作成例<電子データ（CD-R）にて提出するもの>

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（ダイヤモンド切削工具形状の超精密測定に関する研究）
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論文内容要約

This thesis presents the ultra-precision measurement of geometry of diamond cutting tools and evaluation of its results which can be applied to automation solution for in-process measurement. For the ultra-precision measurement, a novel measurement method has been proposed and developed.

In Chapter 1, general background about the use of diamond cutting tools, and the motivation and the aim for ultra-precision measurement of the tools are described. Diamond cutting tools play an important role for ultra-precision machining. In the ultra-precision machining for fabricating precision components such as optics and functional surfaces with micro patterns, the form accuracy and sharpness of the tool cutting edge are the critical factors which influence the accuracy of the machined surfaces. Edge sharpness and form accuracy on edge contours should be strictly controlled to assure the machinability. It should be noted that not only the form accuracy of cutting edge but also the surface accuracy on the tool faces should be monitored to control the mechanical friction during diamond machining. The form accuracy of a single point diamond is required to be several tens nanometers to implement ultra-precision machining, the measurement for edge contour is therefore demanded with a high resolution of nanometer level. In addition, on-machine measurement of the tool cutting edge is strongly desired because a removal of the cutting tool from the machining lathe would induce a certain amount of tool misalignment when carrying out the tool installation again. Even if such an installation error is small, it should be taken seriously in cases of ultra-precision machining.

Conventionally, scanning electron microscopes (SEMs) have been used to observe the diamond cutting edges. The measurement in a vacuum condition is essential for the SEMs, which is difficult to apply for on-machine measurement. In addition, quantitative evaluation by conventional SEM takes lots of cost and time. In cases of optical instrument, measurement of diamond cutting tools is possible in on-machine condition. However its lateral resolution is principally limited by the diffraction limitation. An atomic force microscope (AFM)-based measuring instrument, which is appropriate for on-machine measurement, has previously been proposed to evaluate the form of the tool cutting edge. In the instrument, an optical alignment system was employed to align the AFM probe to the tool cutting edge instead of using an optical microscope on a commercial AFM. The proposed instrument realized on-machine measurement of micro cutting edge with a nanometer resolution. Quantitative three-dimensional measurement results including sharpness of cutting edge were successfully achieved. However, due to the limited measurement range of the AFM system, it takes a long measuring time for form measurement of a large scale cutting tool.

This thesis proposes an optical method to measure the geometry of a diamond cutting tool with a high measurement resolution. In addition, rapid evaluation for millimeters range is possible to achieve a high practical value in its use. Moreover, on-machine condition for tool measurement is essential to avoid installation error by detaching cutting tools from the machine tool. The goals of the this thesis can be defined as following,

- Evaluation target: edge contour and tool faces of diamond cutting tool
- Short measurement term: shorter than 1 min.
- High resolution: under 10 nm.
- Long measurement ranges: over 10 mm square.
- Valid for in-process measurement.

The background, motivation and aim of this thesis are described.

In Chapter 2, the AFM-based measuring instrument including an optical alignment system is employed to investigate a cutting edge having a micrometers scale. The measurement target is limited by the measurement range of several tens of micrometers. A non-contact measurement method is proposed for edge contour measurement. Large-scale edge contour can also be measured in a short time by using a focused laser beam spot, which is called the micro-optical stylus in this thesis. The micro-optical stylus can be employed for not only the contour measurement but also the optical aligning system for the AFM-based measuring system. The micro-optical stylus having a diameter of several micrometers is scanned over the cutting edge of a diamond cutting tool to investigate the edge contour. And then, the gap between the center point of the optical axis of micro-optical stylus and the tool edge can be obtained by utilizing the light intensity of the laser beam passed around the cutting edge. By combining the measured gap and the information of the scanning path of the micro-optical stylus, the tool edge contour can be evaluated with a nanometer resolution. Possible sources of measurement errors in the tool edge contour evaluation are also discussed. Furthermore, computer simulation is carried out to confirm measurement resolution of the developed system along the tool edge contour. The limitation of the proposed method is investigated about lateral resolution from the results of theoretical simulation. An optical probe, which consists of a laser diode, a photodiode and an objective lens, is constructed to test the feasibility of the proposed method. The constructed instrument is applied to on-machine measurement of edge contours of diamond tools. The tool form of a straight cutting edge is successfully evaluated by scanning the laser spot over the cutting tool edge. By scanning the laser spot on the cutting tool edge while detecting variations of light intensity of the laser beam which passes through the tool tip, the tool form of the straight cutting edge is successfully evaluated. A diamond cutting tool having a 2 mm nose radius is also investigated by the measurement instrument. The feasibility of the proposed instrument has been confirmed by the experiments of edge contour measurement.

