Development of 3D-based On-Machine Measurement Operating System

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This paper proposed an efficient manufacturing system using the OMM (on-machine measurement) system. The OMM system is software-based 3D modeler for inspection on machine, and it is interfaced with machine tools via RS232C. The software is composed of two inspection modules; one is touch probe operating module, and the other is laser displacement sensor operating module. The module for touch probe needs the inspection feature extracted from CAD data. The touch probe moves to workpiece by three operating modes as follows: manual, general and automatic mode. The operating module of the laser displacement sensor is used to inspect profiles and very small holes. An advantage of this inspection method is the ability to execute on-line inspection during machining or afterward. The efficiency of proposed system which can predict and define the machining errors of each process was verified, so the developed system was applied to inspect a mold-base (cavity, core).

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1. Introduction

In general, the system of mechanical manufacturing is consist of three processes; Design, Manufacturing and Inspection. In existing systems, it has been tried out to maximize the efficiency of manufacturing through construction of the connection system of each process. Recently, the study of connection system of CAD/CAI (Computer Aided Inspection) or CAD/CAM/CAI has been executed.[1,2,3] The research of CAIP(Computer Aided Inspection Planning) which establishes the inspection plan with the feature definition of each process and CAPP(Computer Aided Process Planning) which integrates manufacturing and inspection with a concept of process has been also implemented.[4,5]

Because most of the existing inspection processes is executed in the field by off-line type, the study of this system has been carried out as a concept of separated system. However, in recent, interests to construct the system which is possible to reduce manufacturing processes and validate errors of each process are increased. Accordingly, the research for the on-line system which is able to execute a manufacturing and an inspection side by side in a unit is requested continuously. The OMM system of commercial inspection methods is recognized as being suitable for these requests, but the precision of this system is lower than the precision of the existing off-line one. Because the OMM is executed on a machine tool, this system includes errors of the machine tool and errors of all inspection tools, so many studies for compensating errors of machine tool have been executed. Moreover, Lee and Chung had been studied to apply these compensation method to the free-surface inspection.[6,7]

In this paper, in order to increase the efficiency of manufacturing system, the 3D-based on machine measurement operating system which is able to perform an inspection process with a manufacturing process on a machine tool is proposed. The developed OMM system consists of two modules; one module operates a touch-type probe, and the other module operates a laser displacement sensor. Both modules are operated complementally by connecting each system. Because the developed system uses the on-line communication, it is possible to reduce the time required of an inspection process by a large margin.

Besides, this system has an advantage that the operator can certify the extent of error occurrence for all processes by executing the inspection process after each process directly. The developed system is appropriated to the inspection of workpieces which are allowed to the error of ±0.010㎜ by comparing with the result of CMM inspection. For the verification of this system, the manufacturing process and the inspection process were executed for a practical mold.

2. OMM Operating System

2.1 Selection of the inspection method according to features

Fig.1 shows the basic structure of the OMM operating system. The inspection feature is extracted from the feature information of CAD/CAM, and the inspection module is determined after defining the inspection feature by operator. According to the determined inspection module, the OMM operating system calculates the inspection path, the inspection points and the inspection position and verifies whether the inspection tool comes into collision with a workpiece or not.

