Available online at www.sciencedirect.com

ScienceDirect

Natural Gas Industry B 3 (2016) 439–444

www.elsevier.com/locate/ngib

Research Article

Oriented cluster perforating technology and its application in horizontal wells☆

Chen Huabin*, Tang Kai, Chen Feng, Chen Jianbo, Li Benchi, Ren Gouhui

Well Logging Company, PetroChina Chuangqing Drilling Engineering Co., Ltd., Chongqing 400021, China

Received 10 May 2016; accepted 1 September 2016
Available online 27 March 2017

Abstract

An oriented cluster perforating technology, which integrates both advantages of cluster and oriented perforating, will help solve a series of technical complexities in horizontal well drilling. For realizing its better application in oil and gas development, a series of technologies were developed including perforator self-weight eccentricity, matching of the electronic selective module codes with the surface program control, axial centralized contact signal transmission, and post-perforation intercluster sealing insulation. In this way, the following functions could be realized, such as cable-transmission horizontal well perforator self-weight orientation, dynamic signal transmission, reliable addressing & selective perforation and post-perforation intercluster sealing. The combined perforation and bridge plug or the multi-cluster perforation can be fulfilled in one trip of perforation string. As a result, the horizontal-well oriented cluster perforating technology based on cable conveying was developed. This technology was successfully applied in unconventional gas reservoir exploitation, such as shale gas and coalbed methane, with accurate orientation, reliable selective perforation and satisfactory inter-cluster sealing. The horizontal-well oriented cluster perforating technology benefits the orientation of horizontal well drilling with a definite target and direction, which provides a powerful support for the subsequent reservoir stimulation. It also promotes the fracturing fluid to sweep the principal pay zones to the maximum extent. Moreover, it is conductive to the formation of complex fracture networks in the reservoirs, making quality and efficient development of unconventional gas reservoirs possible.

Keywords: Horizontal well; Cluster perforating; Oriented perforating; Cable conveying; Sealing; Dynamic conductivity; Fracturing (rock); Shale gas

1. Technical background

Exploration and development of unconventional gas reservoirs, such as shale gas [1–3] and coalbed methane (CBM) [4,5], have vigorously developed in China and become an important component of the national energy strategy. In majority of these operations, horizontal-well engineering technology is used to enable stabilized production and long service cycle. Staged fracturing [6], a necessary stimulation technique in unconventional oil & gas exploration and development, can generate fracture networks in reservoirs to maximize the connectivity to oil and gas. Cluster perforating is preferred to support the staged fracturing completion. During horizontal drilling, however, wellbore trajectory may depart from the reservoir upward or downward. Therefore, in addition to cluster perforating, orientation of perforation should also be considered to ensure the subsequent stimulation benefits of the effective reservoirs [7].

Cluster perforating [8] is a revolution in perforation technology within China. In practice, composite bridge plugs [9] are utilized to divide the target interval for stimulation into sections, each of which is further divided into clusters. The perforating string and the composite bridge plugs are conveyed by cables to the target zone in a single trip, and the

☆ Project supported by the National Major S&T Project "Shale gas reservoir stimulation technology" (No.:2012ZX05018-004).

* Corresponding author.
E-mail address: chb4019@sina.com (Chen HB.).

Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2016.09.001

bridge plug setting and multi-cluster perforating operations are completed successively [10,11], thereby creating the conditions for the subsequent staged fracturing. This technology provides a solution to the lack of oriented perforation in multi-stage firing control, section division by drillable composite bridge plugs, selective perforating, pumping in horizontal wells [12], and high-pressure wellhead blowout prevention technologies.

Oriented perforating [13] is a relatively mature technology that is often used for perforating in vertical wells along the maximum horizontal principal stress and in horizontal wells. The active orientation is used in vertical wells [14], such as the cable associated with the rotary sub, and the passive orientation is applied in horizontal wells [15], such as the eccentricity design or balance weight design of the perforator.