In Chapter 3, the proposed method is improved to have a high resolution below 10 nm in the lateral direction. The measurement direction on the lateral plane along the optical axis indicates the direction respect to the edge contour. In the proposed method, stability of the laser power emitted from a light source will affect the measurement accuracy of the tool edge contour. A modified optical design is therefore applied to the evaluation system so that a laser power drift and influences of common-mode noise can be compensated in real time. A modified evaluation system consisting of a laser diode, a beam splitter, a pair of lenses and two photodiodes is developed. By utilizing the compensation system, the noise level of the optical profiler can be improved to 1.5 mV. The on-machine measurement system is established by synchronizing the motion of the X- and the Y- slides on the diamond turning machine and the acquisition of PD outputs from the micro-optical stylus. The specification of the measuring system and the recording conditions are described in this thesis. To verify the feasibility of the developed optical profiler based on the modified optical stylus, the performance of the system is evaluated. As a possible source of measurement error in the tool edge contour evaluation, the geometrical limitation of measurement target by optical path interruption is discussed by applying the double-scan path method. For the round cutting edge measurement, both the raster-scan path method and direct-scan path method are employed. The direct-scan method achieved high-speed edge contour measurements in 6 s for the measurement range of 3.5 mm. By using the developed measuring system, both the straight cutting edge and the round cutting edge of diamond tools are evaluated. In the measurement result of the straight cutting edge, the measurement repeatability is found below noise level to be about ±5 nm over the area of smooth edge contour. For the round cutting edge measurement, both the raster-scan path method and direct-scan path method are employed. The direct-scan method achieved high-speed edge contour measurements in 6 s for the measurement range of 3.5 mm. Throughout the experiments, the feasibility of the developed measurement system is confirmed. As a possible source of measurement error in the tool edge contour evaluation, geometrical limitation of measurement target by optical path interruption is discussed by applying double-scan path. In the measurement results with a straight cutting edge and a round cutting edge, the measurement repeatability is evaluated.

In Chapter 4, the rake and flank faces with surface finishing are evaluated by developing an interferometer of Linnik configuration. The form accuracies of tool faces are reflected in the formation of edge contours on the understanding the manufacturing process of cutting edge tool. The form accuracy of edge contour is based on the qualities of the form error on the tool faces. General consideration about application of interference microscope is introduced. Based on the optical specification of the developed interferometer system, the interferogram is calculated about spectrum characteristics over the bandwidth of the light source. In addition, the inteferometric visibility reduction influenced from a low refraction index of diamond surface is calculated and compared with an experimental result. The development of analysis tool for scan detection from the interference fringe is carried out to obtain three-dimensional result from successive image results. To diminish the influence of dispersion error of light source, the analysis tool includes the least squares fit of 5π-cosine on the sampled interferogram. Geometric correction of interferometer is adjusted about the optical path alignment. The magnification number of the optical system is then investigated. A scanning white light interferometer with the Linnik-configuration was designed and constructed. By employing three stacked stages, the measurement motion to accumulate interference information can be conducted. The measurement results of rake face, and its evaluation for roughness of the surfaces are conducted. In the measurement result of rake faces, micro-wear on cutting edges is evaluated. The measurement result of flank face is also evaluated for roughness and waviness on the surface. It is verified the flank face and rake face have been fabricated under the required form accuracy.

In Chapter 5, an optical measuring station of cutting tools is proposed to evaluate cutting edge contour and tool faces of diamond cutting tools. The optical profiler mentioned in chapter 3 can rapidly measure edge contours of diamond cutting tools with a nanometric resolution in on-machine condition. Although the cutting edge can be measured by the optical profiler, the tracing task demands sub-micron accuracy in the three-dimensional direction. On the sectional plane with respect to the optical system, the accuracy of tracing is limited by the size of the micro-optical stylus. The tracing accuracy along the vertical direction of the optical system is required to optimize the size of the micro-optical stylus. Mapping the PD outputs in the three dimensions by coil-motion scan is carried out. The repeatability among the repeated tests can not satisfy the allowable accuracy for scanning path. To improve the tracing accuracy, an optical measuring station which consists of a micro-optical stylus component and a Linnik microscope is proposed. The Linnik microscope has the ability to measure discontinuous structures with a vertical resolution below 1 nm. By using filters and polarizing optical components, the two optical measurement methods are combined to share the same optical axis, which are utilized to measure and evaluate the edge contour of the cutting tool. In a static condition, the rake face is measured by the interferometer so that a tracing path for tool contour measurement can be generated. By referring the generated tracing path, the tool contour is measured by the micro-optical stylus. By utilizing the two methods, the automatic solution for cutting edge profiling is described. The feasibility of the established measuring station is experimentally verified.

In Chapter 6, summary and conclusions of this thesis are described.