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Characterization of wear and profile of diamond drill bit by optical profilometry

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A new technique to measure wear and profile of impregnated diamond drill bit for mineral exploration is presented. A three-dimensional surface mapping of worn diamond drill bit surface is obtained by the laser triangulation method. With adequate algorithms all relevant data can be obtained. Consequently, the volume loss between two distances cored can easily be measured with a great precision. Moreover, computerized cross sections of the worn surface give relevant information about the profile resulting from the drilling process.

I. INTRODUCTION

The wear measurement and the profile evaluation of impregnated diamond drill bits are usually difficult to perform with exactitude, and prone to large errors. The volume determination by liquid displacement measurements is inaccurate when the volume lost is small and the specimen is large. Habitually, the wear of diamond drill bits is evaluated by calculating the weight loss between two distances cored.[1] Unfortunately, this procedure is tainted with large errors because the weight loss can come from the noncoring bit. The wear can also be measured using the linear bit wear, which can be measured with a micrometer jig.[1,2] With this system, profiles are obtained by taking measurements across each segment of the bit from the inside to the outside peripheries. Afterward, the volumetric loss due to wear is evaluated by subtracting the variations in profile shape measured at two distances cored. This system allows us to evaluate the wear rate by calculating the volume loss after discrete distances cored. However, this technique gives only an evaluation of the profile and wear because only few readings at different positions on the bit surface are taken.[3,4]

In order to improve for an impregnated diamond drill bit the profile evaluation and to measure directly the volume loss with a great precision, we have used the laser triangulation method and adapted this technique to the diamond drilling field. In this paper, we present the principle of operation of this technique and the apparatus design. We also present some results as well as the advantages and the disadvantages of this new technology.

II. PRINCIPLE OF OPERATION

Basically, the optical three-dimensional mapping profilometer is composed of four components: a motorized positioning system, a visible laser diode source, a camera, and a computer for data acquisition and analysis of results.

The system is designed for testing standard impregnated diamond drill bit (DDB) of different sizes. Because of the radial symmetry of the DDB, their surface is scanned using a circular displacement stage driven by a single stepping motor. A laser triangulation device is then used for measuring the geometry of the drill bit surface along an imaginary line that crosses the surface radially. This way, the surface is divided into several hundred pie shaped slices with truncated tips. The surface geometry measurement along one radial line is repeated for each slice and is considered to be representative of the surface radial geometry for the entire slice. The surface geometry is further divided into volume elements equally distributed along each radial line. The volume of one slice element may be computed by multiplying the measured surface height at each of the punctual location by the corresponding slice element surface computed from the bit circular shape and its radial distance from the center of the bit. The sensor accuracy for the height measured over any single point of the surface is 35 μm, thereby limiting the accuracy of the measurement of each individual volume element.

The laser triangulation device is designed for measuring the surface geometry radially across the bit from one stationary position (see Fig. 1). A laser diode attached to a lens assembly is placed above the DDB and is used to project a beam of light along a direction perpendicular to its surface. The beam of light illuminates the surface along one single line (see Fig. 2). A 2D charge coupled device (CCD) television camera positioned at 45° with respect to the laser beam collects the light scattered by the surface of the DDB. Images of each profile are digitized and analyzed by a computer connected to this camera while the DDB executes a complete revolution around its center axis. At any time a monitor allows us to visualize the profile of the surface. Each image is immediately analyzed in order to extract and keep in memory only the surface geometry data. The whole surface of the DDB is scanned and the results are memorized for further off-line analysis. Finally, the volume can be calculated with respect to a reference plane located above the surface of the DDB.

