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NORINCO GROUP

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NORTH SPECIAL ENERGY GROUP CO.,LTD

# The inclined well Set Firing Angle Oriented Perforating technology and application

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# Abstract



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**After developed the setting-firing-angle oriented perforator of straight wells that can be perforation by the principal stress direction of formation, Xi'an Wuhua Juneng Blasting Equipment Co., Ltd. developed the setting-firing-angle oriented perforator of inclined well, and developed the three-phase and four-phase oriented perforator of inclined well based on it. The perforator can cause every perforating charge fired to goal orientation through the set angle. The technology can obviously increase the output of oil and gas well applied in oil field.**

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# 1 Introduction



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**Oriented perforation is a new perforating technology. It can perforate towards two principal stress directions of formations, the most easy-to-broken direction and the direction easily linking with high permeability zones. Therefore, it can obviously increase the output.**

**The permeability in different directions of the well-around oil and gas formation is not same, for example, because that the max stress for the development direction of carbonate formation's crack and the development direction of sedimentary rock strata's joint, and the flow direction of the gravel strata deposition, which is called the principal stress direction, the relative permeability is much better than the other direction.**

# 1 Introduction



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**Most oil and gas formations are not level. They have inclined angle and direction. The principal stress direction and inclined direction are not the same. However, the normal perforating direction is perpendicular to the perforating gun. Therefore, the oriented perforation technology we mentioned before is not the firing at the principal stress direction exactly, but firing at the projection direction of principal stress in the horizontal plane. Since such an angle of "principal angle" is omitted, the jets cannot really achieve the purpose of oriented perforation. This is one of the reasons that the production increasing effect of oriented perforation is not quite distinct.**

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# 2 The theoretical basis of oriented perforation



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## 2.1 The formation principal stress

**Various stresses generated by a formation itself due to weathering, deposition and crustal movement, etc. are called formation stress, e.g., self-weight stress, compressive stress, fold stress and dislocation stress of formations. The sum of various stress vectors that the formation is applied is its maximum stress, also called principal stress.**

## 2 The theoretical basis of oriented perforation



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### 2.1 The formation principal stress

**Principal formation stress is directional and shows irregular surface state extension in formations. Because of stress concentration, the static load of rock masses in the principal stress direction of formations is less than that in other directions, namely, external force required for breaking rock masses in the principal stress direction of formations will be much smaller than that in other directions. Therefore, when perforating, the penetration depth caused by firing perforating projectiles at the principal stress direction of formations will be much greater than that at other directions. Moreover, by perforating along the principal stress direction, jets will more easily break rock masses of formations and improve the permeability around perforations so as to improve the perforation efficiency and obtain higher productivity.**

## 2.2 Other basic concept



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**inclined direction is the tilt direction of formation;**

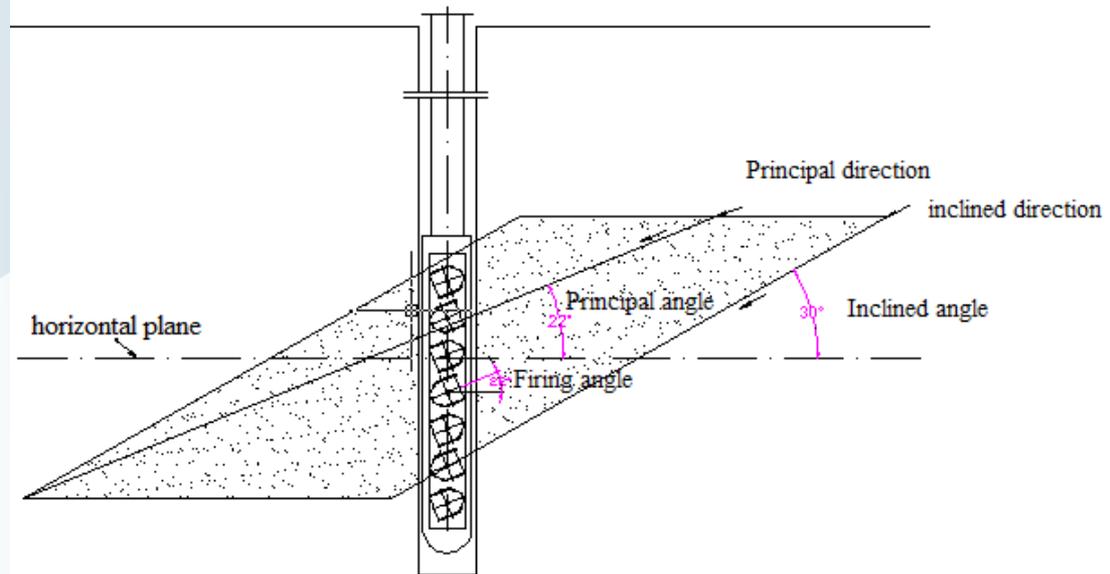
**Inclined angle is the tilt angle of formation;**

