euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016

www.euspen.eu

# Shaping of lens array mold surfaces by electrical discharge machining with a multiple-ball electrode

Hideo Takino[1], Takahiro Hosaka[1], and Yuki Nobe[1]

[1] *Chiba Institute of Technology, Japan*

*takino.hideo @it-chiba.ac.jp*

**Abstract**

To efficiently produce lens array molds, we have proposed a method for shaping the elements of a lens array mold by electrical discharge machining (EDM). In the proposed method, the electrode is constructed by arranging conductive spherical balls in an array. By using this electrode in the EDM process, a number of lens elements can be simultaneously shaped on a mold surface to produce the mold efficiently. In a previous study, we developed an electrode with a single ball, and machined a lens array mold with 16 elements by the electrode in order to examine the fundamental removal characteristics of our proposed method. In the present study, we developed a multiple-ball electrode involving three balls. To demonstrate the effectiveness of the proposed method, a lens array mold with 48 elements was processed by the multiple-ball electrode. As a result, the lens array mold was successfully machined by the multiple-ball electrode. The experimental results demonstrate that the multiple-ball electrode enables the shaping of the multiple lens elements with short process time. These findings prove the effectiveness of our method with the multiple-ball electorde for the production of the lens array mold.

Keywords: lens array, mold, electrical discharge machining, EDM, surface, optical fabrication

## 1. Introduction

In the general fabrication process of a lens array mold, considerable time and labor are required for the shaping of optical surfaces; a numerical control machine tool is used in the shaping step, in which each element is shaped individually by feeding the tool precisely. To efficiently produce lens array molds, we have proposed a method for shaping the elements of a lens array mold by electrical discharge machining (EDM) [1]. Since EDM can remove hard materials more easily than precision grinding and cutting, the molds can be efficiently produced. In the proposed method, the electrode is constructed by arranging conductive spherical balls on a baseplate in an array [2]. By using the electrode in the EDM process, a number of lens elements can be simultaneously shaped on a mold surface to produce the mold efficiently. In a previous study [3], we developed an electrode with a single ball, and machined a lens array mold with 16 elements by the electrode in order to examine the fundamental removal characteristics of our proposed method.

In the present study, we developed a multiple-ball electrode involving three conductive balls. To demonstrate the effectiveness of the multiple-ball electrode, a lens array mold with 48 elements was shaped, and evaluated the resulting surfaces.

## 2. Principle of fabrication method of lens array mold by electrical discharge machining with spherical ball electrode

Figure 1 shows the principle of our proposed fabrication method. In general, a lens element of the lens array is not a full hemisphere but part of a hemisphere. When the parts of hemispheres are shaped by the electrode shown in Fig. 1, the elements are necessarily generated at intervals; Fig. 1 schematically shows that the elements are produced with an interval of one element in each EDM process. Therefore, to produce a lens array mold whose elements are densely arranged, the repetition of the EDM process is required to fill the intervals with elements.

In the present work, we designed a spherical ball electrode, as shown in Fig. 2. The balls are fixed on the baseplate by force using plate springs. By using the baseplate with high flatness, the balls can be positioned along the Z direction with high accuracy. The balls are also accurately positioned along the X and Y directions by setting them into the holes of the holding plate. The tilting of the tops of the balls affects the variation of the depth of the lens elements. Thus, the electrode is set to an EDM machine via a tilting mechanism that levels the electrode.

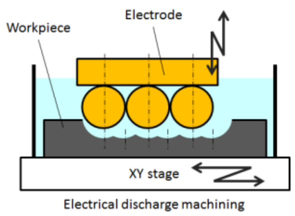


**Figure 1.** Fabrication of lens array mold by EDM.

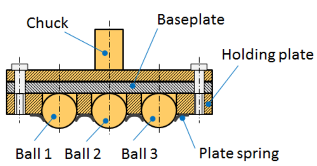


**Figure 2.** Spherical ball electrode designed in this study.

## 3. Experimental method

### *3.1. Electrode*

In the present study, we developed an electrode including three balls. The baseplate and the holding plate are made of stainless steel and copper, respectively. The balls are made of copper and their diameter is designed to be 4 mm, which are placed at an interval of 6 mm. The balls are fixed on the baseplate by plate springs made of stainless steel.

### *3.2. Machining of lens array mold*

We shaped a lens array mold with 48 lens elements in this study. Stainless steel was used as the workpiece material. The distance between the elements is 1.5 mm. The depth of the elements is 350 µm. The curvature radius of the lens elements is 2.1 mm. To shape such a mold surface, the same EDM process was performed 16 times, in which the electrode was positioned at intervals of 1.5 mm. In one EDM process, three lens elements were shaped simultaneously because the electrode holds three balls. Since the ball of the electorde had a curvature radius of 2 mm, the clearance between the removed surface and the electrode surface during the EDM process was set to 0.1 mm to produce lens elements with a curvature radius of 2.1 mm. After the EDM processes, the surface profile of the workpiece was measured using the three-dimensional measuring instrument employing a laser probe.

A commercially available electrical discharge machine was used in this work. The EDM process conditions were determined through an expert system normally installed in the electrical discharge machine.

