

# **Development of an Integrated Apparatus of MicroEDM and Micro3D-CMM with a High-accuracy Probe-rotation Mechanism**

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## **Abstract**

Measuring the inner walls of microholes is one of the target for miniaturized 3-dimensional coordinate measuring machines (3D-CMMs). In this paper, we describe a  $\mu$ EDM/ $\mu$ 3D-CMM complex apparatus, and a  $\mu$ 3D-CMM with a rotatable probe. Such a mechanism eliminates the processes of removal and installation of a probe. In addition, it enables the measurement of 3D coordinates without probe installation errors. The  $\mu$ EDM has 5-axes motion and a small tabular electrode. Three axes control the linear motions of the electrode and the mandrel, and two axes control the tilt of the electrode and the mandrel. This machine can form a ( $\phi = 300 \mu\text{m}$ ) rod into various shapes (L-shape, T-shape, needle-shape, etc). The  $\mu$ 3D-CMM can measure the inner wall of a microhole ( $50 \mu\text{m} < D < 800 \mu\text{m}$ ) by rotating the L-shape probe.

## **1 Introduction**

Progress in technologies for evaluating the shapes of microcomponents is essential for progress to be made in microscale machining technologies. Measuring high aspect ratio structure such as the inner wall of a microhole is a difficult task for scanning electron microscopes and optical measuring devices. Therefore, a miniaturized coordinate measuring machine<sup>[1]</sup> is a useful device for such measurements. Sheu and Leach have developed a micro-CMM combined with micro-EDM to fabricate probes<sup>[2]</sup>. In this research, we add a rotation mechanism to a  $\mu$ 3D-CMM<sup>[3]</sup> that is developed by our team, and to reduce new errors that are added by its addition, we integrate a micro electric discharge machine ( $\mu$ EDM) with a plate electrode into the  $\mu$ 3D-CMM.

## **2 Integrated $\mu$ EDM/ $\mu$ 3D-CMM apparatus**

After machining the probe outside the  $\mu$ EDM, we install it in the  $\mu$ 3D-CMM. However, when the probe is installed in the new  $\mu$ 3D-CMM, decentering, parallelism, and rotation errors occur. These errors are in excess of a few micrometres. To

evaluate a microshape, we need sub-micrometre accuracy from the  $\mu$ 3D-CMM. To eliminate installation errors, we integrate a  $\mu$ EDM into the  $\mu$ 3D-CMM. The  $\mu$ EDM has 3 axes of translation and 2 axes of rotation because a great deal of flexibility in tool control is needed when making a complex-shape probe.

## 2.1 Device configuration

A diagram of the novel  $\mu$ 3D-CMM is shown in Fig. 1. The device has three sets of stages. The first set is the upper set. This set has shared usage in the EDM and the CMM. It comprises a Z-axis linear motion stage, a Z-axis nano-positioning stage, and a C-axis rotation mechanism. The shaft of the C-axis rotation mechanism holds the workpiece and the probe. The second set is the lower left set. This set is used in the EDM. It comprises an X-axis linear motion stage, a Y-axis linear motion stage, and a B-axis rotation stage. The tip of the B-axis rotation state has a tool electrode. The tool electrode is the only component that is inside the oil tank, which measures 50 mm  $\times$  38 mm  $\times$  40 mm. The third set is the lower right set. This set is used in the CMM. It comprises an XY-axes linear motion stage and an XY-axes nano-positioning stage. Samples are placed on top of the latter stage. The lower sets are set on the selector stage and moved under the upper set for use in either the CMM or the EDM.

## 2.2. Vibrating rotation mechanism

The C-axis rotation mechanism must have sub-micrometre rotational accuracy, be small, and be able to be positioned at any angle, because it is used in the CMM. However, this is an exacting demand for existing rotation stages. Thus, we developed

