Improvement of downhole probe control system for the measurement of hydraulic fracturing at considerable distances from the working contour

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Abstract. Actual issues of improving the design of the downhole probe as part of equipment for the practical implementation of the method of measuring hydraulic fracturing in mine conditions were discussed. The variants of the probe operation control schemes are presented using a single press pipeline, designed to simplify the installation of the equipment in the borehole, especially at considerable distances from the working contour. The new design map for controlling the process of probe packing is considered. Its application eliminates unstable deformation of sealing elements, in case of the well diameter increase above the nominal value, ensuring reliable sealing of the test area.

1. Introduction
The method of hydraulic fracturing (HF) stress measuring on borehole walls is used for the purpose of experimental determination of stresses acting in a rock massif [1–5]. Advancement of the measuring hydraulic fracturing technology would be impossible without improving technical means within the HF equipment and largely contributes to the method’s practical implementation in mine conditions. This equipment includes the IVK Gidrorazryv (Hydrofracking) measurement and calculation system (MCS) developed at the Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences (SB RAS), which was used in different versions for rock mass stress state monitoring at a number of mines: Uralkaliy, Silvinit, Norilsk MMC, Tashtagol deposit (in the production operation conditions at the Federal State Unitary Enterprise Mining and Chemical Combine) [6–8].

2. Features of the developed tool
The main component within IVK Gidrorazryv system is a downhole probe ensuring the hydraulic fracturing of the test interval of borehole walls. The practical hydraulic fracturing measuring in mine conditions have prompted an important direction for improving the probe design, which involves searches for technical solutions that will simplify its installation in the borehole and provide for reliable control of its operation, specifically, at significant distances from the working contour [9].

The probe design suggests the presence of two high-pressure pipelines: the one supplying the fluid into the channel to enable the packer operation in the test section of borehole, while the second one directs the fluid flow into the channel connected to the inter-packer interval for hydraulic fracturing of the borehole walls.

The complete structure with two supply pipelines to maintain the downhole probe operation significantly increases the structure weight, besides its installation takes a long time. Moreover, minor
Depressurization of any piping reduces reliability of the entire system. In this context, researchers from the Chinakal Institute of Mining SB RAS have proposed several versions of the control system providing for operation of a downhole probe with a single supply pipeline.

In the technical solution [10], a design of the working fluid supply from a single pipeline coupled to different tubes of the downhole probe includes a driving handle with an eccentric installed on the probe end face and controlled using an idler cable. However, the mock-up test results showed that turning the driving handle to the desired position using the idler cable can be problematic at larger distances, which eventually brings disorder to the sequence of connections between the internal tubing of the probe and the pressurized pipeline, and therefore challenges the hydraulic fracturing process control. As such, the control scheme has proven effective at distances not more than 5 m from the wellhead.

The control scheme proposed in [11] for downhole probe with a single high-pressure pipeline suggests using a necked spool incorporated in the probe body. The spool movements are ensured by changing pressure of the fluid supplied from the pump, while the idle cable is used only for draining the working fluid after completion of the hydraulic fracturing, which does not require great accuracy. This technical solution simplifies the process of the borehole probe control, thereby improving the accuracy of its operations while performing hydraulic fracturing measuring at significant distances from the wellhead.

However, note that the placement of the channel switch control distributors in the downhole probe housing complicates its design and reduces maintainability. To solve this problem, the modified design is proposed for autonomous locations of hydraulic distributors connected to the probe by short high-pressure pipelines (Figures 1 and 2). In the case of the spool distributor (Figure 1), the channel switch is controlled by axial displacement of the spool, which is fixed by a locking tongue in the new position, after redirecting the rigid pressurized tubing. With the two-valve distributor (Figure 2), the control of fluid supplied either to the inter-packer space or for probe packing is also performed using the rigid pressurized tubing. In this case, the valves are opened by pushers, whose position is determined by the rotating eccentric.

The spool-type hydraulic distributors are commonly used in hydraulic systems where the nominal pressure value does not exceed 32 MPa. Therefore, the valve-type distributors are viewed as most appropriate for future applications as part of tools for hydraulic fracturing measuring.

![Figure 1](image-url). Schematic diagram of a spool-type hydraulic distributor for the borehole probe control; A, B—channels for fluid supply to the borehole probe body: 1—distributor case; 2—spool; 3—fluid supply channel from the pump; 4—spring; 5—high-pressure pipeline; 6—tongue fixation.
Figure 2. Schematic diagram of a two-valve hydraulic distributor for the borehole probe control; A, B—channels for fluid supply to the borehole probe housing; 1—distributor housing; 2, 3—valve spring and ball; 4, 5—pushers; 6—eccentric; 7—sealing; 8—channel for fluid supply from pump; 9—high-pressure pipeline.