III. SPECIFIC DESIGN CONSIDERATIONS

The purpose of the instrument is for measuring volume variations from the beginning of a wear test. The absolute location of the reference plane is not relevant. However, it is imperative that its location relative to the DDB base stays precisely the same for all the measurements and particularly after several removals and reinstallation of a given

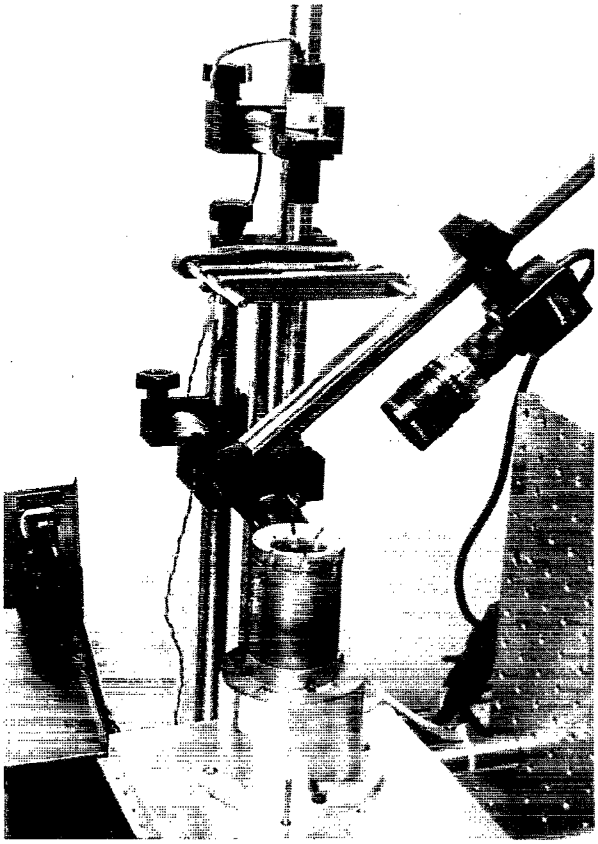

FIG. 1. The DDB wear measurement system.

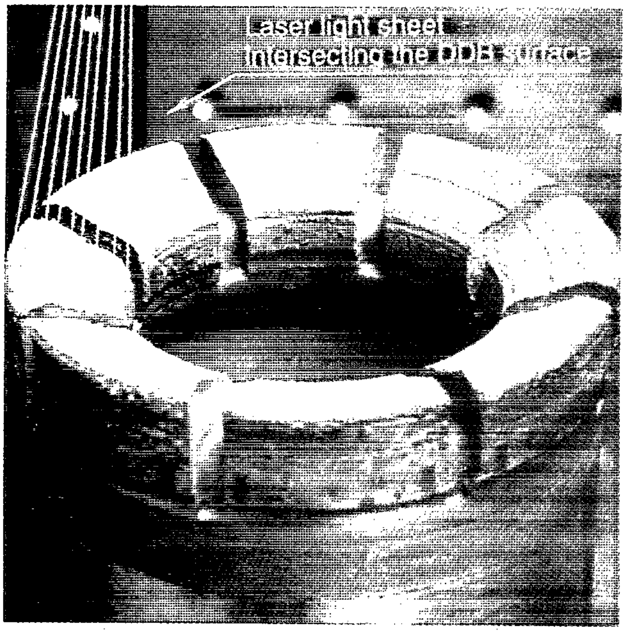

FIG. 2. Laser line on the surface of one segment of a BQ size diamond drill bit.

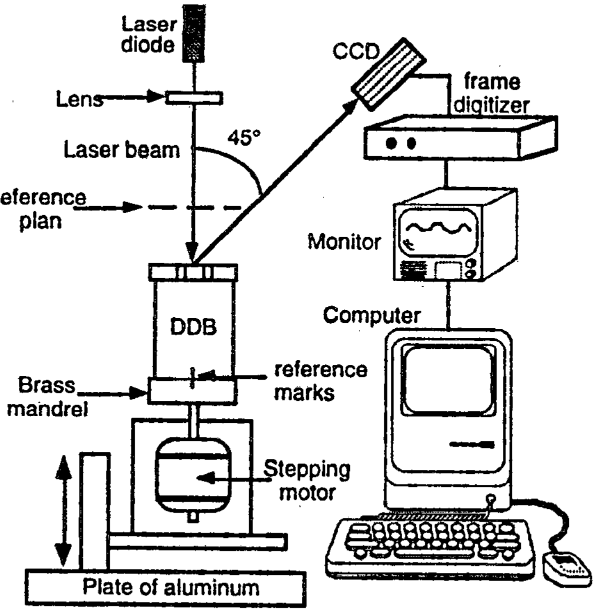

FIG. 3. Schematic representation of the diamond drill bit wear measurement system.

