Journal of Engineering Physics and Thermophysics, Vol. 72, No. 5, 1999

INCREASING THE PERFORMANCE CHARACTERISTICS OF A CUTTER USED TO SAW DIAMOND CRYSTALS

V. K. Goncharov, M. G. Kiselev,
V. T. Minchenya, and M. V. Puzyrev

UDC 621.793:621.373.826

We show that the application of two-sided ultrasound charging to disks used to cut natural diamond crystals and further hardening of surfaces by depositing diamond-like film on them considerably raise the performance characteristics of a cutting instrument.

The basic performance characteristics of the disks that are used for mechanical sawing of diamond crystals are: cutability, which is evaluated by the volume or weight of the diamond removed from the zone of processing per time unit; firmness, which is characterized by the quantity of diamond raw material removed by one cutting disk; the thickness of the cut; and the quality of the surface areas of semifinished products processed, which determines the output of suitable products [1].

A high level of these characteristics is predominantly ensured by the state of the diamond-carrying layer formed when the side surfaces of the cutting disks are charged. The charging methods applied at the present time, which are based on the rubbing grains of diamond powder into the side surfaces of the disks by a plane washer or by a knurling tool, cannot ensure a high level of their performance and also increase the capacity of the charging process by processing two sides of the disks simultaneously. The thing is that, because of the extremely low rigidity of cutting disks, the friction forces that appear in two-sided rubbing-in lead to their warping and crumpling. To avoid this, it is necessary to decrease the normal load acting on the side surfaces of the disk, thus decreasing the magnitude of friction forces appearing in the zone of processing. However, a decrease in the level of force loading of the diamond grains exerts a negative influence on the process of their penetration into the material of the disk. Hence, it follows that it is impossible to effect high-quality two-sided charging of cutting disks by the traditional scheme of mechanical rubbing-in of diamond grains, which is confirmed in practice. Therefore, at the present time a search is being made for the most progressive methods of mechanical introduction of diamond grains into the material of disks, among which we can note the method of charging with the use of ultrasound.

Due to the vibration-impact regime of the interaction of the deforming element with the surface processed, the occurrence of the process of ultrasonic charging is characterized by the penetration of diamond grains into the surface of the disk at a very small value of friction forces, which does not cause its warping. This suggests that the use of the method of ultrasonic charging will make it possible to realize the scheme of two-sided processing of cutting disks, thus raising their performance characteristics and creating prerequisites for adapting the operation of charging to automation [2].

To determine the optimum regimes of two-sided ultrasonic charging of cutting disks, a series of experiments was carried out, in the course of which the following parameters were varied. The static loading P_{st} changed from 10 to 30 N; the amplitude of ultrasonic vibrations A_0 changed from 2 to 6 μm; the frequency of rotation of transformers n_{tr} changed from 100 to 500 rev/min; the time of charging ranged from 30 sec to 3 min; and the speed of the sawing disk n_d changed from 2.5 to 40 rev/min. Bronze cutting disks (BrOF 6.5-0.15) with a diameter of 76 mm and a thickness of 0.05, 0.06, and 0.07 mm were subjected to charging. The diamond micropowder ASM 28/14 was used. After processing, the disks were annealed and subjected to an abrasive ability test on a special installation.

A. N. Sevchenko Scientific-Research Institute of Applied Physical Problems at the Belarusian State University, Minsk, Belarus. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 72, No. 5, pp. 1004-1007, September-October, 1999. Original article submitted November 4, 1998.

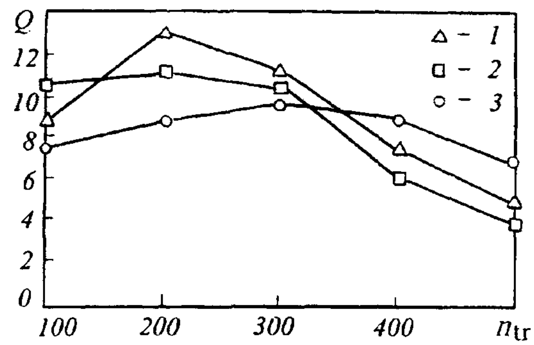

Fig. 1. Dependence of abrasive ability Q of sawing disks on the frequency of rotation of transformers η_{tr} and frequency of disk rotation n_d: 1) 2.5 rev/min; 2) 15; 3) 30. Q, g; n_{tr}, rev/min.

The abrasive ability (Q) of the side surface of a charged sawing disk was evaluated by the wear of a hard alloy specimen for a definite time of attrition. The magnitude of the wear was determined by weighing the specimen with a VLA-200 analytical balance before and after the tests.