Packing of the borehole test interval is an important stage in the measuring hydraulic fracturing technology development. The probe control system must ensure reliable sealing of the inter-packer interval, precluding the working fluid entrance into the contact zone between the sealing element (packer) with the borehole wall, or bypassing it. There are two main types of packers that differ in the principle of operation: 1) injection (inflatable) and 2) clamping packers. Note that there are no inflatable packers for mining hydraulic fracturing (and medium-head injection works) of Russian make. The previous design solutions of the downhole probe [12] with inflatable packers in the form of cylindrical reinforced elastic shells fixed with immovable clipped sealing rings on the rods have failed to ensure the quality sealing off of the borehole test section: under the system pressure in excess of 10 MPa the elastic shells were pressed out into the annular space between the probe housing and borehole wall.

The borehole probes design of IVK Gidrorazryv MCS utilizes the clamping type sealing made of polyurethane elastomer. The mine experiments revealed that frequently, particularly, in conditions of a heterogeneous rock massif, the borehole diameter may exceed the nominal allowable value at the site where the probe is situated, otherwise cavities and roughness manifestations will appear on its walls. In such cases, the clamping type sealing elements do not come into contact with the hole walls, which therefore entails loss of their stability, and in addition causes their nonuniform deformation (“corrugated” type) along the length. As a result, the borehole test interval fails to be properly sealed off (Figure 3).

Figure 3. Unstable deformation of the polyurethane packer under axial compression.

To ensure reliable sealing off of the test area when the borehole diameter exceeds the nominal allowable value, a new structural design scheme for the borehole probe packing procedure control has been proposed, which allows to completely eliminate unstable deformation of the sealing elements and provides for their additional pressing against the borehole walls. The technical solution is protected
by the Russian Federation patent [13]. The downhole probe design solution with improved probe packing control system is shown in Figure 4.

![Figure 4. Borehole probe (RF Patent 2652407): 1—housing; 2—conical nuts; 3—sealing elements; 4—fixed rod; 5—hole in the rod; 6—cylinders; 7—working cavities; 8—valves; 9—rods; 10—shank ends; 11, 13, 17—channels; 12, 14—sockets; 15—cavities under sealing elements; 16—springs; 18—metal rings.](image)

After placing the probe at the target depth of the borehole, the fluid is supplied through socket 12 via channel 11 to the working cavities 7 of cylinders 6, which, driven by the fluid pressure, begin to move apart in the axial direction, compressing the sealing elements 3. In the cases when the borehole diameter is within the nominal permissible value, the sealing elements tend to expand radially under the action of axial force and therefore become tightly pressed against the borehole walls, without losing their stability and thereby sealing off the borehole test section perfectly well. If the borehole diameter at the location of the borehole probe is greater than the nominal permissible value and the sealing elements do not come in contact with the borehole walls when exposed to axial compression, the cylinders 6 perform the maximum allowable axial movement limited by the stroke length of the rods 9 with the end shanks 10, compressing thereby the sealing elements to their ultimate stability value. The axial movement of the cylinders 6 is ceased by the opening of valves 8 assisted by the fluid flow from the working cavities 7 via channels 17 in the cavity 15 below the sealing elements. In this case, driven by the fluid pressure, the latter tend to be radially bent (as shown by the dotted line) until they are pressed against the borehole walls. The sealing elements’ tightness at the ends is achieved due to their conical shape and the force pressing them against the inclined surfaces of conical nuts 2 and cylinders 6; while their strength is ensured by metal enveloping rings 18 installed on their outer surfaces from the end sides. After sealing the borehole test section, the fluid is supplied via the socket 14 along the channel 13 to the isolated borehole section in advance of the hydraulic fracturing of its walls. When the borehole probe is
dismounted, the pressure in the supply pipelines is reset to zero and the sealing elements are returned to their original position by the force of springs 16. The performance efficiency and reliability of this design has been confirmed in a series of laboratory tests.

3. Conclusions
The proposed modifications of the borehole probe control schemes using a single high-pressure pipeline will facilitate the equipment installation, in particular when the borehole section selected for hydraulic fracturing is outlying from the working contour.

To ensure tightness of the test area packing in cases where the well diameter exceeds the nominal permissible values, the developed borehole probe design eliminates the sealing elements’ unstable deformation under axial compression. A reliable sealing off of the test area is provided by additional pressing of the sealing elements against the borehole walls due to the pressure rise in the cavities located below them.

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