

USE OF FLUID BEAMS TO ESTABLISH A CLEAN ZONE FOR IN-PROCESS OPTICAL MEASUREMENT

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Introduction

It is known that in precision machining, a large sum of energy could be transformed into thermal energy, generating excessive heat that induces thermal deformations. Due to the thermal deformation of the machine and the workpiece, the machining accuracy could be affected. The thermal deformation can be related to various sources including an uncontrolled environment, the friction that results from the interaction between the cutting tool and the workpiece, and the shear fracture that results from the formation of chips during machining. If coolants are applied at the intersection of the cutting tool and the workpiece, the heat generation can be reduced by the lubrication function of the coolant and the effect of the heat that causes the thermal deformation is removed by the cooling function of the coolant. Using coolants can be effective to improve the machining accuracy.

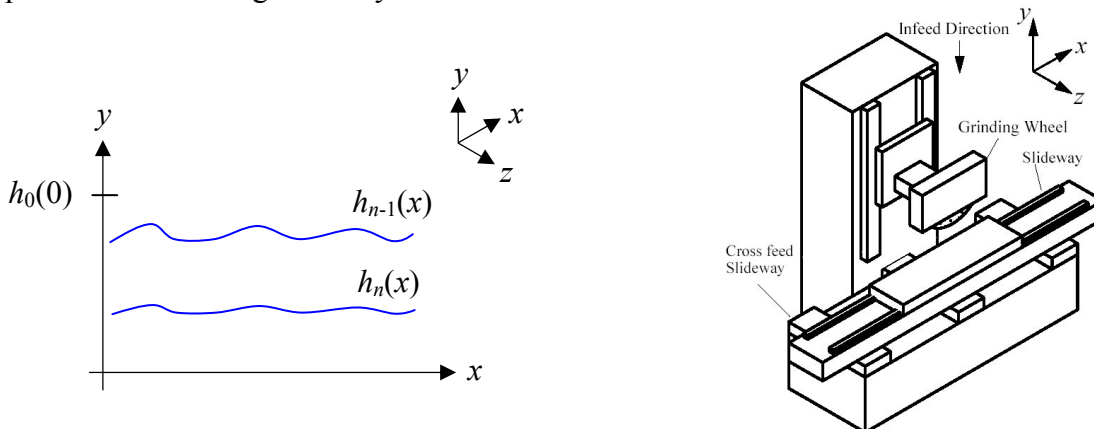


Fig. 1 Surface profiles during machining **Fig. 2** High speed table motion in surface grinding

However, the use of coolant could make the in-process optical measurement of the workpiece surface profiles difficult. In order to control the process to improve the machining accuracy, it is desirable to measure the workpiece profiles $[h_{n-1}(x), n = 1, 2, \dots]$ during the process of machining, as shown in Fig. 1, where n is the pass number.

In-process measurement has been investigated in two areas, condition monitoring and workpiece surface measurement. The condition monitoring is to achieve optimal machining states, while the workpiece surface measurement is to provide control the workpiece surface profiles. In the latter case, a detecting probe either in a wave form, or in a mechanical stylus form, is used to measure workpiece surface profiles. Due to the high speed motions typically involved in precision machining, as the table motion in the x direction in Fig. 2, the mechanical stylus methods cannot be used in order to avoid scratches, likely caused by the contacting styluses on workpiece