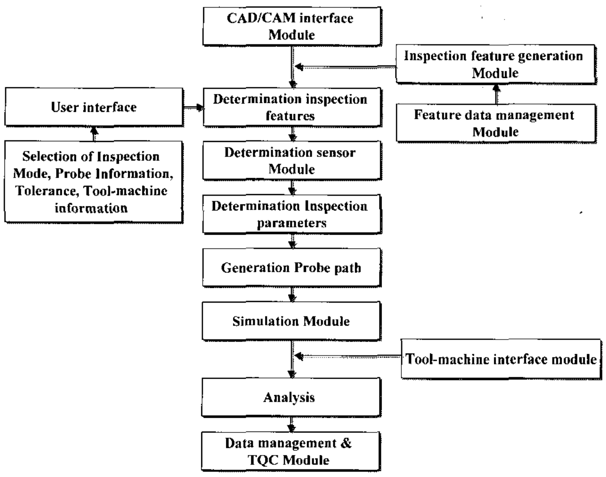


Fig.1 The structure of developed OMM operating system

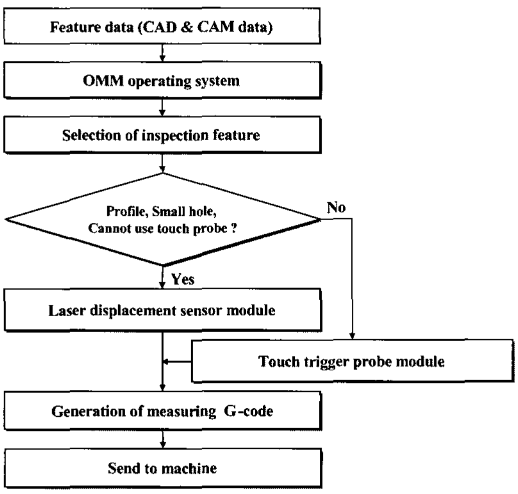


Fig.2 The algorithm for sensor selection

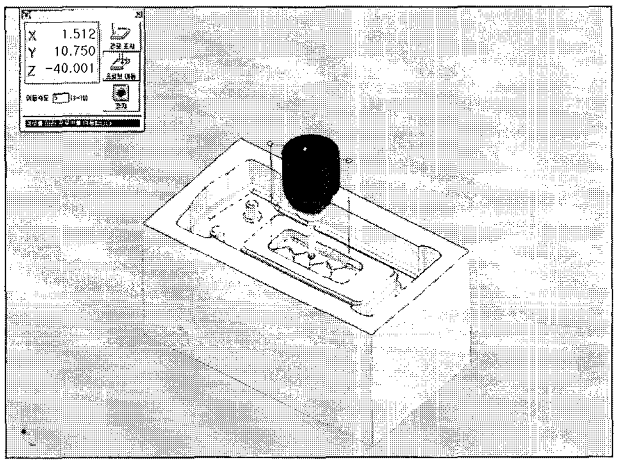
After the inspection variables are determined, it is possible to generate the G-code for inspection, and to simulate the inspection process in the system. When all inspection steps are completed, the operator is confirmed whether the inspection process is executed or not, and the inspection process progresses after transmitting the inspection G-code to the machine tool. In case of the general features, the operator can select the inspection module voluntarily, but a minuteness hole or a profile region which is difficult to use the touch trigger sensor is measured using the laser displacement sensor as shown in Fig.2. However, the touch trigger sensor which is possible to be exchanged using the ATC(Automatic Tool Change) of a machine tool is useful to execute the on-line inspection for a manufactured workpiece. However a laser displacement sensor has an inconvenience that the equipment of sensor is carried out manually on account of a power supply line. The inspection feature is extracted using the CAD/CAM feature data, and this data is based on the surface.[8] For executing the inspection process efficiently, the inspection mode is constituted of three modes; a manual mode, a general mode, and an automatic mode.

2.2 The OMM Operating Program

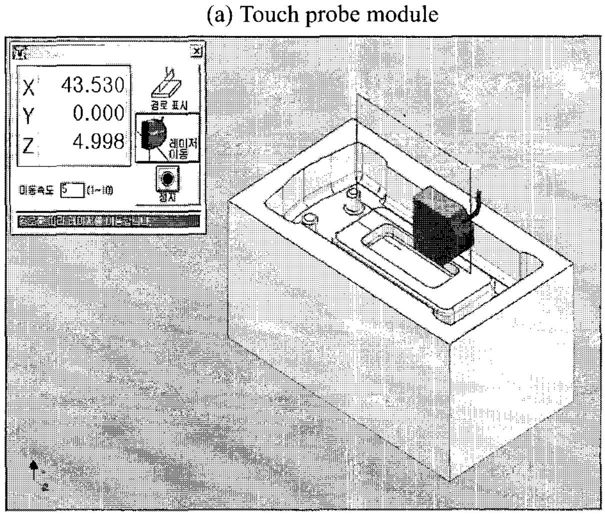
The OMM operating program developed in this study consists of nine parts; 1) the CAD/CAM interface, 2) the machine tool interface, 3) the module of operating a touch trigger sensor, 4) the module of operating a laser displacement sensor, 5) the transmission/reception part, 6) the tolerance control part, 7) the simulation part, 8) the manufacturing/inspection part, and 9) the analysis part of an inspection result.

The developed software was made using AutoDesk inventor API(Application Program Interface) and Visual C++. A connection of the CAD/CAM feature data enhanced for the visual effect, and the efficient decision of inspection position when the inspection variable was possible in the OMM operating system. In addition, for the efficiency of this process, the 3D type was realized unlike the 2D type of a CMM. The interface between a machine tool and the developed system was constructed using RS232C.