**Principal direction is the principal stress direction of formation;**

**Principal angle is the angle between the principal direction and the horizontal plane;**

**Firing angle is the angle between perforating projectile and the radial plane of gun body.**

**Wherein, inclined direction, inclined angle and principal direction may be acquired from logging interpretation data, and principal angle needs to be calculated from inclined direction, inclined angle and principal direction.**



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### 3 The principle and structure of inclined well oriented perforator



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Previously, perforating charges in all perforators are perpendicular to perforating gun body. The perforating jets of oriented perforators actually fire at the projection direction of principal stress in the horizontal plane. Since such an angle of "principal angle" is omitted, the jets do not really aim at the principal stress direction and thus cannot really achieve the purpose of oriented perforation.

If the firing angle of each perforating projectile can be set according to the principal angle, the perforating jets would really aim at the principal stress direction. The angle adjusting projectile carrier structure we design is mounted in straight and deviated well oriented perforator to form a set firing angle oriented perforator.

# 3 The principle and structure of inclined well oriented perforator



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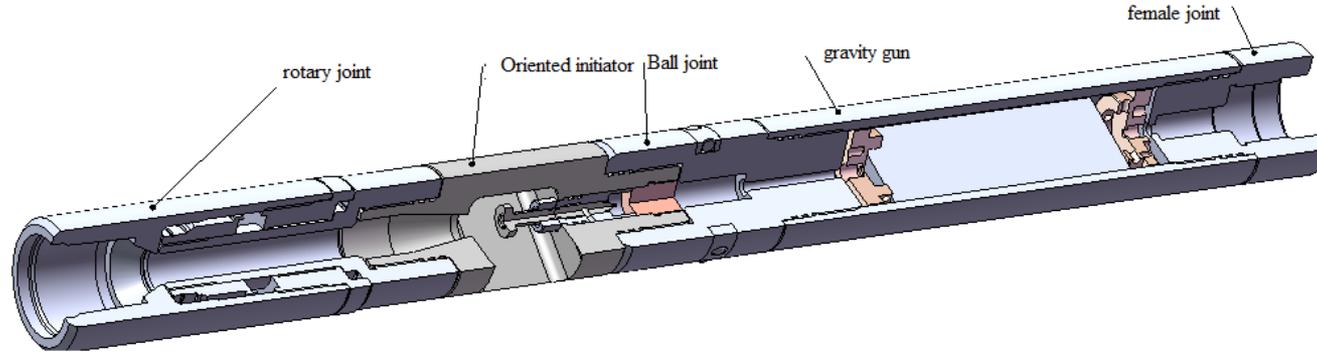
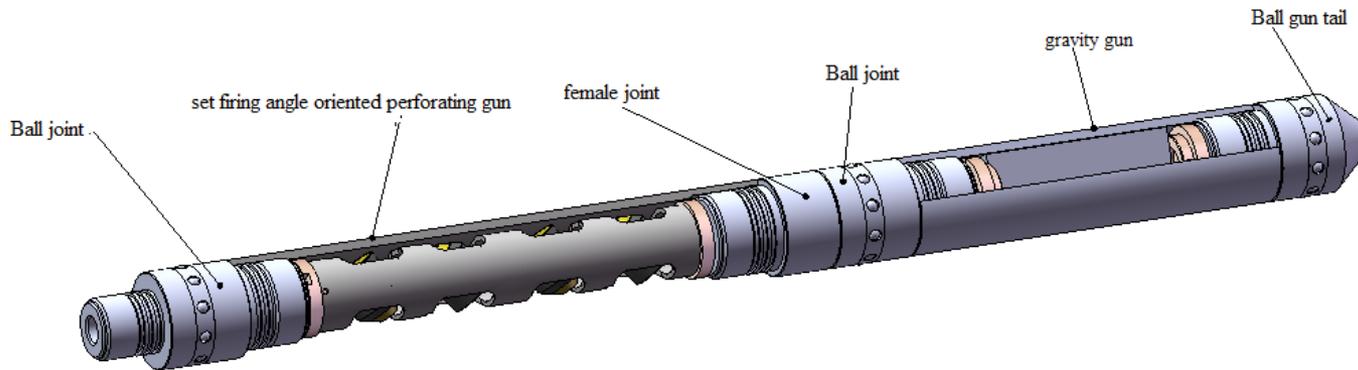


