Thus, the quality of the parts obtained is determined above all by the quality of the fabrication of the rollers, i.e., by the accuracy of the machining of the profile, by the accuracy of the fit of the set of rollers, and by the roughness of their surface.

ELEMENTS OF THE MECHANICS OF THE PROCESS
OF THE MILLING OF DAMAGED METALS IN
A BOREHOLE

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In connection with the liquidation of damages in oil and gas wells, there is a considerable volume of work on the milling of damaged metals in a borehole. To increase the efficiency of the milling, the instrument must assure the greatest removal of metal from the damaged object with the greatest wear resistance of the cutting edge. These conditions permit a considerable reduction in the number of lowering—hoisting operations connected with the replacement of a worn instrument and accelerate the maintenance of the well. To eliminate damages in wells being worked and being drilled, different types of milling instruments are used [1]. The cutting edges of these millers have a different construction and are made of different hard alloys. It must be noted that the breakdown and cutting of metals in a borehole are complex processes and have as yet been insufficiently investigated.

In the Azerbaidzhan Scientific—Research Institute for Petroleum Machinery, investigations have been made and experimental and constructional work has been carried out on the building of high-efficiency well millers of improved construction. In a specially built experimental unit, investigations were made of the cutting edges of model millers, consisting of a composite of pulverized hard alloys and a matrix material. The conditions of the tests were close to borehole conditions (the specific load on the sample was 50 kg/cm², and the rate of rotation was equal to 90 rpm).

Fig. 1. Dependence of specific capacity q of different materials on the duration of their testing: 1) VK2; 2) VK8; 3) VK6; 4) VK10; 5) VK15.

Fig. 2. Construction of FZ miller.

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The experiments showed that cutting edges made of pulverized hard alloys have high cutting capacity and wear resistance. To select the most efficient hard material, in the experimental unit tests were made of cutting edges made of different brands of tungsten-carbide materials (VK2, VK3, VK8, VK10, and VK15). Figure 1 gives curves of the change in the specific capacity (the ratio of the removal of metal to the value of the wear of the cutting edge) of the tested materials as a function of the duration of the tests.

As can be seen from Fig. 1, materials VK2 and VK8 showed good specific capacity. Test-stand tests and production tests, carried out in the Azneft', Krasnodarneftegaz, Kuibyshevneft', and other combines, have demonstrated good service life and high efficiency (8-10 m of passage over the metal for one instrument) for the cutting edges of millers made of pulverized hard alloys held in a matrix material (binder). With the milling of a damaged object using such millers, they are self-sharpened, since, with the volumetric wear of the cutting edge in contact with the surface of the object being milled, during the cutting process new cutting edges emerge. Under these circumstances, a layer of metal is cut off by several cutting edges. This cutting principle is incorporated in the construction of FZ millers (Fig. 2), developed by the Azerbaidzhan Scientific-Research Institute for Petroleum Machinery, and mass-produced by the Bol'shevik machine building plant (Baku) in accordance with GOST 26-02-1011-74 [1].

Let us examine the cutting process and the force effect in the elements of the cutting edge of these millers. The investigation of the cutting forces and their characteristics with application to borehole conditions is of theoretical and practical importance for improving and increasing the wear resistance and cutting capacity of borehole millers, and permits basing the design and fabrication of the milling instruments on more optimal parameters. Along with this, the study of the characteristics of the cutting forces is of interest also for determining the conditions for the stability of the cutting elements in the binder.

It must be noted that the cutting effect of the cutting edge, other factors being equal, depends also on the arrangement of the pulverized hard alloys at the contact surface of the cutting edge, i.e., on how many hard particles with sharp edges participate in the cutting in the interval of time under consideration.

With the sintering of the cutting edge of a borehole miller, the cutting elements, i.e., the pulverized hard particles, held in a binder, are arranged arbitrarily over the whole volume of the edge and, at the moment of contact with the cutting surface, the sharp edges can be in different positions, for example, A, B, and C (Fig. 3). An important condition of the cutting is the value of the leading angle $\gamma$. Thus, in position A, the value of $\gamma$ is negative ($\gamma < 0$); in position B, the value of $\gamma = 0$. According to the data of [3] and [4], with negative and zero values of the leading angle, the cutting force at the leading surface of the cutting element attains its greatest value. In position C, i.e., with $\gamma > 0$, more favorable conditions are created for cutting and removal of the chip.

Figure 4 shows the scheme of the forces acting on the leading part of the cutting element of the working edge of a miller during the cutting process (position C, see Fig. 3), and bringing about deformation of the shaving. The distribution of the normal stresses along the line of contact of the leading surface is characterized by the curve abc. The normal force $N$ is the resultant of these stresses. As a result of the friction of the shaving along the leading surface of the cutting element, tangential stresses arise whose sum gives the force of friction $f$. The sum of the forces $f$ and $N$ gives the force of shaving formation $R$. In a direction perpendicular to the cutting surface, there acts the force $P_2 = R \sin \omega$ (here $\omega$ is the angle of the action, i.e., the angle between the vector of the force $R$ and the vector of the cutting rate, in whose direction there acts the force $P_1$).