For the efficiency of data transmission/reception, a separate communication port was used for each case. In the operation of inspection tool, it was allowed to be assigned the inspection feature and position by operator in program viewer. In occasion of a tolerance management, if the information of a tolerance was included in the CAD data, a tolerance was managed by the OMM operating system. Otherwise, because the comparison results with the inspection result and a tolerance was represented, the operator had to input a tolerance into the OMM operating system. In simulation, the movement of inspection tools, the position of inspection, the number of inspection points and the G-code were showed. If the CAM data was provided to the OMM operating system, it is possible to execute the simulation of manufacturing processes. Moreover, when the inspection process was execute after the manufacturing process, it was possible to determine the inspection variable in consideration of the tracks of tool(cusp). The error showed after the inspection process was a difference between the CAD data and the inspection result. In occasion of being a tolerance, it was showed to the operator whether an allowable tolerance was approved or not.



(a) Touch probe module



(b) Laser sensor module

Fig.3 The OMM program

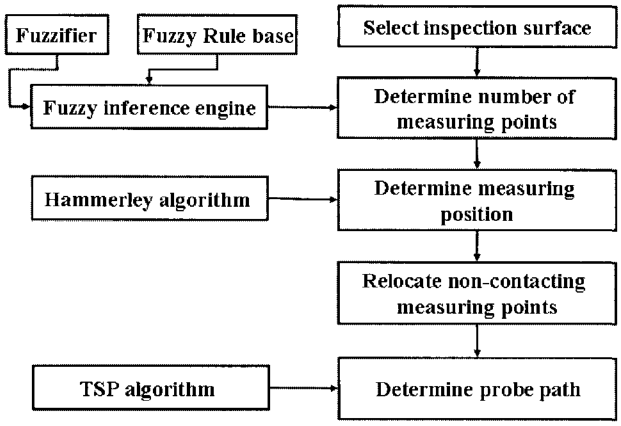
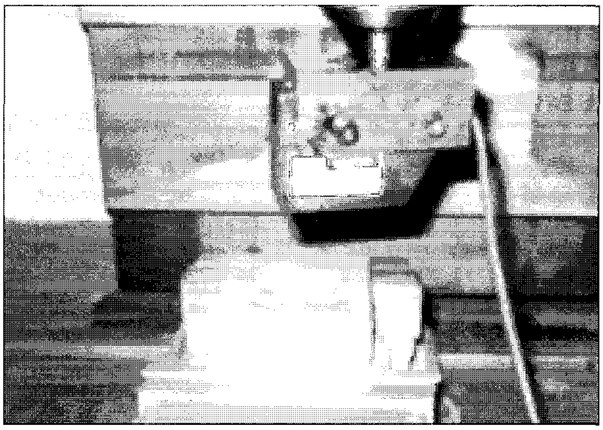
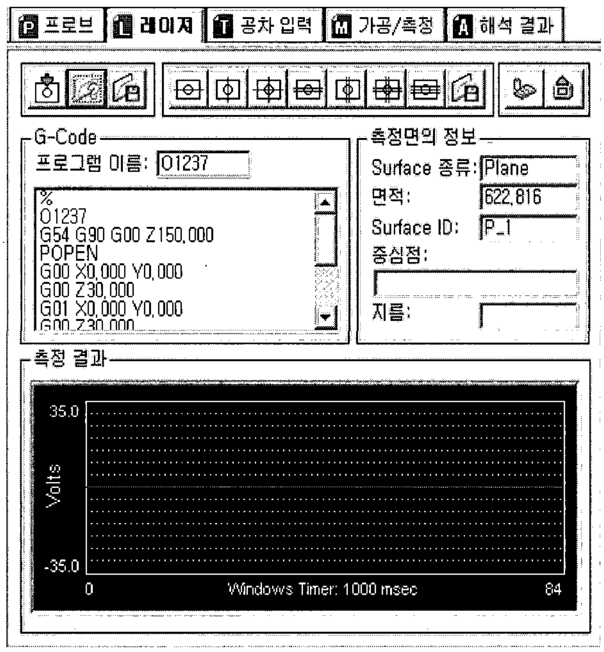