diagram of inclined well oriented perforator



The inclined well oriented perforator consists of the following components, as shown in Figure: rotary joint, Oriented initiator, Ball joint, gravity gun, set firing angle oriented perforating gun.

### 3 The principle and structure of inclined well oriented perforator



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**The working process is as follows:**

**Before downhole, according to the stress direction of known or perforating direction, adjust the perforating charge angle in perforator inside, based on the role of well inclination , the gravity gun stresses and the rotary joint auto rotation, the perforating jets can aim at the requires perforating direction, then initiation after depth calibration.**

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## 4 The theoretical calculation

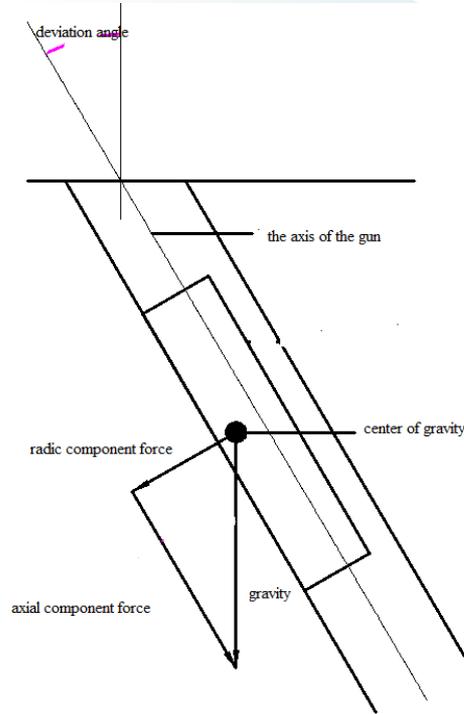


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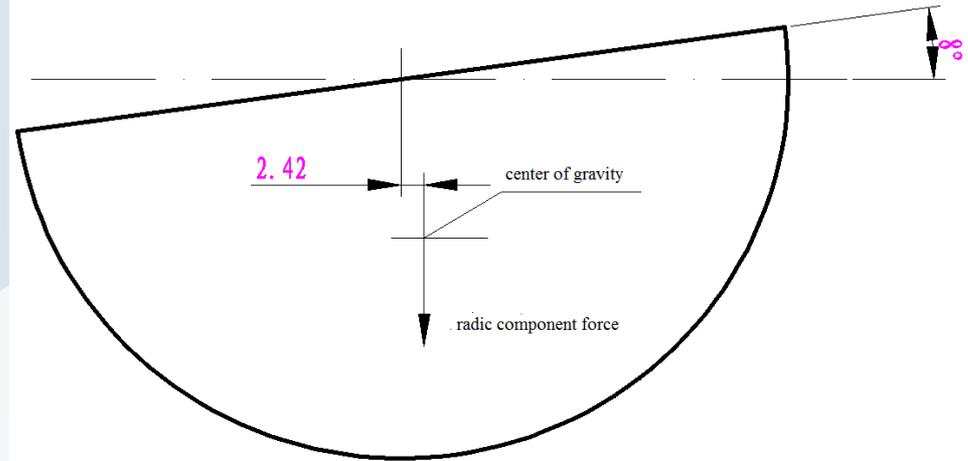
**The auto rotation of setting-firing- angle oriented perforating is mainly relying on the rotary joint's free rotation and gravity gun's automatic orientation.**

**In inclined wells, completion pipe string in complex stress, deformation and motion state, by which the axial force (tension), radial extrusion pressure, bending moment, mud or completion fluid buoyancy and the casing or the naked eye on completion pipe friction on the column. It is precisely because of these forces, force analysis of the completion string become complex and difficult.**

# 4 The theoretical calculation



**gravity torque**



**diagram of offset of 8°**

**For perforated string, except gravity gun, the others are the axial symmetry structure. Therefore, gravity torque of column rotation is generated by gravity gun.**

## 4 The theoretical calculation



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Seen from Figure, the string rotates on the torque is generated by the radial component force of gravity. Therefore, the inclined angle is bigger; the gravity torque angle of the well is bigger. Small inclined angle will cause too small gravity torque. The inclined well oriented perforation technique is applied to the well with the hole deviation in more than 20 degrees. The theory calculation result for the minimum hole deviation ( $\pm 8^\circ$ ) directional precision as follows.