Oriented cluster perforating technology integrates both the advantages of cluster [16] and oriented perforating technologies and provides the solution to the following challenges: ① "dynamic orientation and static cluster selective perforation" during oriented cluster perforating; ② normal sealing and addressing of remaining perforating guns after perforating at a certain cluster; and ③ signal and conductivity under dynamic conditions, and perforator self-weight eccentricity.

2. Processes and characteristics

Technical solution of horizontal-well oriented cluster perforating should be combined with the designed structure and process optimization, in order to solve such challenges as clustering selective perforation, arbitrary perforation phase orientation, signal transmission & power supply while orientating the perforator, and sealing of unfired perforator after perforation.

2.1. Cluster selective perforation

Since a combination of electronic selector (Fig. 1) and electronic detonator is applied in electronic cluster perforating, the assembled perforator used in the non-oriented perforating mode could not be dynamically rotated, and electronic selector and electronic detonator are assembled within the joint to ensure reliable wiring and grounding. Perforator used in the horizontal-well oriented cluster perforating, however, could be randomly rotated, and it is required to package the electronic selector and detonator into the perforating gun so that they can rotate with the perforator to ensure reliable electronic addressing and conductivity.

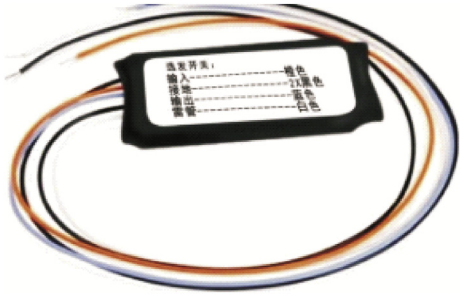

Fig. 1. An electronic selector.

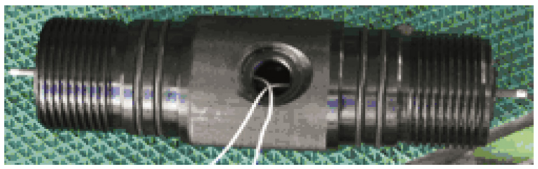

Fig. 2. A sealing design sample.

2.2. Sealing and insulation

While the cluster perforator is run in the hole, an absolute sealing of parts assembled within the gun should be ensured before perforating. Following the perforation at one cluster, reliable sealing and insulation of other unfired perforators should be ensured. The structure of the oriented cluster perforating is designed to solve the sealing problem. The gun barrel is sealed with seal ring and joint, and the joint between clusters are sealed with insulating lead wire pole and seal ring, to ensure reliable sealing and insulation of the perforator after perforating (Fig. 2).

2.3. Orienting structure

Oriented cluster perforator is based on a self-weight orientation principle. By introducing the eccentric balance weight associated with ball-bearing in the carrier, the center of gravity for the perforator always shifts to one side. The direction for jet flow of perforating charge shall be placed according to the demand of production. The detonating cord is wrapped on the outside of the carrier to keep a reasonable clearance from the gun barrel. Perforating direction in horizontal wells remains unchanged regardless of the rotation of the perforating gun barrel (Fig. 3).

2.4. Dynamic conductivity

The oriented cluster perforator rotates randomly while running into the hole, and the designed dynamic conductive

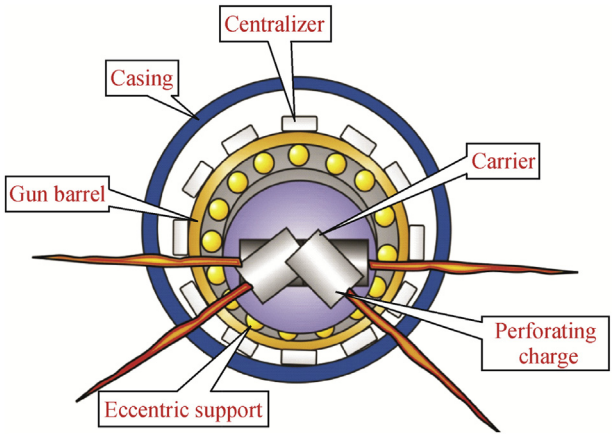

Fig. 3. Schematic diagram showing the orientation principle.