To establish the efficiency of the proposed method, comparative tests were carried out with a batch of cutting disks charged under different conditions. The cutability and durability of some of them were determined directly in sawing crystals of diamond under conditions of commercial production, while a similar batch of disks were subjected to tests for abrasion of the hard alloy T15K6 by the side surface of the cutting disk. This procedure is described in more detail in [3]. A comparison of the data obtained revealed the presence of a certain stable relationship between the cutability of disks in sawing crystals of diamond and their abrasive ability in tests of abrasion of a hard alloy.

The dependences of the abrasive ability of charged sawing disks on the frequency of rotation of the transformers and of the disk are presented in Fig. 1. If follows from the analysis that there are optimum values of these parameters at which the maximum abrasive ability of sawing disks is attained. So, the frequency of the transformers must attain 200 rev/min, and the frequency of the rotation of the disk must attain 2.5 rev/min.

The decrease in the quality of charging of sawing disks when $\eta_{tr} > 200$ rev/min is explained by the change in the operating conditions of the acoustic vibrational system. The thing is that with the intensity of ultrasonic excitation and static loading being constant, the ultrasonic vibrations are attenuated with an increase in the speed of rotation of the transformer due to an increase in interference fit. As a result, the level of its vibration-impact regime decreases, and this is accompanied by a decrease in the amplitude of vibrations of the intermediate damping element, and this in turn worsens the conditions of penetration of the diamond grains into the zone of charging and their subsequent vibration-impact rubbing-in. Under the conditions of the experiments carried out, when the transformers rotate with a frequency of 350-450 rev/min, the vibration-impact regime of the operation of the acoustic vibrational system is replaced by an impactless one, resulting in a sharp decrease in the quality of charging of the surfaces of sawing disks.

On the basis of a generalized analysis of the results of the experimental investigations, we determined the optimum regimes of two-sided ultrasonic charging of sawing disks.

Measurements showed that, when the initial thickness of blanks was 0.05 mm, traditional charging brought it to 0.067 mm, whereas ultrasonic charging resulted in 0.056 mm. This confirms the fact that in the latter case a greater penetration of diamond grains into the material of the disk occurs. It should be emphasized that a decrease in the thickness of the disk decreases the losses of diamond raw material in sawing, and this makes the finished product cheaper.

Industrial tests showed that, in comparison with the reference disks, those processed with ultrasound ensure an increase in the:

a) intensity of sawing by 3.8–4.1%;

b) efficiency of labor by 1.4–4.1%;

c) good-to-bad yield of products in the "sawing" and "grinding of surface areas" by 0.3–0.6%;

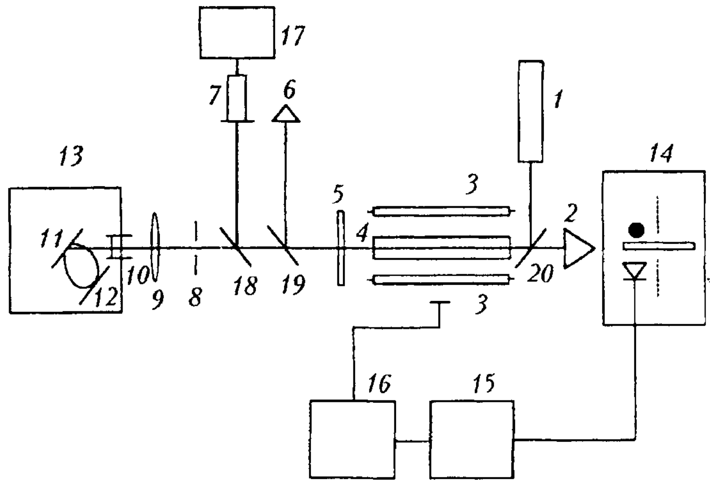

Fig. 2. Schematic diagram of experimental setup for depositing diamond-like films: 1) adjusting helium-neon laser; 2) prism of total internal reflection; 3) pump lamps; 4) working body of laser; 5) semitransparent mirror; 6) calorimeter; 7) photodetector; 8) diaphragm; 9) lens; 10) window; 11) graphite target; 12) substrate; 13) vacuum chamber; 14) synchronization unit; 15) pulse delay circuit; 16) power supply; 17) high-speed oscillograph; 18-20) beam splitters.

d) efficiency of labor in the "grinding of surface areas" by 2.7–3%.

Thus, it is shown that two-sided ultrasonic charging of sawing disks makes it possible to considerably increase their operating characteristics and substantially intensify the process of the formation of a diamond-carrying layer on their side surfaces.