Fig.4 The algorithm of inspection parameters



(a) Laser sensor

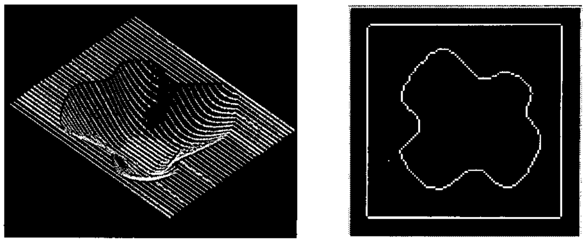


(b) Operating function

Fig.5 The laser displacement system for OMM

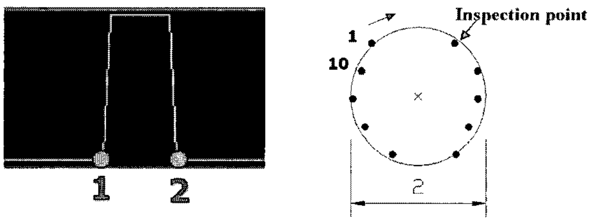
2.3 The operating module of a touch trigger sensor

The operation of a touch trigger sensor consisted of four components; the inspection mode, the decision of the inspection variables, the generation of the G-code and the simulation mode (Fig.3(a)).



(a) The profile measuring (b) The edge generation

Fig.6 The profile inspection and edge generation



(a) The one line measuring (b) The inspection of hole

Fig.7 The laser inspection of ∅ 2mm hole

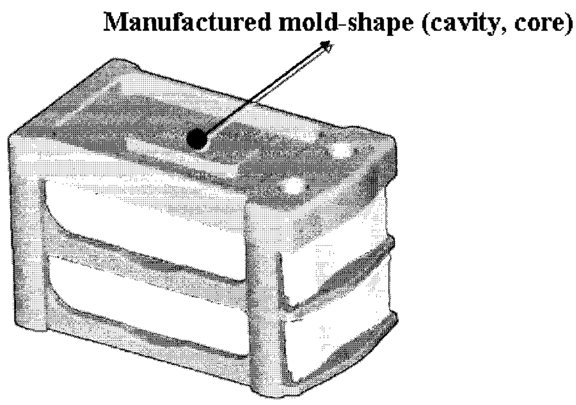
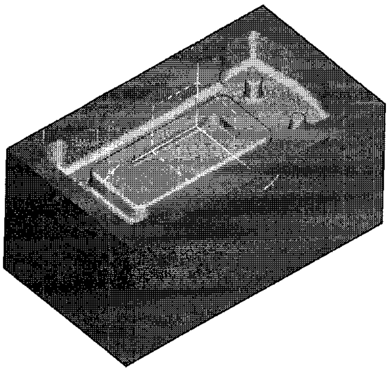


Fig.8 The workpiece used in simulation

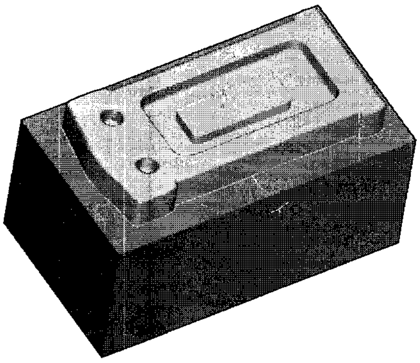
As mentioned in section 2.1, the inspection mode has three types; the manual mode, the general mode, and the automatic mode. In case of the manual mode, the inspection position was input by the operator. This is the general method which is accepted in the existing touch type inspection. The general mode which is able to measure a general 3D feature is to decide inspection variables (the inspection position, the number of inspection points, and the inspection path) by appointing the 3D feature unlike the manual mode. The automatic mode is to execute the inspection process using the 2D-based feature which is conversed from the 3D feature information of the CAD/CAM data. In the automatic mode, inspection variables are decided by the algorithms in each step. Because of difficulty to inspect automatically for free 3D feature information of CAD/CAM data, the measuring process was implemented after converting 3D feature into the 2D-based information. The inspection results were consisted of six items (flatness, straightness, etc). For a integrated geometry, the inspection result were consisted of four items(right angle degree, cylindricity, etc). Thus the inspection results of the existing 3D-based feature were difficult to be applied to a single geometry.

2.4 Decision of inspection variables

When the inspection process is executed using a touch trigger sensor, the inspection position, the number of inspection points and the inspection path must be decided. Fig.4 shows the algorithm to decide inspection variables.