1) 、 the gravity torque calculation that hole deviation of  $20^\circ$  and offset of  $8^\circ$

The weight of 2 meter, diameter 102mm, gravity gun: 41kg.

The center of gravity position that offset of  $8^\circ$  : $x=2.42\text{mm}$ ;  
 $y=-17.23\text{mm}$

Take the deviation angle of  $20^\circ$  for calculation, the gravity torque of two 102 gravity guns:

$$M=G \times \sin 20^\circ \times 2.42=0.665\text{N m}$$

## 4 The theoretical calculation



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2) 、 the friction torque calculation that hole deviation of  $20^\circ$  and offset of  $8^\circ$

The friction torque has two parts, one part is the one-way thrust ball bearing gun column axial force generated of rotary joints, and the other part is ball bearing radial component force produced by a perforating gun string.

The approximate formula of friction torque calculation of ball bearing used in engineering as follows

$$M = \mu d_m P_0 / 2$$

$\mu$  —Friction Coefficient

$d_m$  —Bearing the pitch circle diameter, mm

$P_0$  —The equivalent static bearing load, N

## 4 The theoretical calculation



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Hole inclination of  $20^\circ$  axial friction torque:

$$M_{\text{轴}} = 0.5\mu F_{\text{轴}} d = 2.82 \times 10^{-5} \text{GN m}$$

Radial friction torque:  $M_{\text{径}} = 0.5\mu F_{\text{径}} d = 1.28 \times 10^{-5} \text{GN m}$

The total torque:  $M_{\text{总}} = M_{\text{轴}} + M_{\text{径}} = 4.1 \times 10^{-5} \text{GN m}$

G—String gravity

Two gravity guns can be driven to the maximum weight

$$m = \frac{0.665}{4.1 \times 10^{-5} \times 9.8} = 1665 \text{kg}$$

Therefore, in the circumstances that the inclination of 20 degrees and the orientation accuracy of 8 degrees, two gravity gun can rotate 1665kg string in theory. The two gravity gun can rotate 4m perforating gun number in theory as follows.

$$N = \frac{1665 - 170.5}{133} = 11 \text{根。}$$

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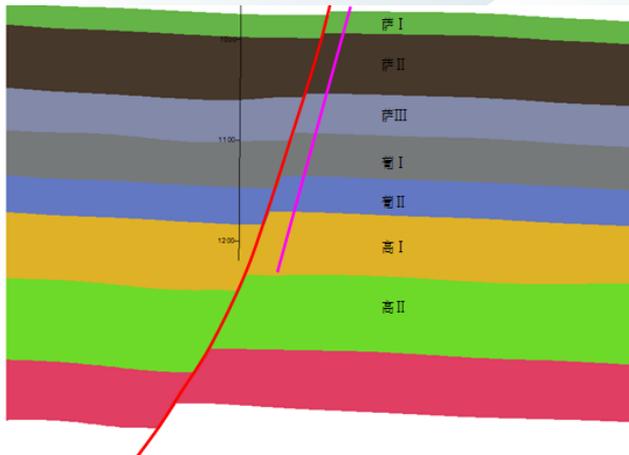
# 5 Fixed surface perforation



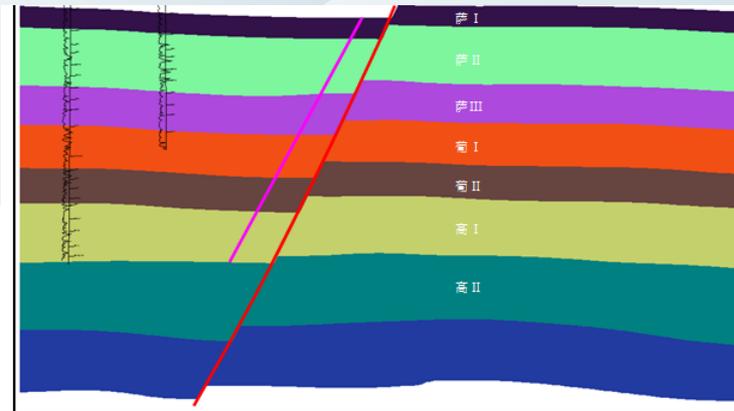
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Setting-firing-angle oriented perforating technology has special advantages in directional water injection, directional fracturing and acidizing operation in directional, then introduces some set firing angle oriented perforating under the conditions of special wells.