surfaces, and as a consequence, excessive wear of the stylus tips in contact with the workpiece. It seems that the non-contact measurement methods have to be utilized. The non-contact methods utilize waves in two ways, waves are originated from the interaction between the workpiece and the cutting tool, or waves come from an external source. The latter type has the advantage of being in the category of non-contact measurement, avoiding scratches and wear, which are the disadvantages associated with the stylus probes. However, under the condition of wet grinding, where coolant would be used to remove the heat generated, and when the probe is made of light waves, the light, which is from an external source, would not reach the workpiece surface, as, it is very often, the coolant used for machining is optically opaque and the light is stopped by the layer of coolant (Fig. 3). A detecting probe in the form of ultrasonic waves may be considered. Since ultrasonic waves, typically at the frequency of 50kHz or above but far below that of light, are able to propagate in the liquid and reach the workpiece surface, although the liquid is optically opaque. It has been seen that workpiece surface roughness can be detected by measuring the changes in the echoed beam intensity. In addition, the distance between the sensor and the workpiece surface could be obtained if the flight time of the ultrasonic beam reflected from the workpiece surface is measured [1]. The ultrasonic probe has the advantage that the coolant does not have to be optically transparent. However, the accuracy may be limited in the ultrasonic method. The flow of coolant could adversely affect the propagation of the ultrasonic waves in the coolant layer. The ultrasonic waves are of mechanical. The frequency is typically 5-1000MHz, far below the frequency of the light waves. For these reasons, the achievable measurement accuracy of an ultrasonic method would not be as high as that of an optical method. Optical measurement has long been investigated and commercially available products are capable to reach very high resolution, often nanometers. This indicates that the ultrasonic method, which is compatible with the optically opaque coolant, may not be the best choice, if there is a solution for the problem of light being stopped by the coolant layer before reaching the workpiece surface, making the workpiece surface inaccessible. In this sense, it is proposed to use an assisting fluid system to overcome the opaque barrier. In this new approach, a fluid beam is established through the use of an applicator (Fig. 3) to build a small zone that is optically clean, termed as transparent window, to enable the workpiece surface accessible to optical measurement systems. The advantages of the proposed method are that the wear problem of the contact methods and the inaccessibility problem of the non-contact methods are removed. This could permit the in-process optical measurement to reach to very high precision, since the optical methods can be applied.

Transparent Window

In order to generate a necessary transparent window, the applicator is used to position in the coolant layer along the direction of the table movement (Fig. 2-3) and maintain a clearance d between the applicator and the workpiece surface (Fig. 3). A transparent fluid is then applied to a small area on the workpiece surface through the applicator. The clearance is to be small so that the transparent fluid can be easily directed to the workpiece surface. The applicator is also used to redirect the majority of the coolant to the two sides. This will be beneficial for the establishment of the transparent window and for the minimum use of transparent fluid. Since the range of the clearance d is small, a fine adjustment mechanism is required. If d is too large the transparent window will be difficult to establish. Conversely, if too small, the possibility of contacting the workpiece will be large.

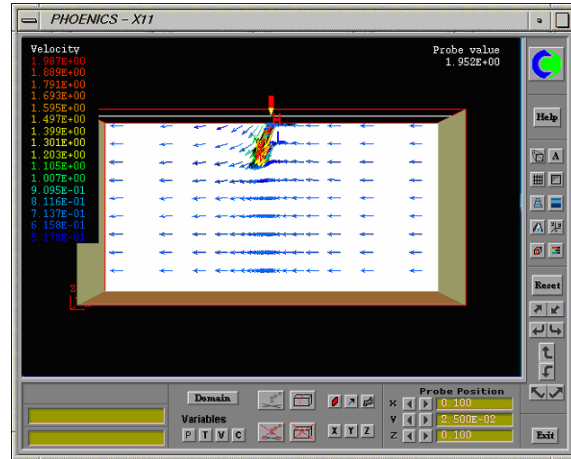
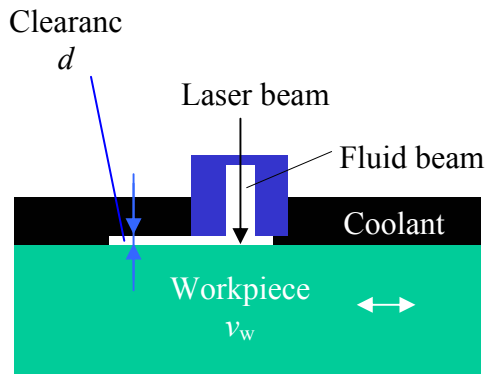


Fig. 3 In-process optical measurement **Fig. 4** Flow pattern of the fluid beam at $v_w=5\text{m/s}$

