5-Axis Control Ultraprecision Micromachining of Axial-Flow Pump as a 3-D Micropart

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Summary

The study deals with the creation of 3-D microparts, which consist of complicated curved surfaces, by means of 5-axis control milling technology. As a concrete target shape, an axial-flow pump of 5 mm in diameter is selected and defined by use of 3-D CAD system. The shape designed in the study is based on that of the inducer, which is a vane wheel with 3 blades for the rocket engine turbopump. In order to manufacture the target shape, our own 3-D CAD/CAM system developed for 5-axis control milling is used. Assuming that a workpiece of oxygen-free copper is machined by use of a 5-axis control ultraprecision machining center and a tungsten carbide ball end mill of 0.2 mm in radius, NC data of a micro axial-flow pump is successfully created for 5-axis control micromilling, while avoiding the collision between the cutting tool and the workpiece.

I. Introduction

In recent years, the demands for key microparts are obviously growing for the miniaturization and the integration of industrial products, especially in the fields of electronics devices, optical elements, medical instruments and so on[1]. It is vital to develop 3-D microfabrication technology in response to these demands. Ultraprecision machining is suitable for 3-D microfabrication due to its high flexibility of manufacturing a variety of workpiece shapes and material kinds to be machined when compared to semiconductor fabrication technology such as lithography[2]. Above all, with the development of 5-axis control ultraprecision machining center, it is becoming possible to manufacture more and more complicated micro shapes than ever before. 5-axis control micromilling enables to manufacture workpieces with complicated free-form surface with high accuracy and high machining efficiency, while avoiding the collision between the cutting tool and the workpiece. The typical instance of 5-axis control micromilling is such an overhung shape as seen in impellers[3].

The objective of the study is to create microparts, which consist of complicated curved surfaces, by means of 5-axis control micromilling. As a concrete target shape, an axial-flow pump as illustrated in Fig. 1 is selected. In the study, the shape is reduced into 5 mm in diameter, which is about three hundredth part of the actual model and small enough as a micropart. It is thought that the shape can be applied to a micro axial-flow pump for a water-cooling system of electric devices, an artificial heart and so on.

Figure 1 illustrates an overview of an inducer, which is a concrete target shape in the study. This shape is created only by means of 5-axis control machining because of its overhung shapes of each blades.

II. Ultraprecision Machining System

In the study, the ultraprecision machining center ROBONANO by FANUC LTD. is used for micromilling experiments. Figure 2 illustrates the structure of the machine. It is designed, based on the concept of friction-free servo mechanism. Thus, air bearings are adopted for all bearings for rotational, translational and other
movements, thereby eliminating solid friction completely. The machine is composed of five movable axes, X, Y, and Z axes for translational axes, B and C axes for rotational axes. The performance of the ultraprecision machining center is as follows: the resolution of translational axes is 1 nm and that of rotational axes is 1/100,000°, as listed in Table 1.

In addition, a high speed air turbine spindle, driven by air, is set on B table in 5-axis control machining. A high precision tool chucking mechanism is mounted to the air turbine spindle to keep the milling tool in the rotational center of the spindle, which allows 3-D ultraprecision machining[4].

### III. 3-D CAD/CAM System

#### 3.1 Software Construction

In the field of 3-D ultraprecision machining, it is vital to generate tool path on the basis of an accurate definition of a target shape by 3-D CAD system. In the study, DESIGNBASE by RICOH Co., LTD. is used in order to define 3-D shape data and to develop CAM system, which generates tool path to automatically manufacture 3-D microparts, with the interface that DESIGNBASE provides. Figure 3 shows the flowchart of the CAD/CAM system for 5-axis control machining from the definition of configuration data to the generation of Numerical Control (NC) data. The program of the system is written in C language. It finally outputs NC data after acquiring data necessary to generate tool path. The flow chart of the system is illustrated in Fig. 3.

The CAM system is composed of the main processor and the post processor. The main processor generates Cutter Location (CL) data consisting of a long list of tool locations, tool axis vectors and cutting codes. The post processor converts CL data generated by the main processor into NC data which are command values to the processing machine. In the study, the post processor developed in our laboratory is used, which is suitable for the construction and the significant digit of each axis of ROBONANO[5].

#### 3.2 Object Definition

The target shape defined by the above-mentioned...
system on the 3-D CAD is illustrated in Fig. 4. The shape is composed of pressure surface, suction surface, shroud surface, hub surface and nose surface. At first, the CAD system takes out coordinate value data of the inducer, which are required in order to generate the target shape data. The data are based on the coordinate value data for numerical simulation of the inducer[6]. Then, a group of sculptured surfaces, which comprises the each blade of the inducer, i.e. the pressure surface, the suction surface and the shroud surface, is generated. Furthermore, the surface data of the hub surface and the nose surface with identical shapes to those of the actual inducer are generated based on the manufacturing drawing of it. In addition, our own developed system can define the target shape in desired size. In the study, the target shape is 5 mm in diameter.

### 3.3 Tool Path Generation

As previously mentioned, our own CAM system generates NC data, based on the target shape data defined by the CAD system. At first, the main processor generates offset surfaces required to create tool path, taking account of the dimension of the target shape and the radius of the cutting tool. Then, it generates CL data by use of the offset surface data. Figure 5 illustrates the way to determine tool axis vectors. Tool locations are determined from parameters of offset surface data. Tool postures are determined for the side of the cutting edge of the tool to be tangent to each surfaces of the blades in order to machine those surfaces avoiding the collision between the tool and the workpiece.

### IV. Machining Simulation

The NC data to machine the blade surfaces generated by the CAM system described above is verified, using NC simulator. In the study, NCSIMUL2000 by SPRING Technologies is used as a machining simulator. The software loads NC data and reversely converts them into CL data, based on the axis construction of the processing machine tool. Then, it simulates the change in a workpiece shape from the swept shape of a tool. The simulated result is illustrated in Fig. 6. From the simulated result, it is seen that the CAM system developed in the study can create the target shape.

### V. Concluding Remarks

The objective of the study is to create microparts,
which are composed of complicated curved surfaces, by means of 5-axis control milling. As a target shape, a three bladed axial-flow micro pump of 5 mm in diameter is designed by use of 3-D CAD system. To create the shape, our own CAM system for 5-axis control milling is developed.

In the machining simulation, the NC data generated by the CAM system was verified, and it is confirmed that our own CAM system can create the target shape.

From these results, it is confirmed that our own CAM system can create a complicated micropart, which has possibilities to be put to practical use. From now on, it is necessary to accomplish a cutting experiment to verify whether the workpiece can be actually machined into the identical shape to the simulated result.

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References