(a) The cavity



(b) The core

Fig.9 The geometry of manufactured molds (cavity, core)

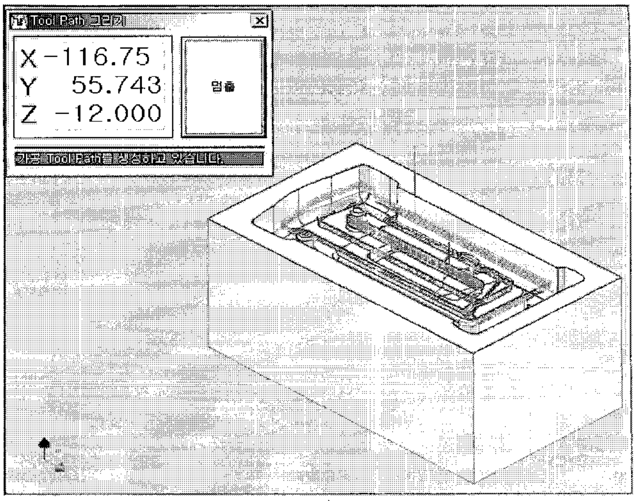
The number of inspection points is computed by the fuzzy system, the inspection position is computed by Hammersley's method, and the inspection path is yielded by TSP method. The area of the inspection feature, the precision of the used machine tool and the tolerance are defined by the number of inspection points. Input variables which must be entered by the operator are a precision of the machine tool and the allowed inspection error. Hammersley's algorithm was applied to the proposed system in this study. Because the number of inspection points which complies with an inspection precision was smaller than an occasion which the method of the existing grid type inspection.

2.5 Operating module of a laser displacement sensor

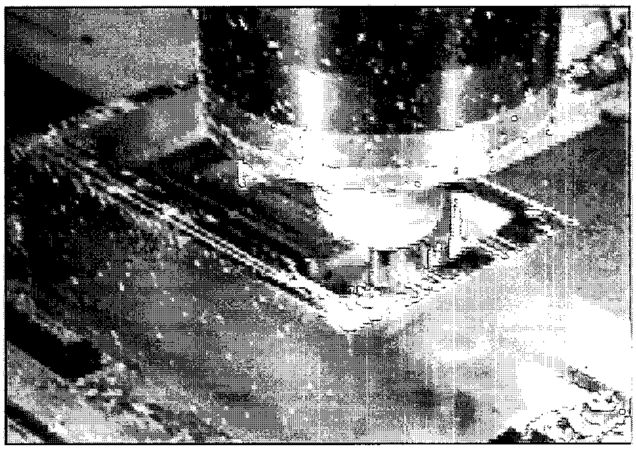
In case of the existing inspection on machine, a touch trigger sensor was used generally, but the module which might operator a laser displacement sensor as a non-touch type sensor was added in this study. However, as stated above, a laser displacement sensor was difficult to use ATC, so the fixture of a tool holder was made for changing manually as shown in Fig.5(a). This module is to measure a minuteness hole or a profile. Fig.3(b) shows the module of operating the laser displacement sensor. Fig.5(b) shows the movement of a sensor and the window of a result of the inspection processing. Because the inspection method using laser did obtain the information of the specific position, an operator could acquire the feature information by inputting the grid-type inspection path. Fig.6(a) shows the result of the profile inspection process using laser, and Fig.6(b) shows the result of edge detection using a profile. Fig.7 shows the result of measurement for a hole with 2 ㎜ in diameter. From the inspection result, the cylindricity was 0.12750.

3. Simulation and Experiments

For testing the developed OMM operating system, a workpiece was selected as shown in Fig.8, and the molds were manufactured.



