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Development and Application of the 40-Type Perforator for Casing Deformation Wells

Bo Zeng [1], Chen Jing [1], Yi Song [1], Yulong Liu [2], Nayun Zhou [1], Cheng Shen [1], Jian Wang [2]

[1] Shale Gas Research Institute of PetroChina Southwest Oilfield Company, Chengdu, Sichuan 610051, China
[2] China Petroleum Logging Co, Ltd. Southwest Branch, Jiangbei, Chongqing, 400021, China

Abstract: To address the inability of the 40-type small-diameter perforator to meet the perforation requirements of 5 1/2" deformed casing in horizontal wells, a perforating gun tube with a wall thickness of 3.2 mm and 160-grade steel was designed. This design effectively increased the available internal space within the gun body, enhancing the perforating gun's resistance to detonation-induced deformation under increased charge conditions. Consequently, the single-shot perforating charge was increased from 3 grams to 4 grams. In terms of the gun and charge design, the limited internal space of the gun was maximized, and a shaped charge liner structure was adopted to enable high-clearance distal perforation, ensuring both perforation depth and casing hole diameter. The newly developed 40-type perforator has been widely applied in blocks such as the National Demonstration Platform for Reservoir Stimulation in northern Dianqian, becoming an effective technological solution for perforation operations in deformed casing wells.

Keywords: Casing Deformation Well; Perforated Gun Barrel; The 40-type Perforator.

1. Introduction

At present, for well conditions with a diameter less than 56mm after casing deformation in China, it is not possible to use mature perforating devices of size 51 and above for perforation operations; The conventional 40 type perforator is mainly used for oil pipe perforation operations. It is in a biased state in the 5 1/2 "casing, with a perforation height gap of up to 74.3mm and a single firing hole charge of only 3 grams, resulting in the inability to penetrate the far end of the 5 1/2" horizontal well casing and a small average perforation diameter, which is difficult to meet the requirements of sand fracturing transformation in casing deformation sections [1]. Therefore, it is urgent to develop a 40-type perforator suitable for 5 1/2 "casing deformation horizontal wells.

2. Development of Type 40 Small Diameter Perforator

2.1. Optimization and Size Control of 40 Type Pipes

In order to solve the above difficulties, it is necessary to increase the dosage of perforating ammunition, which puts higher requirements on the anti-explosion and anti-external pressure of the perforating barrel body, as well as the size of the inner hole. Develop new materials to achieve high strength and impact toughness of the tube body after heat treatment. Simultaneously changing the original cold rolling processing method to a combination of cold rolling and precision cold drawing can achieve better precision in inner and outer diameter dimensions [2].

Adding certain alloying elements to the steel composition of the perforating gun barrel body product maintains low C and Mn values, ensuring the mechanical properties and pipe toughness after quenching and tempering. According to actual testing results, while ensuring a certain level of impact toughness, the higher the strength of the pipe, the more advantageous it is for suppressing the explosion and expansion of the pipe body. Adding a certain amount of Nb and V microalloying elements to achieve grain refinement can improve the strength and toughness of finished pipes [3]. In order to ensure good tempering stability of the pipe body, prevent tempering brittleness, and improve high temperature resistance, a certain amount of Mo element is added to the steel [4]. In addition, during the steelmaking process, it is required to perform Ca treatment on the molten steel to change the morphology of MnS inclusions into granular form [5], improve the transverse impact toughness of rolled pipes, and ensure that the pipes have similar toughness in all aspects during perforation explosions to prevent pipe cracking. The chemical composition of the selected materials is shown in Table 1:

Table 1. Chemical composition of steel grade (mass fraction) %

C	Mn	P	S	Cr	Nb	Mo	V
0.27~ 0.33	0.40~ 1.00	≤0. 012	≤0. 005	0.30~ 0.90	0.02~ 0.10	0.30~ 1.00	0.02~ 0.10