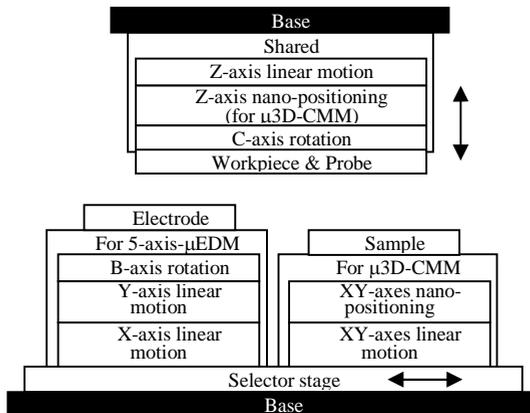


Fig. 1: Diagram of  $\mu$ 3DCMM and  $\mu$ EDM

a vibrating rotation mechanism that is based on a new principle. The shaft of the mechanism is held at the top and bottom by V-block bearings and leaf-springs. The shaft is vibrated by a piezoelectric device under the lower V block, which rotates the shaft. The frequency of vibration is about 3 kHz and the continuous vibration rotates the shaft continuously. The shaft is pulled up by a magnet and makes contact with the base through a ball. Thus it can be pulled down easily. We use a workpiece holder on the shaft because we need to be able to replace the workpiece easily. This rotation mechanism has a synchronous rotation error of around 1  $\mu\text{m}$  and an asynchronous rotation error of about 0.1  $\mu\text{m}$ . By correcting the synchronous rotation error, we can obtain a high accuracy rotation in our device. The rotation positioning accuracy is about 1 degree. When we vibrate the workpiece or the tool electrode in the EDM, machining efficiency is increased dramatically<sup>[4]</sup>. Thus, when we use this rotation mechanism in an EDM, we can vibrate the shaft using a piezoelectric device. When we do not need rotation, we select a frequency that does not result in the shaft rotating, and when we need rotation, we select a frequency that makes the shaft rotate.

### 2.3. 5-axes $\mu\text{EDM}$

The  $\mu\text{EDM}$  has high machining flexibility because it has 5 axes. However, in this machine, the tool electrode (11 mm  $\times$  11 mm  $\times$  1 mm) is extremely larger than the workpiece ( $\phi$  300  $\mu\text{m}$   $\times$  10 mm). Thus, the high flexibility and the extreme dimensional difference between the workpiece and the tool electrode resulting in very complicated tool path calculation. To simplify the calculation, we approximate an ideal probe shape by multiple flat surface shapes (Fig.2). Each surface of the approximate geometry is machined by the plate tool electrode by changing the tilt angle and the travel distance of it. Thus we calculate the value of the tilt and the travel distance. The final position vector of the tool in the workpiece coordinate system is  $\mathbf{r}_w$ . And the origin position vector in the tool coordinate system is  $\mathbf{r}_T$ . Equation 1 relates  $\mathbf{r}_w$  to  $\mathbf{r}_T$ . And the parameters ( $x, y, z, \psi, \theta$ ) in the coordinate transform matrix in eq.1 mean axial displacement values. The coordinate transform matrix is based on shape generation functions<sup>[5]</sup>. Thus, we calculate the value of the tilt and the travel distance by configuring  $\mathbf{r}_w$  and  $\mathbf{r}_T$ . And the approach vector of the tool electrode is the normal vector of the surface on the approximate geometry.



Fig. 2: Shape of probe

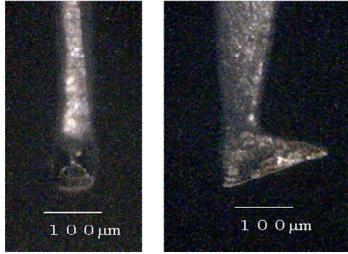


Fig. 3: Front and side views of probe

$$\mathbf{r}_w = \mathbf{A}^6 \mathbf{A}^3 \mathbf{A}^1 \mathbf{A}^2 \mathbf{A}^5 \mathbf{r}_T$$

$$= \begin{bmatrix} \cos \theta \cos \psi & -\sin \theta & \cos \theta \sin \psi & -y \sin \theta + x \cos \theta \\ \sin \theta \cos \psi & \cos \theta & \sin \theta \sin \psi & y \cos \theta + x \sin \theta \\ -\sin \psi & 0 & \cos \psi & z \\ 0 & 0 & 0 & 1 \end{bmatrix} \mathbf{r}_T \quad \dots(1)$$

$\mathbf{r}_w$  : tool electrode vector (at the workpiece coordinate system)

$\mathbf{r}_T$  : tool electrode vector (at the tool coordinate system)

$\mathbf{A}^n$  : a coordinate transform matrix

$x, y, z, \psi, \theta$  : displacement value of X, Y, Z, B, C axes

Figure 3 shows front and side views of the actual machined L-shape probe.

### 3 Conclusion

We can use an L-shape probe without decentering, parallelism, or rotation errors occurring by using a  $\mu$ EDM/ $\mu$ 3D-CMM integrated apparatus with a high-accuracy probe-rotation mechanism. In addition to the L-shape probe, we can make other shape probes such as T-shape or star-shape. Using this machine, we can evaluate the inner wall of a microhole (< 500  $\mu$ m) comprehensively.

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