(a) The tool-path simulation

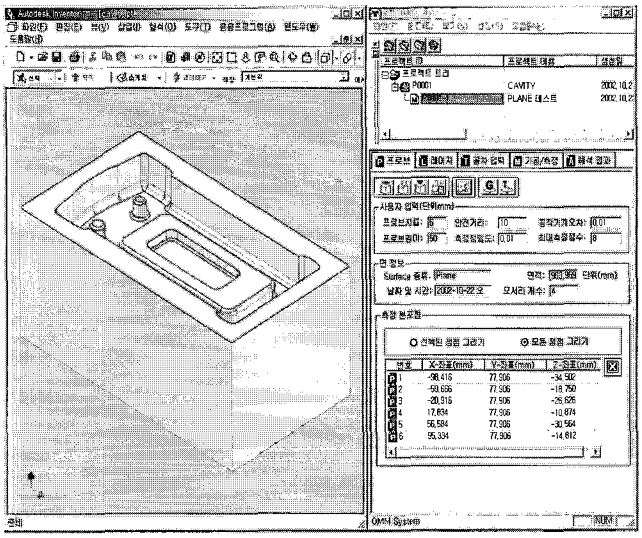


(b) The machining

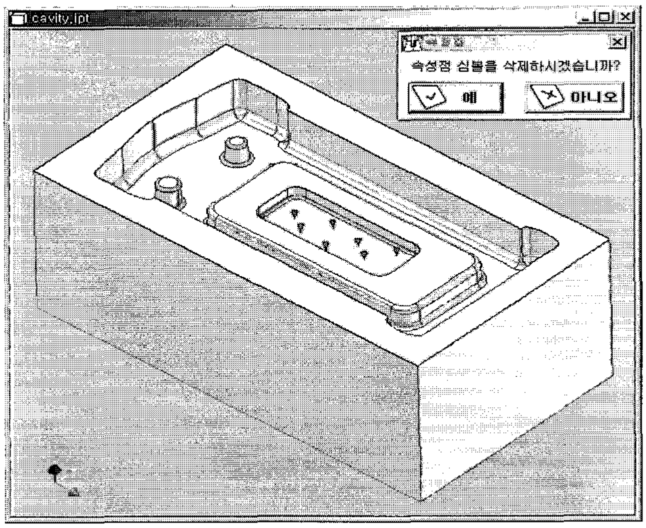
Fig.10 The tool simulation and machining

Fig.9 shows the produced injection molds which has the dimensions of 400× 225× 190mm and has a cavity and a core. The material of the molds was SUS420. The 3-axis SIRUS-3(FANUC 18-MC, Hwacheon Machine Tool Co., Ltd.) machine tool was used, and the linear scale was equipped at each axis(x, y, z) for complementing the precision of the inspection on machine. The used inspection tools were MP700(RENISHAW) as a touch trigger sensor and LK2100(KEYENCE) as a laser displacement sensor which has the maximum inspection range of 100 ㎜. To reduce the inspection error, the error of the machine tool was measured before the processes, and this result was input to the operating system.

So it was made that the inspection result was compensated the error of a machine tool. Before a cavity is made, the tool path was simulated, and certified by the developed operating system as shown in Fig.10(a), and then the manufacturing process was executed.(Fig.10(b)) The manufacturing process progresses through four stages; a roughing stage, a semi-finishing stage, a clean-up stage, and a finish stage. The inspection process was executed after each stage, and the error of each stage was confirmed. Fig.11(a) shows the process to confirm the inspection feature using the CAD data from the developed system, and the interface module and the inspection variables are decided as shown in Fig.11(b). After the inspection variables are decided, the collision check of a touch trigger sensor was simulated (Fig.12(a)). If the result of a simulation was confirmed that the inspection path of the touch trigger sensor was safe, the inspection position and the inspection path of the touch trigger sensor was transmitted.

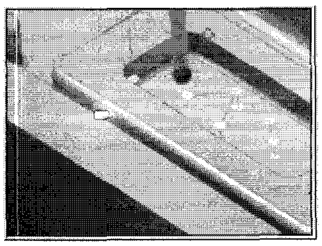


(a) The installed CAD data

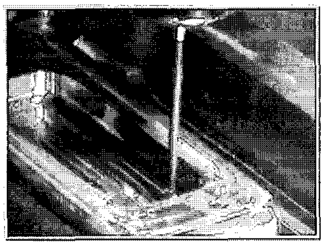


(b) The determination inspection parameters

Fig.11 The pre-inspection process about cavity



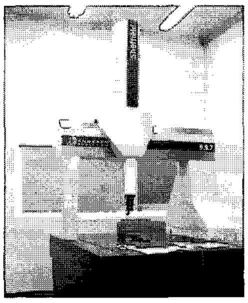
(a) The simulation of inspection



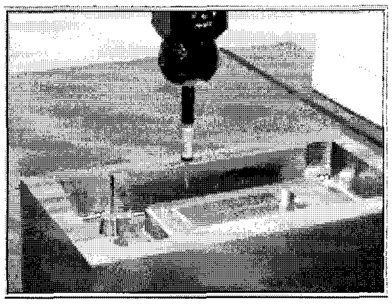
(b) The inspection using developed OMM system

Fig.12 The simulation and inspection

The safety distance between a touch trigger sensor and the workpiece was 3 ㎜. Fig.12(b) shows the process to execute the inspection on machine along the decided conditions. After the inspection on machine, for evaluating the inspection precision of the developed system, the inspection result of the system was compared with the inspection result of a CMM(Fig.13). Table 1 shows the inspection result of the workpiece using this system. The inspection feature was decided in consideration of a combination of a cavity, and a core using expert knowledge.