For this reason, a small servo motor may be used with feedback from an inductive sensor mounted on the applicator. To control the servo system, one method is to use optimal dc values established through experiments, and as such a large number of tests are necessary. Another method is to use optical sensors to measure the workpiece surface directly, based on a strategy that if no reflection is received, the applicator is lowered down by a step and this is repeated until reflection signals are detected, indicating that a transparent window is established. This approach will require a safety switch to avoid the applicator too low, a possibility to contact the workpiece. This approach is advantageous since the control algorithm adjusts to the actual situation, and as such the number of tests can be reduced. A fluid system is used to deliver the transparent fluid to the workpiece surface through the applicator. Due to the pressure in the system, the fluid would flow out evenly from the bottom of the applicator. The fluid beam can be affected by several factors including the coolant speed and the clearance between the workpiece surface and the fluid beam applicator. Due to two fluid flows are involved, the interactions between them can be complex. This requires a computational fluid dynamics approach (CFD) be utilized. In this investigation, a CFD package, PHOENICS, was used. The CFD models were established and the mesh model generated. The flow patterns and the velocity profiles were obtained (Fig. 4). It was found that the velocity of the fluid beam should be set at 5m/s approximately or higher, when the velocity of the coolant is 0.64m/s, to enable the beam to reach the workpiece surface [2]. Under this condition, the clearance between the workpiece surface and the applicator can have many choices. In the actual situation, it was quite small [3].

Experimental Testing and Discussion

Experimental testing has been carried out on an ESG-818ASD surface grinding machine to test the proposed method. In the experimental tests, a Keyence LB-70 laser triangulation sensor was used to measure the test workpiece surface profiles under the coolant condition (Fig. 5). The profiles were compared with those obtained without any coolant being applied. In Fig. 5, the effect of the machine vibrations was involved. If two laser sensors were used to measure the workpiece profile derivatives through the clean zone, the effect could be removed. The results of the experiments (Fig. 5), although at the scale of millimeter due to the limitation in the resolution

of the LB-70 laser sensor, confirm the computational model for the fluid beam to be established, demonstrating that the proposed method can be a suitable solution to the problem.

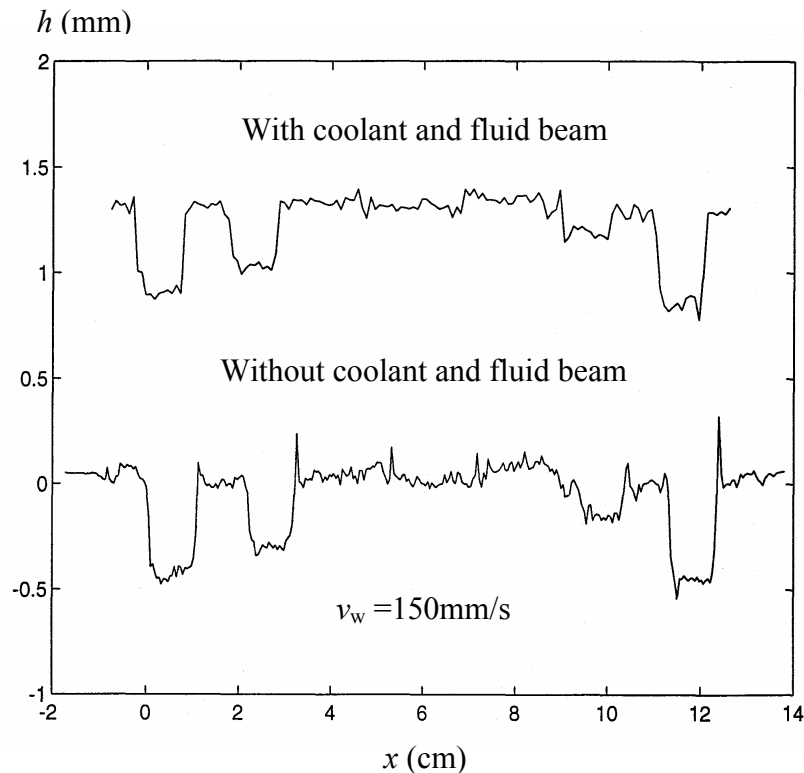


Fig. 5 Workpiece surface profiles obtained with coolant and without coolant

Conclusions

In-process optical measurement is desirable but has several main difficulties to overcome. The proposed use of a fluid beam to establish an optically clean zone can be a good solution for the in-process optical measurement problem. Preliminary tests show that the proposed approach is feasible.

Acknowledgement

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