DDB test sample. Therefore, the DDB (ex.: BQ or XRP bit size) is screwed on a threaded brass mandrel that is maintained in is centered by the shaft of a computer-controlled stepping motor (see Fig. 3). A reference mark punched on the DDB must match a corresponding mark on the mandrel. The brass support and the motor's shaft are perfectly perpendicular to each other. The stepping motor is maintained in place by a support that is placed on a 50-mm-thick plate of aluminum. The DDB can be moved vertically using another stepping motor fixed on the vertical support. The DDB and the motor assembly are centered under the laser beam. The laser beam pass through a focusing lens which illuminate a small portion of one segment from the inside to the outside peripheries. The laser source projects a 50-μm-wide light line from the inside to the outside diameters perpendicularly to the DDB surface. A camera is placed along a direction at 45° away from the laser beam in order to collect the light coming from the reflection of the laser beam on the surface of the DDB. In this way, an entire profile of one section of one particular DDB segment is produced on the surface of the camera imaging plane. The camera is connected to a monitor that is connected to a frame digitizer within the computer (an IBM/PC compatible 486, 50 MHz). For each profile measurement, four images are first digitized at four closely spaced locations around the DDB and summed together in order to average out speckle noise. An algorithm based on the first moment computation is then used for converting the two-dimensional image into a line vector representative of the surface profile; two equations based on eight calibration coefficients are then used to convert the data to a vector of calibrated space values. The results are stored for further analysis.

The surface of the DDB must be painted with a mate coating after a drilling test and prior to a surface profile measurement in order to eliminate specular reflections caused by the diamond particles. The coating attenuates surface reflectivity variations and thus, eases substantially the image analysis complexity and improves the accuracy of the measurements. The coating operation requires only a few seconds within a measurement cycle that lasts for several minutes. Experimental tests have shown that the same DDB covered with one layer and then with two layers of paint displayed the same volume readings (within the instrument accuracy). Therefore, the coating thickness variations from one measurement to another may be neglected.

The DDB surface includes several waterways (WW) which are deep indentations, typically between 6 and 8 mm height, to allow cooling water to circulate. The narrowness of the indentation makes the bottom of the WW of a new DDB invisible to the laser triangulation device. As the wear progressively lowers the surface of a DDB, the bottom of the WW becomes visible and their newly available measurement might induce false volume readings. Furthermore, soft DDB matrix used in hard rock formation can tend to form bridges over the WW thereby increasing the apparent drilling surface of the DDB during a drilling test. Care has been taken during the experimental procedure and in the volume computation program to exclude the WW and thus, prevent any related false volume measurement.

Four hundred surface profile measurements are made over a DDB as it makes one full rotation on the circular positioning system. Such a number of measurement is required for the precise identification of the WW location. It also makes possible a substantial attenuation of the measurement noise for which the optical triangulation device is responsible, by statistical averaging. Indeed, one profile measurement is representative of the whole surface geometry because of the radial symmetry and the statistical error of one profile is not correlated with any other profile measurement made around the DDB. Knowing the surface proportion nonoccupied by the WW (typically 85%), the full volume may be estimated from one measurement. The statistical error that characterizes such an estimate is reduced by the square root of the number of profiles used to compute the volume ($\sqrt{0.85\times400}=18.4$). As stated earlier each profile is composed of several height measurements distributed along a radial line. The height accuracy for each individual measurement has been estimated to 35 μm. After averaging the 340 lines, the statistical error of the height for each single point should be as small as 2 μm.

IV. CALIBRATION

The calibration of the system is executed in two separate steps. The optical triangulation sensor itself must be calibrated first. The optical lens design features very little distortion and magnification variations within the field of view; the field of view includes 14 mm along an imaginary radial line that crosses a DDB being inspected and 10 mm in height. Only eight coefficients and two equations are required to translate any point measured from within the camera imaging plane to its corresponding location on the DDB surface using a micrometer scale. The eight coefficients are obtained by measuring the location of a specially designed calibration target at five different locations. The known location in space and the measured location in the imaging plane are then analyzed to compute the coefficients. That process requires less than 1 min and may be repeated easily to verify the exactitude of the calibration.