(a) The CMM



(b) The inspection of CMM

Fig.13 The inspection using CMM (Sheffield)

In the inspection result of the OMM system, the maximum error was 0.0129 ㎜, and the minimum error was 0.001 ㎜. The comparative results from the CMM and the developed OMM system had the maximum error of 0.009 ㎜, and the minimum error of 0.001 ㎜. With regard for the maximum error of 0.009 ㎜, the proposed system was thought to be able to obtain the confident data.

4. Conclusions

In this study, the 3D-based OMM operating system which might execute the inspection process on machine was developed. Simulations and experiments were executed by using the CAD/CAM data, and the comparatively reliable data was obtained. Besides, a possibility was confirmed that the proposed system is applied to the on-line manufacturing process.

From the point of view that the OMM system can carry out the inspection process and the manufacturing process side by side, it is thought that all manufacturing processes may be shortened, and the productivity may be improved by applying this system to the manufacturing system. The results of this study are summarized as follows.

(1) The OMM operating system which is able to operate a touch type sensor and a non-touch type sensor was developed.
(2) The result which was compared with the measured value of the developed system and the measured value of a CMM for the selected workpiece showed the maximum error of 0.009㎜ that is the comparative reliable error.
(3) The inspection system which uses the CAD/CAM feature was made.
(4) The based technology to integrate CAD/CAM/CAI processes was furnished.
(5) Hereafter, the research about the system which could improve the precision of the inspection on machine was needed.
(6) The study of inspection tools and the methods which is possible to be applied to the OMM system is needed continuously.

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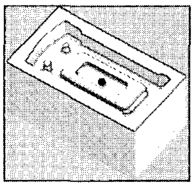
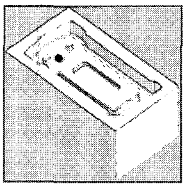
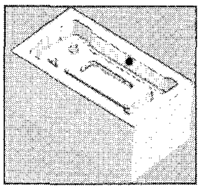
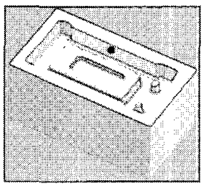
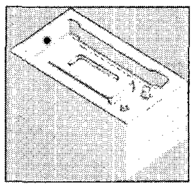
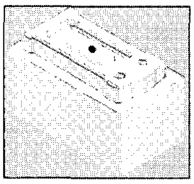
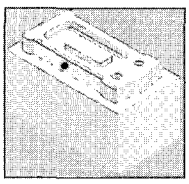
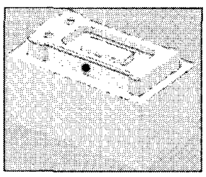
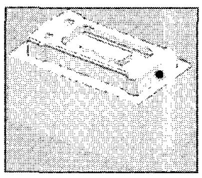
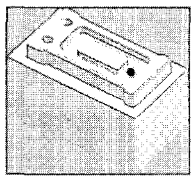
Table 1 Inspection results using OMM/CMM(㎜)

Cavity inspection results					
Feature					
①CAD	-40.000	-50.000	77.908	-77.908	175.487
②OMM	-39.997	-50.008	77.849	-77.953	175.486
③CMM	-40.006	-50.011	77.850	-77.944	175.484
Error (①-②)	0.003	0.008	0.059	0.045	0.001
Error (③-②)	0.009	0.003	0.001	0.009	0.002
Core inspection results					
Feature					
④CAD	38.000	-76.408	76.408	-173.787	23.000
⑤OMM	37.998	-76.326	76.537	-173.837	22.989
⑥CMM	38.006	-76.332	76.528	-173.841	22.996
Error (④-⑤)	0.002	0.082	0.129	0.050	0.011
Error (⑥-⑤)	0.008	0.006	0.009	0.004	0.007