After the wall thickness of the 40 specifications perforating gun barrel product was designed to be 3.2mm, the anti-extrusion capacity decreased by 45% according to the formula for external pressure resistance of the pipe material [6][7]. The compressive strength of the gun body needs to be strong enough to withstand the high-pressure environment of deep wells. In order to meet the requirements of product use, the yield strength of the pipe material needs to be increased to ensure its compressive strength at 160 ℃. Therefore, the samples of the above materials are selected for heat treatment and subjected to tensile strength verification testing at high temperatures. As shown in Table 2, it can be seen that the strength reduction rate of the pipe at 160 ℃ environment is 2.1%, which has little effect on the strength of the pipe at this temperature [8]. However, when tested at 250 ℃, the yield strength decreased significantly by 8.6%. By calculation, it can be concluded that the yield strength of the pipe material at 160 ℃ environment needs to reach 160 steel grade or above, that is, above 1103MPa.

Table 2. Tensile test results of perforating barrel body material in high temperature environment

Sample	Tensile specimen size	Test temperature	Yield strength Rp0.2 MPa	Tensile strength Rm MPa	Elongation rate %	Yield strength reduction ratio %
1#	φ6mm*25mm	room temperature 23℃	1220	1308	16	/
2#	φ6mm*25mm	160℃	1194	1295	17	2.1
4#	φ6mm*25mm	250℃	1115	1284	17	8.6

Perforation cartridge holder and perforating charge need to be installed in the pipe with a diameter of 40*3.2mm. In order to achieve excellent assembly effect, the size tolerance range of the pipe needs to be reduced to better meet the usage requirements. The size and tolerance design range of the pipe are shown in Table 3.

Table 3. Pipe size requirements (Φ 40*3.2mm)

Outside diameter	Outer diameter tolerance	inside diameter	Inner diameter tolerance	wall unevenness	ovality	Curvature
40mm	-0.1~+0.3mm	33.6mm	±0.2mm	≤0.3mm	≤0.4mm	≤1.0mm/m

The manufacturing process is changed to hot-rolled pipe production, followed by cold rolling and precision cold drawing. Both the outer and inner diameters can meet the design requirements. The finished pipe products are hot straightened and formed using a ten-roll straightening machine to ensure a bending degree of ≤1mm/m.

2.2. Design of Matching Dimensions between Type 40 Perforator Gun and Bullet

Under the premise of using a 3.2mm thin-walled perforating gun, the usable space inside the gun has been improved to a certain extent, which is conducive to the design of larger volume perforating charge structures [9]. In order to optimize the limited space inside the gun, optimizations have been made in terms of the clearance between the gun and the charge, the maximum diameter of the charge cover, and the hole density. As shown in Figure 1, an optimized layout design for the gun and charge space has been obtained:

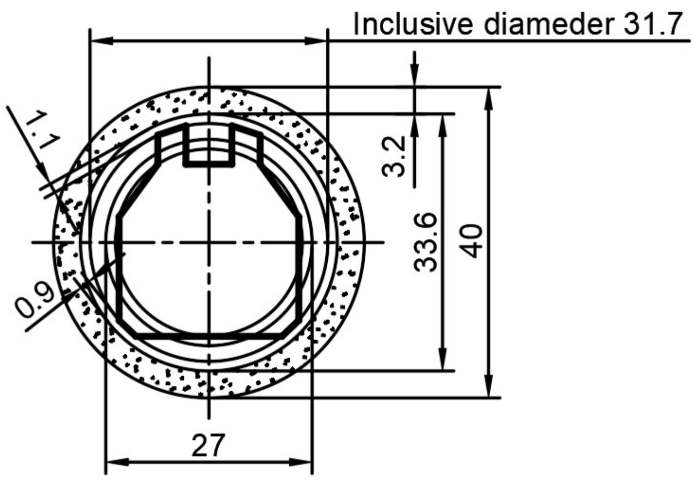

Figure 1. 40 Perforator Gun and Bullet Space Layout Design

By optimizing the layout of bullets in a limited space, a macroscopic structure of a 21mm shaped casing caliber, low fit clearance, and 20 holes/meter perforating bullet was obtained.

2.3. Structural Design of Type 40 Perforated Ammunition Cover

The commonly used structures of medication masks include small cone angle, large cone angle, parabolic, spherical, conical spherical, exponential curve, etc. In order to test the specific functions of different structures for jet shape, various types of medication masks with a diameter of 21mm were designed as shown in Figure 2.

