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INVESTIGATION OF THE ICE CUTTING PROCESS BY THE ROTARY DRILL

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Abstract: An experimental stand for investigation of the ice cutting process by the rotary drill is described. Experiments were carried out at the glaciological station at Vavilov Glacier (Severnaya Zemya), using a KEMS-112 electromechanical ice core drill. The correlation between the main factors: torque, drilling pressure, specific energy of ice rupture, penetration rate, and design of cutters, was determined.

Recommendations for the choice of the cutter geometrical characteristics and the optimum penetration rate are given.

1. Introduction

The specific conditions of drilling operations on extreme remote polar and high mountainous glaciers demand reduction of weight, size and power consumption of the drilling equipment. Industrial type boring rigs and machinery have low drilling efficiency (BOBIN *et al.*, 1988).

At least sixteen different constructions of electromechanical drills for liquid and dry boring have been developed in Australia, Canada, Denmark, France, Germany, Japan, Russia, Switzerland, USA (KUDRYASHOV *et al.*, 1991). Specifications of these drills vary within wide limits: cutting velocity from 0.23 to 1.59 m/s, cutter rake angle from 0° to 45°, cutter clearance angle from 1° to 30°. There is no practical theory for design of ice drill cutters. A limited number of publications dedicated to experimental investigations of the ice cutting process are available (MELLOR and SELLMAN, 1976; BOGORODSKY *et al.*, 1983; UEDA and KALAFUT, 1989). In order to obtain new experimental data, a special stand was constructed in St. Petersburg Mining Institute.

2. Testing Stand and Procedure

The testing stand (Fig. 1) allows to simulate borehole conditions. The KEMS-112 electromechanical drill was designed for deep ice core drilling. To carry out cutting experiments this drill has been modified. The length of the core chamber was made only 1.5 m, and the antitorque system was replaced by two roller lugs. A vertical tube, simulating the borehole, was filled with kerosene (TS-1).

The testing stand and the drill had four sensing resistor elements: (1) linear displacement transducer, (2) drilling pressure gauge, (3) torque gauge, (4) flow meter. Figure 2 shows an electric diagram of signal feeding, amplification and recording. The signals were registered by the N-327/5 self-recorder. The power consumption of the drill electric motor was also recorded by the N-396 self-recorder.