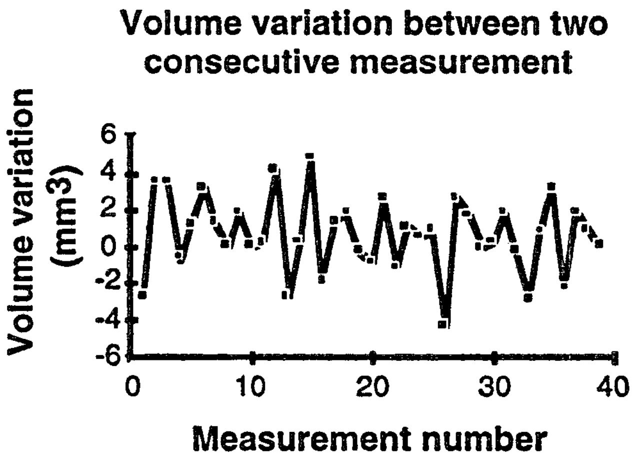

FIG. 4. Variations of the measured volume when the height of the DDB is kept constant.

The purpose of the second step is for finding the exact location of the triangulation sensor relative to the circular positioning system. The sensor is aligned in such a way that the laser beam of light is perpendicular to the DDB surface and that the beam would include entirely the rotation axis of the positioning stage if it were stretched large enough. However, the location of the camera along the radial axis must be changed to accommodate various DDB sizes and thus, must be recalibrated. That operation is accomplished by using a dummy mandrel machined with precision.

The overall accuracy of the instrument has been evaluated by repeatedly measuring the volume of an irregularly worn real DDB surface, first at a fixed height and second at height varying with 76.2 μm (0.003 in.) increments. A standard deviation of 2.1 mm^3 has been computed for the measured volume with the DDB at a fixed height (40 measurements). The volume variations measured while the height of the DDB was kept constant are shown in Fig. 4. The volume measured while the height of the DDB was increasing by 76.2 μm increments (using a linear displacement stage) is plotted in Fig. 5; the mean volume variation is of 122 mm^3 per position with a standard deviation of 3.4 mm^3. For a standard BQ bit (8 WW of 3 mm width) having a drilling surface of 1500 mm^2, a volume loss of 3.4 mm^3 corresponds to a mean height variation of less than 2.3 μm. Therefore, the standard deviation measured for the height of the whole surface is roughly in accordance with the statistical relation stated earlier.

V. RESULTS

Figure 6 shows some results obtained with a commercial BQ impregnated diamond drill bit using the system described in this paper. The trace corresponding to the line L000 represents the original profile of the DDB. This profile corresponds to a common V-rings profile. The visualization of this profile permits us to see an imperfection near

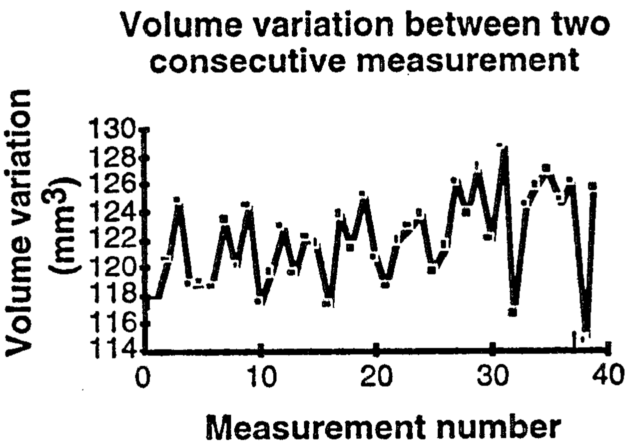

FIG. 5. Variations of the measured volume when the height of the DDB is increased by 76.2 μm increments.