To increase the operating characteristics of sawing disks further, an attempt was made to cover their diamond-carrying layer with a diamond-like film. The latter was deposited from an erosion plasma jet obtained by exposure of a graphite target to pulsed laser radiation in vacuum. The general scheme of the experimental setup is depicted in Fig. 2. A working body 4 made of GLS-6 neodymium-doped glass with a diameter of 30 mm and a length of 630 mm serves as the source of radiation. Pump lamps 3 of type IFP-20 000 were energized by a power supply 16 (GOS-1001M). The resonator of the laser consists of semitransparent mirror 5 and a rotating prism of total internal reflection 2 that changes the Q-factor of the resonator. This scheme makes it possible to effect the regime of laser radiation generation with a modulated Q-factor in the form of a monopulse with a length of 30 nsec (at half height) and an energy of up to 9 J. A synchronization unit 14, which consists of a photodiode and an incandescent lamp and a delay circuit 15, forms a synchronization pulse to start a high-speed oscillograph 17 (S7-10V). The latter and photodetector 7 control the time parameters of radiation. The radiation energy is controlled by an IKT-1M calorimeter 6. To control the characteristics of the laser radiation, a portion of it is branched off by beam splitters 18 and 19. The entire optical circuit is adjusted by means of a helium-neon laser 1 (LG-105) and a beam splitter 20, which is removed from the resonator before laser operation. The laser radiation emitted is focused by a lens 9 and is admitted into a vacuum chamber 13 through a window 10. A graphite target 11 is set at a certain angle to the optical axis of the laser for the convenience of setting the item 12 onto which the film is sputtered without intercepting the laser beam.

To determine the composition and the parameters of the diamond-like films obtained in this way, the sputtering was performed on quartz, glass, silicon, and bronze (BrOF 6.5-0.15) plates.

The properties of the films were investigated by Raman scattering spectra [4] and by the spectra of transmission and reflection [5-7]. The relief of the films and their thicknesses were controlled by means of an atomic-force microscope. We carried out experiments to determine the effect of the distance from the target to the substrate and the power density of the affecting laser radiation on the quality and rate of sputtering of the diamond-like film.

As a result of the investigations carried out we succeeded in obtaining defect-free diamond-like films with a density of 2.9 g/cm^3 without substantial inclusions of a graphite phase. Conditions are found for carrying out multiple sputterings at large rates of formation of diamond-like films without decreasing their quality. A 0.05 μm-thick film is formed in one laser pulse.

Using this method, diamond-like films were sputtered onto sawing disks into the working surfaces of which diamond grains were introduced beforehand by the method of ultrasonic charging. The film bonded the diamond grains to the base and to each other. In this case its thickness amounted to 0.5–1 μm.

Comparative tests of the disks on which a diamond-like film was deposited by the method of laser sputtering as a reinforcing surface with the disks obtained by mechanical charging showed that in the first case, when a natural diamond is sawn, the quality of the surfaces processed increases. The durability of the disks increases by a factor of 1.5, with the temperature in the zone of cutting decreasing by 30–40%. This is especially notable when large crystals are sawn.

Thus, using laser deposition of diamond-like films on the surface of sawing disks preliminarily charged by ultrasound, one manages to obtain an instrument with higher performance characteristics. This technology can also be used to produce the processing surfaces of faceting disks.

REFERENCES

1. M. G. Kiselev, S. S. Savitskii, V. T. Minchenya, G. A. Vasilyuk, and É. A. Martsinkevich, *Almazy Sverkhtvyord. Mater.*, No. 12, 5-6 (1983).
2. M. G. Kiselev, V. T. Minchenya, and I. A. Kas'yanenko, *Increasing the quality of charging of sawing disks by their ultrasonic superfinishing*, Minsk (1995), Deposited at VINITI 07.04.95, No. 954.
3. A. M. Bocharov, M. G. Kiselev, and V. T. Minchenya, *Kolyma*, No. 1, 3-4 (1992).
4. A. S. Bakai, A. V. Baranov, and V. E. Strel'nitskii, *Poverkh. Fiz. Khim. Mekh.*, No. 3, 92-98 (1990).
5. Yu. A. Bychkovskii, V. P. Kozlenkov, I. N. Nikolaev, E. V. Charyshkin, and A. A. Chistyakov, *Poverkh. Fiz. Khim. Mekh.*, No.4, 145-149 (1990).
6. S. N. Tarasenko, *Fiz. Khim. Obrab. Mater.*, No.5, 84-87 (1990).
7. S. I. Frolov and V. I. Gavrilenko, *Ukr. Fiz. Zh.*, 36, No. 4, 510-511 (1991).