By testing the functions of different types of drug mask structures, the test results show that the drug mask structures and uses have the following functional characteristics as shown in Table 4:

2.4. Indoor Testing of 40 Type Perforator

The 40-type perforating device is made of a high-strength perforating gun barrel made of 160 steel grades with an outer diameter of 40mm and a wall thickness of 3.2mm. Its temperature and pressure resistance performance are shown in Figure 3.

The black curve in Figure 3 represents the temperature resistance curve, and the red curve represents the pressure resistance curve. Gun body testing shows that the gun body can withstand pressure for 30 minutes at 160 ℃/120MPa, and then continue to be pressed to 145MPa. After disassembly, it was found that the appearance of the gun body specimen was not deformed, and the plug was removed, with no leakage inside, which can meet the requirements of temperature and pressure resistance environment in the well.

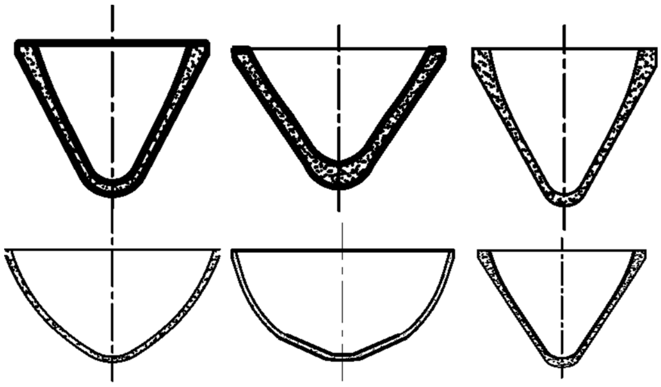

Figure 2. Structural Design of Different Medication Masks

Table 4. Functional characteristics of perforation of different structured drug masks

Shape of medication mask	Perforation performance and function
Small cone angle structure	Deep perforation depth, small perforation aperture, used for deep penetration perforation
Large cone angle structure	Shallow perforation depth and large perforation aperture, used for large-diameter perforation
Parabolic structure	Shallow perforation depth and large perforation aperture, used for large-diameter perforation
Spherical structure	Medium perforation depth and large perforation diameter, used for large-diameter perforation
Cone spherical structure	Shallow perforation depth and large perforation aperture, used for large-diameter perforation
Exponential equation curve structure	Better perforation depth, larger casing aperture, used for deep penetration perforation

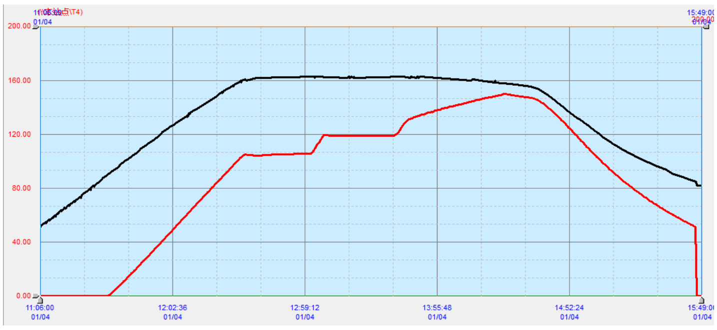

Figure 3. Temperature and pressure resistance test of 3.2mm wall thickness 40 type perforating gun

After understanding the influence of different structures on perforation performance, a structural design with a dome ball top and lower inner and outer exponential equation curves was ultimately adopted to control the variable jet shape. Ground mounted perforation tests were conducted under the condition of a 12.7mm thick wall 5 1/2 "casing. The perforation shape after perforation is shown in Figure 5.

The test results show that using high-grade reinforced thin-walled perforating gun pipes, the gun body expands to meet the standard after perforation, and the distal diameter of the 5 1/2 "casing reaches 4.1mm, which meets the requirements for use and has the conditions for on-site construction application.