the external diameter, i.e., on the right side. The next trace corresponding to the line L001 shows the profile after 0.46 m drilled whereas the line L006 shows the profile after 5.5 m drilled. The profile analysis allows us to see that the surface near the inner diameter wears faster than the surface near the outer diameter. For a diamond tool designer, the profile analysis could be extremely useful to improve design and performances of the DDB. With the particular profile analysis presents in Fig. 4, the diamond tool designer could decide to increase the concentration of the diamond from the outer to the inner diameter of the DDB to decrease the wear on the surface near the inner diameter. The tool designer could also be interested to decrease the wear near the inner diameter by increasing the size of the diamond used at this place. The analysis of the profiles allows us also to see if the inner and the outer diameters of the DDB remain constant during the drilling. Figure 6 suggests that the outer diameter showing that the number of kicker stones should be increased on the inner diameter in order to obtain a uniform surface wear and extend the useful life of the bit.

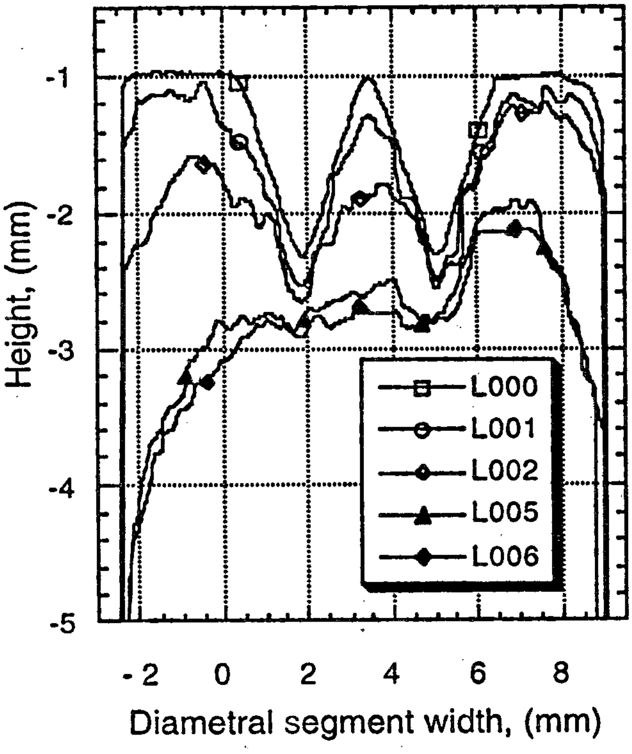

FIG. 6. Profiles representation after different distance drilled with the same DDB.

VI. DISCUSSION

We have demonstrated that with very little precaution, the profile and the volume loss of the impregnated DDB can be obtained by using the laser profilometry technology. Although we have not pushed the technique further on to improve the overall accuracy, it seems quite likely that an accuracy can be better than 5 mm^3 and that the surface height variations may be measured with a resolution better than 2.5 μm.

We have used this DDB wear measurement system to measure the profile variations and the volume loss of BQ and XRP impregnated diamond drill bits in laboratory, and have found it to be robust and easy to use. A typical measurement of profile and volume loss, including the calibration of the apparatus, could be done in less than 15 min. Measurement time may be reduced to less than one minute by using a digital signal processing (DSP) board currently available on the market and that fits inside the IBM/PC compatible computer. The overall optical system including the computer is evaluated to \$20 000 US. We believe that this instrument could be useful to any person involved in diamond drill research and in particular to DDB manufacturers for production quality evaluation.

ACKNOWLEDGMENT

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[1] D. Miller and A. Ball, J. S. Afr. Min. Metall. **90**, 283 (1990).
[2] G. J. Bullen and M. W. Bailey, Sélection d'exposes présentés a la Conférence De Beers Dusseldorf '79, pp. 2.14.1–2.12.10.
[3] D. Miller and A. Ball, Int. J. Rock Mech. Min. Sci. Geomech. Abstr. **27**, 363 (1990).
[4] V. B. Cassapi, D. Ambrose, and M. D. Waller, presented at the Drillex '87 Conference, organized by The Institution of Mining and Metallurgy and the British Drilling Association, and held in Stoneleigh, Warwickshire, England, 7–10 April 1987.