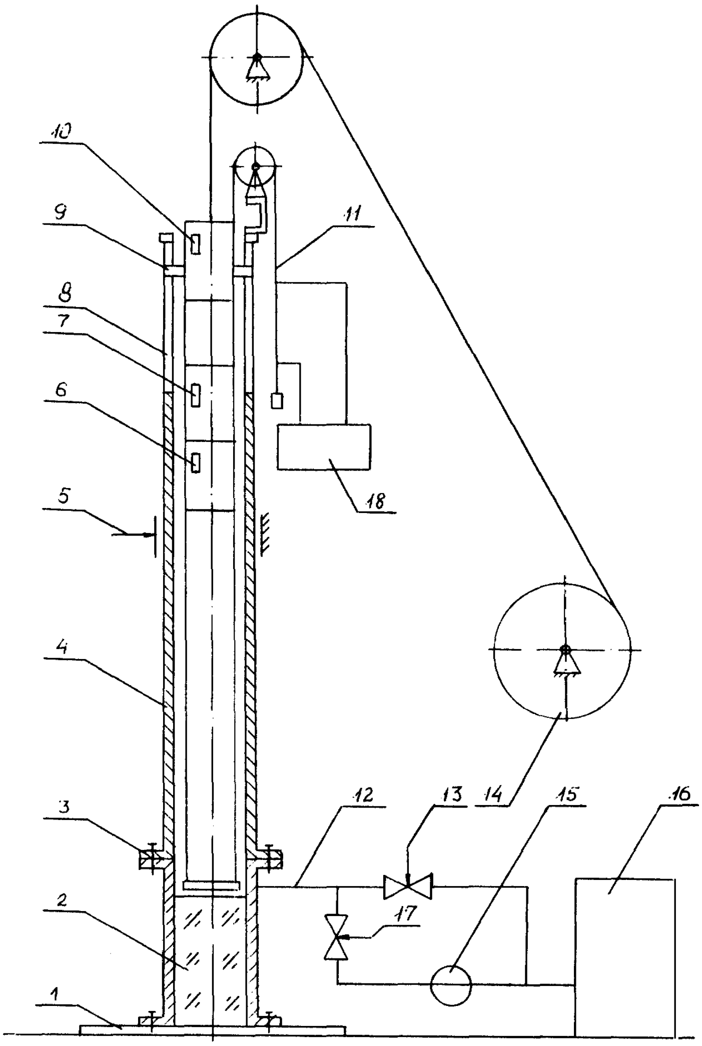

Fig. 1. Scheme of the testing stand: 1-base, 2-ice, 3-flange, 4-tube, 5-yoke, 6-flow meter, 7-torque gauge, 8-slot, 9-roller lug, 10-drilling pressure gauge, 11-linear displacement transducer, 12-tubes, 13-valve, 14-winch, 15-pump, 16-kerosene tank, 17-valve, 18-control panel.

The drilling head was equipped with three cutters. Cutters with rake angle of 0°, 15°, 30°, 45° and 60° and clearance angle of 2°, 3°, 5°, 7° and 10° were used (Fig. 3). The outer/inner diameters of cutters were 112/87 mm. The rotation speed of the core chamber was 230 rpm, and the velocity at the middle of the cutters was 1.2 m/s. The pump flow ranges from 30 to 40 *l*/min. The penetration rate was varied in the range of 5–40 m/h. The temperature of the artificial ice was –20°.... –25°C. The average drilling depth per run was 0.55 m. A total of 173 experiments were carried out in the summer seasons of 1986 and 1988. The total drilling length was 95.2 m.

3. Results

The results of the first experiments in 1986 were described in the paper by VASILIEV *et al.* (1988). The new results obtained in 1988 are more accurate, but only insignificantly

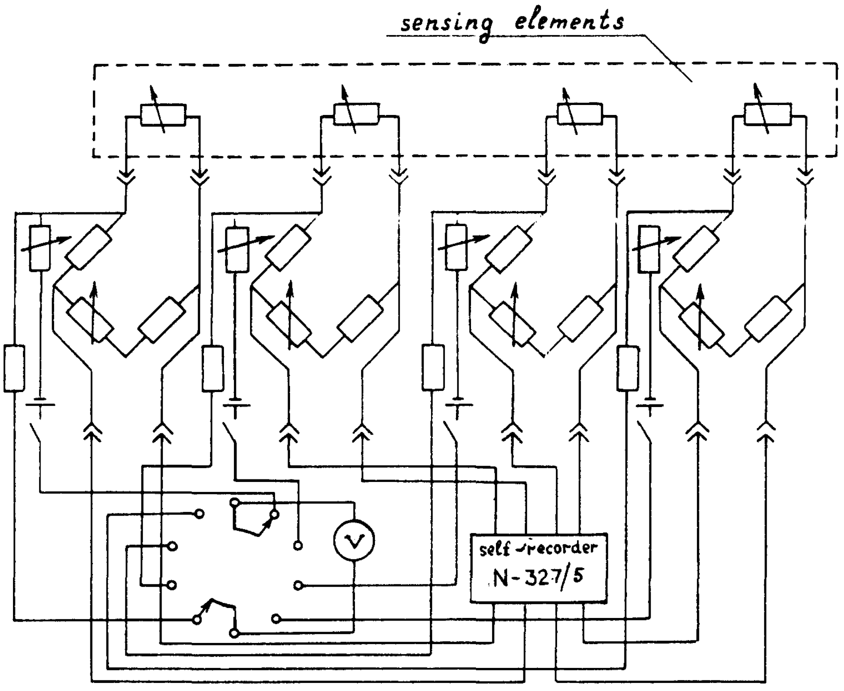

Fig. 2. Electrical diagram of data acquisition system.