There are two high inclined wells of xx oil field in order to tapping the potential of remaining oil, created parallel to the fault plane, hole deviation were 26 degrees and 40 degrees.



track diagram of xx well



track diagram of xx well

# 5 Fixed surface perforation



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**The two wells has the characteristics of multi - layer, thin reservoir, normal perforation has been unable to meet the demand of perforation in this environment, because the conventional perforating is perpendicular to the direction of well, due to thin reservoir and wellbore is not vertical, with conventional perforating will shoot through the thin reservoir, in order to avoid the cross reservoir, raising fluid ratio of oil to water, need to perforating paralleled to the reservoir with set angle of orientation.**

# 5 Fixed surface perforation



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**These wells have two perforation modes:**

**(1) In order to avoid penetrating reservoir, perforation with 14 holes / M for a part of layers, , requires two ranges can adjust angle parallel to the direction of perforation azimuth graphic section, other two sections perpendicular to the inward and outward perforation.**

**(2) The other layers required limited entry perforation and fracturing, perforation can not toward the direction of fault plane, otherwise will thin leak in fracturing.**

**According to the two different perforation modes, we designed two kinds of set angle orientated perforator:**

# 5 Fixed surface perforation

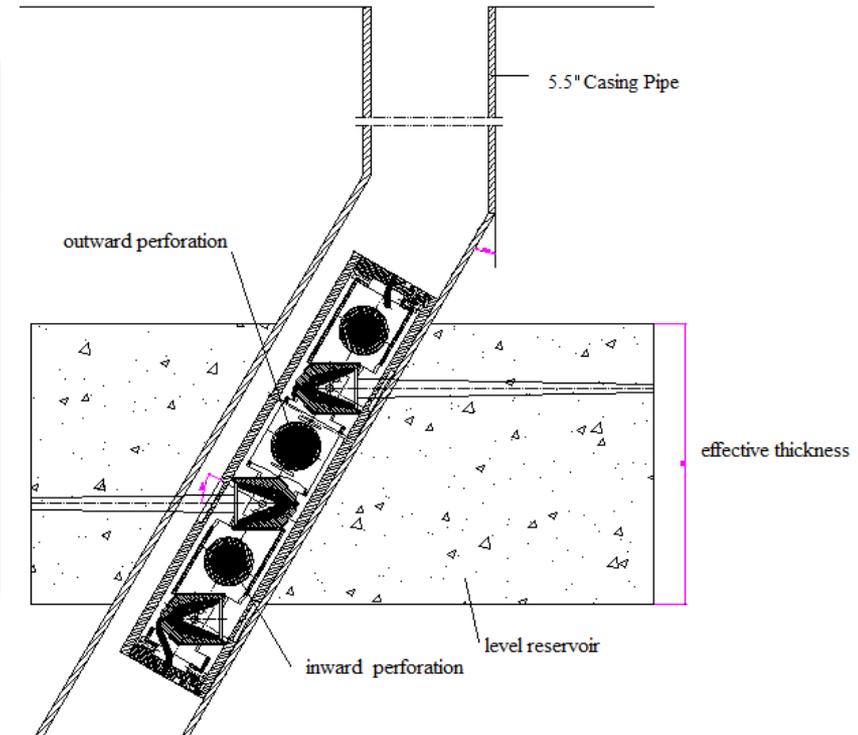


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## (1) setting-firing-angle oriented perforator of four-phase

Used the 'gravity automatic orientation' principle, rely on the radial stress of gravity gun makes the gun column range and direction of deflection uniformly. So, perforating charge that perpendicular to the gun can to-ward both sides along the reservoir level injection. At this time, another twophase of the perforating charge is arranged in the bullet holes of angle modulation. Adjust firing angel according to the angle between wellbore and reservoir before down well, so they will be along the reservoir level direction to injection, has realized the setting-firing-angle oriented perforator of four-phase.