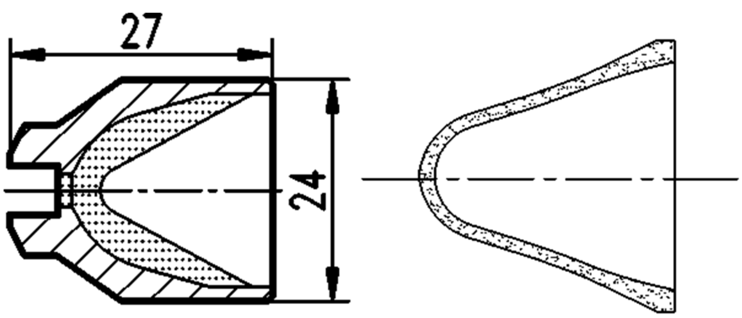

Figure 4. Final finalized drug mask structure

Figure 5. Testing Perforator and Post Perforation Gun and Sleeve Status

3. Application Effect and Analysis

A reservoir renovation platform in the Zhaotong National Demonstration Zone in northern Yunnan and Guizhou is located in a karst landform with complex geological structures and large dip angles. There is a high risk of casing deformation during construction [10]. Among them, the minimum diameter of the 5 1/2 "casing of Well 5 after casing deformation is only 54.89mm, and the conventional 51mm perforator cannot pass through normally. A new 40 type small-diameter perforator is used for perforation construction. After construction, sand fracturing is completed at the wellhead, and the fracturing curve is shown in Figure 6.

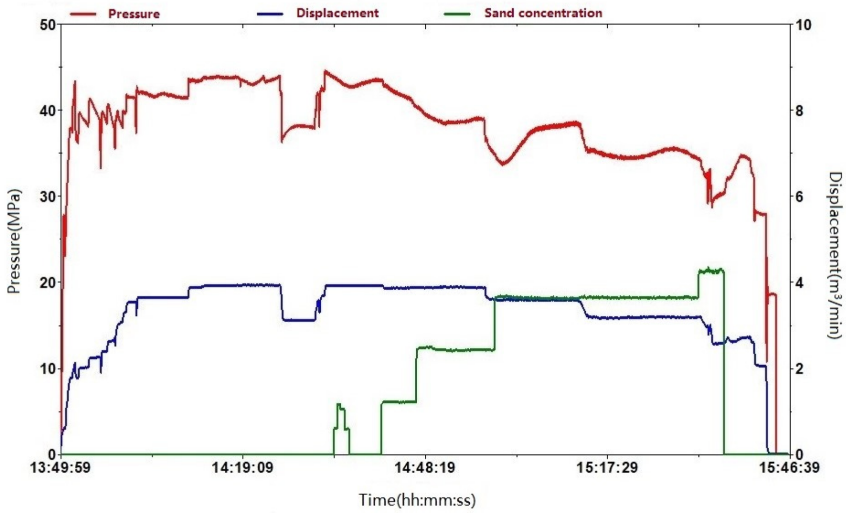

Figure 6. Sand pressure curve after perforation of the No. 5 well in northern Yunnan Guizhou

The above sand fracturing indicates that the pressure and sand addition after perforation are normal. The use of a new 40 small diameter perforating device has achieved effective perforation of 5 1/2 "complex wellbore sections, creating high-quality pores for subsequent fracturing and helping to achieve effective utilization of shale gas reservoirs.

4. Conclusion

(1) We have developed a 40 specifications perforating gun barrel product, which uses a composite process of cold rolling and precision cold drawing to design the chemical composition of the material. After heat treatment, the actual strength of the pipe reaches 1143MPa, with good impact toughness. At the same time, the various dimensions of the pipe are excellent, which improves its resistance to external pressure and explosion, and meets the construction requirements of loading a single charge of 4 grams for a 3.2mm thin-walled perforating gun;

(2) The use of high-grade reinforced perforating guns and a spherical top exponential equation shaped casing structure design has improved the perforation performance of the 40-type perforating charge under high clearance and large casing construction conditions, meeting the perforation application requirements of casing change wells;

(3) The application of the new 40 type perforating device has enabled the small-diameter perforating device to have the perforation performance required for high clearance and large casing. It has been effectively applied in the well transformation area in northern Yunnan and Guizhou, saving the cost and cycle of well transformation, and providing an effective perforating tool for well transformation construction.

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