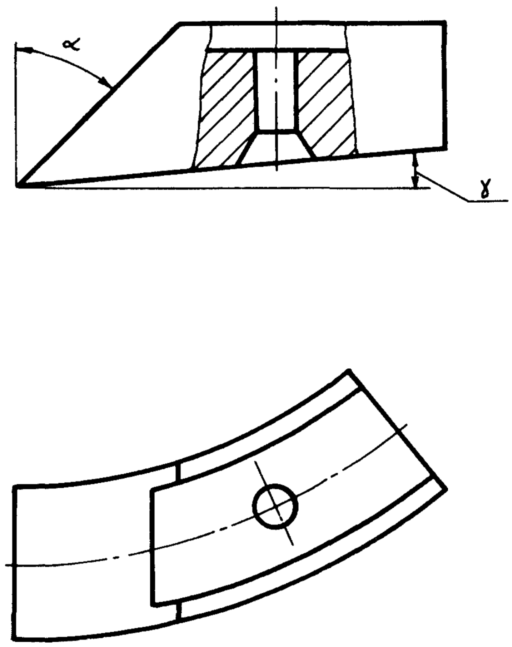

Fig. 3. Cutter.

differ from the previous experiments. This paper is based on the new results.

Plots of torque and drilling pressure *versus* penetration rate are shown in Fig. 4 and Fig. 5. Because the rotation speed of the core chamber in our experiments was constant, 1 m/h of penetration rate corresponds to 0.024 mm of cutting depth of each cutter per

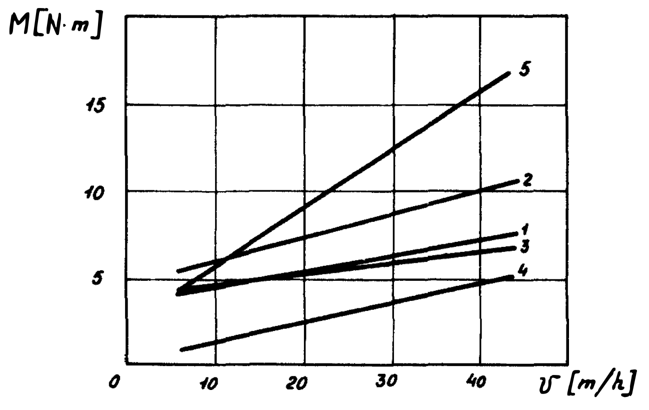

Fig. 4. Torque M versus penetration rate v for cutter with clearance angle 5° and rake angles 60° (1), 45° (2), 30° (3), 15° (4), 0° (5).

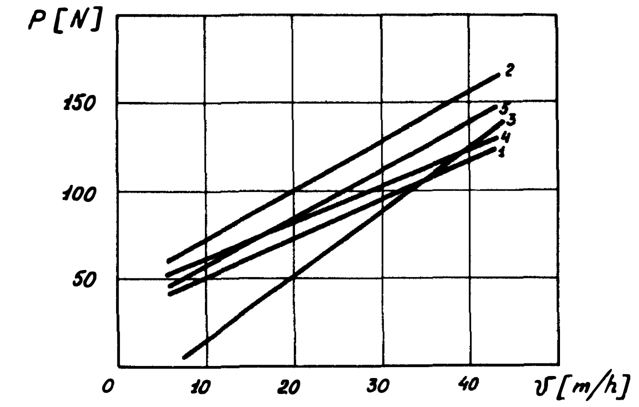

Fig. 5. Drilling pressure P versus penetration rate v for cutter with rake angle 45° and clearance angle 5° (1), 7° (2), 10° (3), with rake angle 15° and clearance angle 5° (4), with rake angle 0° and clearance angle 5°.

revolution of the drilling head. Torque and drilling pressure are directly proportional to penetration rate. The correlation coefficients for these parameters are in the range of 0.86–0.97.

Dependence of torque on cutter rake angle is unusual. Minimum torque was obtained for the rake angle of 15° and maximum for the rake angle of 45° (Fig. 6). Similar dependence was noticed in CRREL experiments (UEDA and KALAFUT, 1989).

The cutters with clearance angle less than 3° contribute most to the drilling pressure (Fig. 7). Dependence of the drilling pressure on the cutter clearance angle is similar to such dependence in the case of brittle material rupturing.

