components are premature failure caused by accessorial underground temperature with increase of well depth. Hydraulic hammers usually use movable vales. Movable valves are easily eroded to cause unstable and inoperative performance of hydraulic hammers by high speed of drilling fluid with solid particles. The failure of springs, seal components, movable valves are mainly caused by structure design, material select, high depth and high temperature of oil and gas well, high solid content of drilling fluid, large power and high frequency impact, etc.. Therefore, the development of hydraulic hammers in oil and gas well drilling should coincide with several principles: first, springs are not used; second, dynamic seal components are reduced, and temperature resistance is improved; finally, movable valves are replaced by fixed valves.

Good adaptability to complicated downhole conditions

Displacement of hydraulic hammer is usually less than 10 L/s, which does not match with 20 L/s ~50 L/s used in oil and gas well drilling site. To address this problem, diffluent devices are often added in hydraulic hammers. However, diffluent devices are prone to be eroded by diffluent fluid. Thus, service life of hydraulic hammers is reduced. Moreover, fluctuating pressure difference caused by diffluent fluid reduces impact acceleration of pistons on bits. Thus, output power of hydraulic hammers is reduced. Density and viscosity of drilling fluid change under complicated downhole temperature and pressure system. Therefore, hydraulic hammers used in oil and gas well drilling should be adaptive to large displacement and variation of properties of drilling fluid.

CONCLUSIONS

Based on the above discussion, the paper brings forward the following conclusions:

(1) Development status of hydraulic hammers used in oil and gas well drilling is as follows: in the first place, direct-action type hydraulic hammers with small size were mainly used in shallow formations, and were extensively used in geology and mineral exploration engineering; moreover, double-action type and fluidic type of hydraulic hammers with relatively large size were mainly used in deep formations, but they were in experiment period, and were not used extensively; finally, reverse-action hydraulic hammers and fluidic-suction hydraulic hammers were researched in early time, and little research were conducted in late time.

(2) Development trends of hydraulic hammers used in oil and gas well drilling is high output power, high manufacture quality of key components, good adaptability to complicated downhole conditions. Further research is needed in application of hydraulic hammers in oil and gas well drilling, especially in deep wells.

(3) From current research and application status, double-action type and fluidic type hydraulic hammers have good application prospects in oil and gas well drilling industry.

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