Methods to create slots–stress raisers in near-wellbore zone

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Abstract. The author reviews methods and tools for cutting slots–stress raisers in drill hole walls for directional hydraulic fracturing. Based on the review, the classification is proposed for the known tools by the method of initiating slotting: mechanical cutting; indentation of hard indenters; percussion effect by a plastic substance; blasting of jet charges. By the number of the patented engineering solutions and the level of implementation, the most popular technique is mechanical cutting. The known tools only ensure creation of slots–stress raisers in soft and medium-hard rocks. It is required to continue studies and to develop new methods and tools for cutting initiating slots for the directional hydraulic fracturing in solid ore.

1. Introduction

One of the extensively developing methods of stress assessment in rock mass is the hydraulic fracturing stress measurement technique. Proposed in the late 1990s, the classical procedures for calculating stress components by the hydraulic fracturing data from several wells require accounting for relations of vertical and horizontal stresses, are cumbersome and very difficult to implement in mines [1, 2]. It seems a promising way to calculate the effective stresses in rock mass by the data of directional hydraulic fracturing in differently oriented well [3, 4]. The preset orientation of the created fracture can be ensured through creation of stress raisers as slots cut longitudinally or transversely relative to the well axis in the packer interval.

By now the practical application of directional hydraulic fracturing with a view to studying stress fields in intact rock masses is limited. In connection with this, for technological advancement and equipment improvement in this research area, we review the existing methods and tools for creation of slots–stress raisers in the near-wellbore zone.

2. Methods and tools for stress concentration slotting in well walls

The known engineering solutions are classified by the method of cutting an initiating slot (Figure 1).

The most licensed and widely applied approach is mechanical slotting. The major advantage of this method is feasibility of creating slots of any shape without initiation of discontinuities in adjacent rock mass, which is impossible with blasting jet charges, for instance [5]. Moreover, the cost and labor input of mechanical slotting is low while slots can be considerably deep.

In the mechanical slotting method, cutters can be pushed out of a cutting tool mechanically or hydromechanically.

In the long view, it will be possible to apply hydraulic initiating slotting by high pressure jets, or thermal slotting by plasma drilling, etc. [5].
By the type and orientation of a created slot relative to the well axis, the known engineering solutions can be grouped as tools for straight-line longitudinal slotting and tools for ring transverse stress concentration slotting.

![Initiating slotting techniques]

**Figure 1.** Classification of initiating slotting techniques.

3. **Tools for longitudinal slotting well walls**

Mechanical tools for cutting longitudinal slots are designed since the 1960s and intended to create stress raisers in well walls for softening rocks before subsequent hydrodynamic or blasting treatment.

Conventionally, the tools are divided into two subgroups:

— tools for cutting longitudinal holes from the well mouth to the full penetration depth of the tool (rigidly fixed cutters);

— tools for cutting longitudinal slots in selected intervals of wells (equipped with mechanism for pushing of cutters from the tool body).

The tools in the first subgroup feature simple design but their application range is limited. These tools are unsuitable for directional hydraulic fracturing as longitudinal slots cut in the hole walls where packers adjoin hinder sealing of the packer interval.

The tools from the second subgroup for longitudinal slotting in the selected intervals of wells are protected by numerous USSR Author’s Certificates and RF Patents. As against the known engineering solutions, these tools feature different design of cutter, mechanism, of cutter pushing-out, spacer and other assemblies. Figure 2 shows alternate designs of longitudinal slotters (without description of components) [6–8].

4. **Tool for cutting transverse slots in well walls**

Development and extensive use of directional hydraulic fracturing in coal mines as a method of difficult roof control and coal degassing initiated engineering of mechanical tools for creation of initiating slots in well walls in perpendicular to the well axis started in the 1980s–90s. Thus far there are many patents for inventions and useful models granted in this area of R&D in Russia, e.g. [9–14].

The implemented and tested engineering solutions are described below.

To implement directional hydraulic fracturing for coal drainage and rock mass softening the Institute of Mining together with Special Design Bureau of Applied Geophysics (SB USSR Academy of Sciences) designed and tested slotters SP-90, ST-90 and SV-90 intended for cutting ring slots in holes with diameter of 90–100 m in mines in Kuzbass [1, 15].