## 4. Results and Discussion

An example of a fabricated lens array mold is shown in Fig. 3. Figure 3(a) shows a photograph of the top view of the mold surface observed by an optical microscope. Each region indicated by the numbers is machined by one ball in the electrode. Fig. 3(b) shows the cross-sectional profile of the surface along line AA' in Fig. 3(a). As shown in Fig. 3, 48 elements were successfully shaped on the surface.

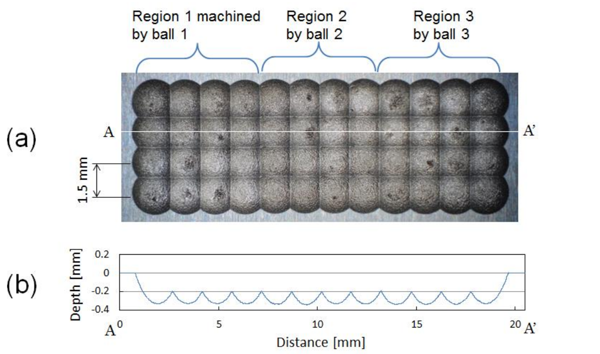


**Figure 3.** Example of fabrication results. Photograph of processed surface (a) and cross section of surface along line AA' (b).

The measurement of surface profiles was conducted for every element. On the basis of the measured surface profiles, the shape accuracy for each element was calculated; note that the shape accuracy includes the surface roughness in this study. The peak-to-valley (PV) values of the shape accuracies for every element are shown in Fig. 4. In Fig. 4, the shape accuracy is shown for each region machined by one ball. As shown in Fig. 4, the shape errors increase as the process proceeds. However, the 48 lens elements are machined with a PV shape accuracy of less than 20 µm. In addition, the PV surface roughness was almost constant and approximately 10 µm. In a previous work [3], we shaped 16 elements by a single ball electrode. The trend of the change in the shape accuracy with the process number for the previous work is almost the same as that for the present 48 lens elements. We have already found that the degradation of the shape accuracy results from the erosion of the ball surfaces, and the shape accuracy can be improved by performing the second EDM process using an electrode with new balls as a fine EDM process.

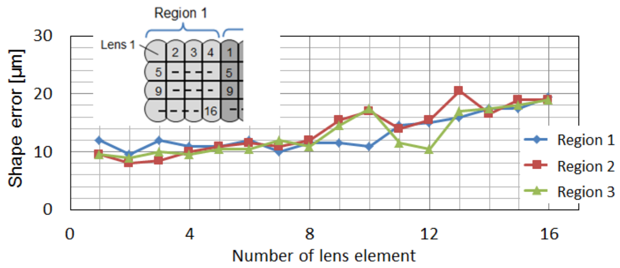


**Figure 4.** Shape error for each lens element.

Figure 5 shows process time for the different EDM processes, in which experimental results for the electrodes with a single ball and with three balls are shown. In Fig. 5, we also show estimated process time for the simultaneous shaping of the three lens elements, which was calculated by multiplying the process time experimentally obtained by the single-ball electorde by three. As shown in Fig. 5, the experimentally obtained process time (13.6 min) for the three-ball electrode is shorter than the estimated process time (17.7 min). This demonstrates that the multiple-ball electrode can be effectively used in the shaping process of the lens array mold. One possible reason for the effectiveness of the multiple-ball electrode is that the discharge area of the multiple-ball electrode is larger than that of the single-ball electorde. Such large area possibly provides high probability of electric discharge, which results in high removal rate.

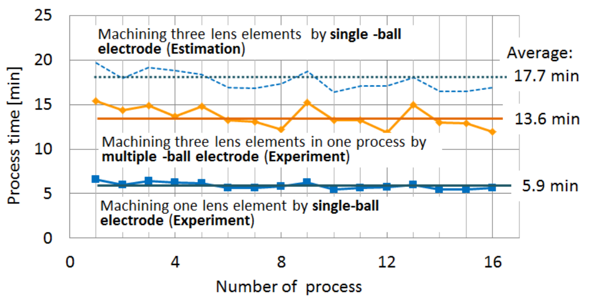


**Figure 5.** Process time of lens elements for different EDM processes.

## 5. Conclusions

We developed a multiple-ball electrode, which includes three conductive balls as discharge areas. To demonstrate the effectiveness of the multiple-ball electrode, a lens array mold with 48 elements was shaped. As a result, the mold was successfully shaped, and its shape accuracy and surface roughness were almost the same as those obtained by the single-ball electrode we previously developed. Moreover, the experimental results demonstrate that the multiple-ball electrode enables the shaping of the lens elements in a short time. These findings prove the effectiveness of our method with the multiple-ball electorde for the production of the lens array mold. The method will be effective as a technique in the shaping step in the production process. After the EDM process, a final process, such as fine grinding or polishing, will be required to obtain optical surfaces depending on the required surface smoothness.

## References

[1] Takino H and Hosaka T 2014 *Appl. Opt.* **53**, 8002-05
[2] Hosaka T and Takino H 2014 *Proc. 15$^{th}$ ICPE* 696-99
[3] Takino H and Hosaka T 2015 *Proc. 15$^{th}$ euspen* 71-72