From experimental results it is clear that the specific energy of ice rupture is inversely proportional to the penetration rate (Fig. 8). Experiments show that the specific energy of ice rapture insignificantly decreases with penetration rate higher than 30 m/h. This can be explained by increase of the size of the ice chips and decrease of the specific surface energy.

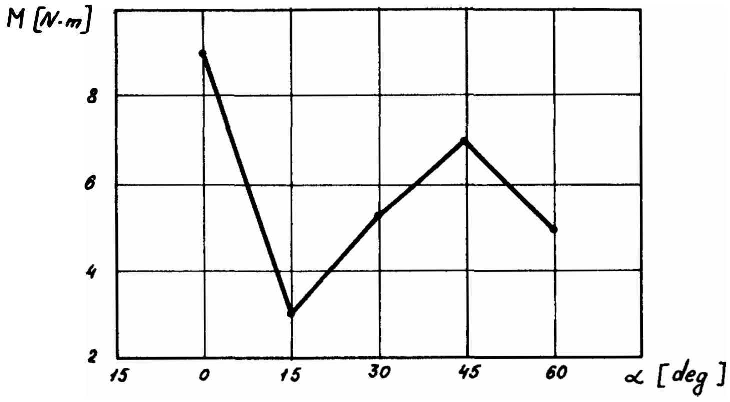

Fig. 6. Torque M versus cutters rake angle α for penetration rate of 20 m/h.

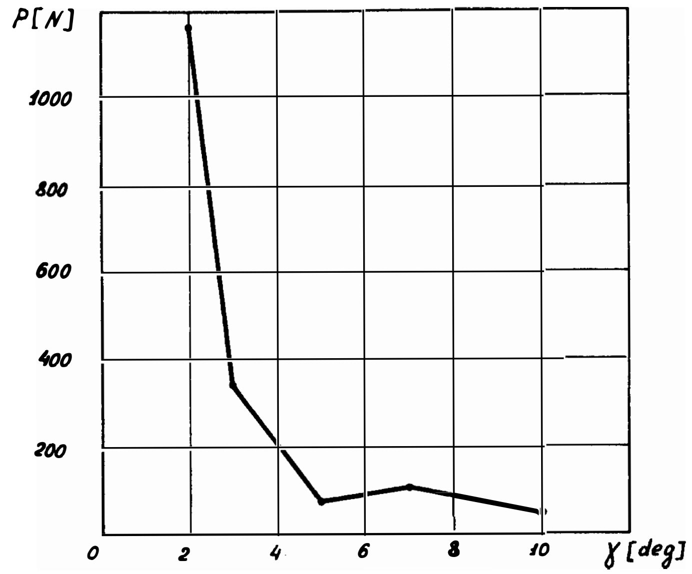

Fig. 7. Drilling pressure P versus cutters clearance angle γ for penetration rate of 20 m/h.

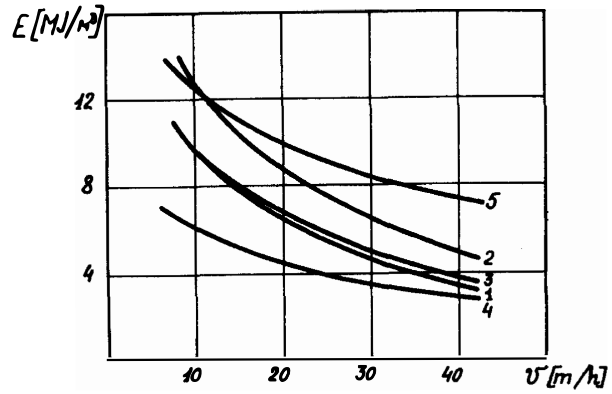

Fig. 8. Specific energy of ice rupture E versus penetration rate v for cutters with clearance angle 5° and rake angles 60° (1), 45° (2), 30° (3), 15° (4), 0° (5).

4. Conclusions

According to experimental results, optimum geometrical characteristics of cutters are 15° or 30° for rake angle and 5° for clearance angle. A penetration rate of 30 m/h is optimal for glacier ice. Furthermore, a penetration rate higher than 30 m/h only insignificantly decreases the total time of drilling (BOBIN *et al.*, 1988).

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