Spring slotter SP-90 has a body inside which, on the axes that are eccentric and parallel to the slotter axis, two cutting tools with hard-metal cutters are installed. The output mechanism of the cutting tools is actuated when the slotter is butt against the well bottom. The design involves two twist spring coils to push and pull cutters. Slotter SP-90 cuts slots in holes with diameter to 185 mm. Wire slotter ST-90, due to a complex design, lacked application. The next in this line was screw slotter SV-90 based on hydromechanical output of cutters from the body. This slotter design provides for
installation of three cutters at an angle of 120° relative one another, which ensures self-centering of the slotter in the well. Slotter SV-90 cuts ring slots at any interval in the well, starting from its bottom.

Figure 2. Longitudinal slotting tools: (a) USSR Author’s Certificate No. 1641994; (b) USSR Author’s Certificate No. 1408067; (c) USSR Author’s Certificate No. 1408068.

For transverse slotting in holes with diameter of 39–46 mm, the Institute of Mining designed mechanical slotters SM-42, SM-45 and SM-45M also tested in Kuzbass mines [16, 17]. The slotter is mounted in a drill rig and entered in a hole with a drill column down to the well bottom. Under the action of the axial force from the drill column, a push stick is gradually slid in the body while the cutters along inclined guides go out of the body though longitudinal openings and cut in the well walls a dish-like initiating slot in the perpendicular plane to the well axis. The change in the motion path of the cutters from a straight (SM-45) to a parabolic line (SM-45M) allowed cutting initiating slots of increased diameter from 105 to 130 mm.

For directional hydraulic fracturing stress assessment in salt rock mass, the Institute of Mining designed a tool cutting transverse initiating slots to 25 mm deep in wells with diameter of 76 mm. The tool was successfully tested in potassium mines of the Upper Kama deposit [18].

It is worthy of mentioning that the above-described tools for cutting ring-wise transverse slots are unsuitable for operation in ore bodies.

The method of initiating slotting under penetration of indenters in the well walls with subsequent hydraulic fracturing is implemented in the tools described in [19, 20]. These tools were not tested in mines. According to the authors’ claim, the application domain of these tools is medium-hard and hard rocks.

The tool for directional crack generation in wells [19] is suggested to use in difficult roof control or in coal degassing. The tool is placed in a well at an assigned depth using tightly jointed rods. The hydromechanical system of push-and-pull of the indenters is meant for the pressure to 15 MPa. The maximum penetration depth of the indenters is 8–10 mm.
The self-advancing down-the-hole tool of the equipment for local directional hydraulic fracturing in long uncased wells in thermal recovery of low-gravity oil is described in [20]. This tool initiates transverse fractures by modules–indenters actuated by pressurized fluid in the fracturing interval. The tool can be equipped with up to 6 indenters uniformly arranged inside the tool body.

A separate group includes tools generating directional cracks at the well bottom based on the impact effect produced by a plastic substance. It is shown in [21] that plastic substance can be used for initiation of cracks crosswise the well bottom without a cutting tool. In this case, a barrel filled with a plastic substance is placed in a hole down to its bottom. The barrel has an opening in the center. In this opening, a rod is inserted. The free end of the rod is hit, which initiates an incipient crack in the plane of the well bottom. This incipient crack, as against an initiating slot, has the minimum possible tip radius. For this reason, due to higher stress concentration at the tip, the further growth of the crack will take places under much lower pressure. The tools based on this operating principle are licensed [22, 23]; yet there are no data on their application in mines.

5. Conclusions
Based on the analytical review, the classification of the method and tools for creation of slots–stress raisers in the wellbore zone has been proposed.

Designers strive to engineer devices for cutting initiating slots in holes for further directional hydraulic fracturing in coal degassing, rock mass softening or enhancement of well productivity in thermal recovery of low-gravity oil. The tools tested in operating mines ensure initiation of slots–stress raiser only in soft and medium-hard rocks.

Aiming to expand the application range of the directional hydraulic fracturing, it is necessary to develop new methods and tools for initiating slotting in holes in hard rocks.

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