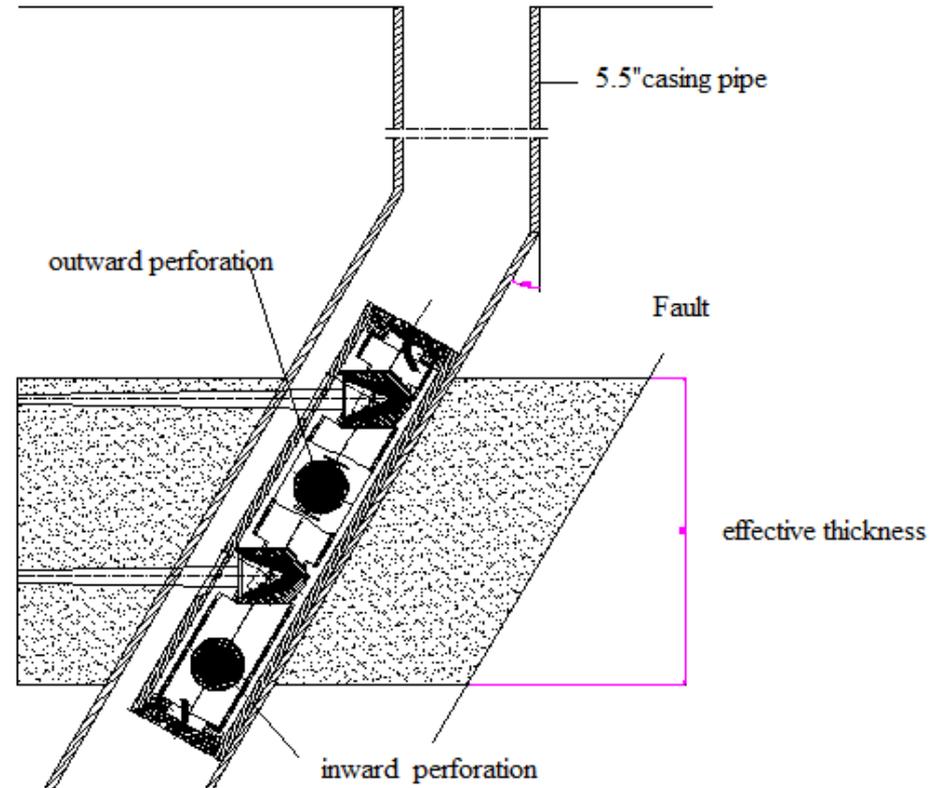
# 5 Fixed surface perforation



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## (2) setting-firing-angle oriented perforator of three-phase

Because the limited perforating require the jet can't toward the fault direction within 120 degree to perforating. We make toward the fault angle adjusting perforating charge toward the opposite direction base on the setting-firing-angle oriented perforator of four-phase.



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# 6 Verification

The inclined well Set Firing Angle Oriented Perforator of our company have test for 6 wells oil field, construction wells and directional results shown in the table below.

Well No.	Gun Model	Well Section	Angle	Orientation error
霍3-X4井	89mm	1451.6---1445.8m	33.02°	4.6°
古xx386-斜xxx井	102mm	1984.7---1962.9m	24.1°	3.4°
喇2-斜PSxxxx井	102mm	1162.2—1144.0m	30.1°	4.8°
和X1井	89mm	2449.0—2440.0m	40.1°	3.9°
和X1井	89mm	2301.4—2286.2m	40.1°	4.5°
X91-斜22井	102mm	2048m~2045m	30.24°	6°

# The perforator test see below



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penetration  
depth of 30  
angle of  
target1



penetration  
depth of 30  
angle of  
target2



penetration depth  
of 0 angle

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**The inclined well setting-firing-angle oriented perforating technology is an advanced technology that can really perforating along the principal stress direction relying on gravity orientation and setting- firing-angel technology. It has obvious effect for oil and gas well production. At the same time , The inclined well setting-firing-angle oriented perforating technology, in some special fields such as directional water injection, directional fracturing and directional acidification, also has special advantages. It also can perforate to the oil and gas reservoir or specified plane in parallel by the firing angle adjustment. In the current situation of less oil and gas resources,the technology has great significance for exploration of thin reservoir potential.**



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**Thanks !**