DISPLACEMENT DETECTION OF SMALL SPHERE USING ECCENTRIC ASTIGMATIC METHOD

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Abstract:

To develop a micro tactile probe used with a micro coordinate measuring machine (CMM), a novel technique for detecting a three dimensional displacement of a small sphere with high sensitivity has been proposed. In this technique, a surface of a metal sphere is included as a spherical mirror in an optical system and changes of optical path arise from displacement of the sphere is detected with a sort of the astigmatic method.

In the optical system, three eccentric collimated beams are generated and each beam moves parallel to the optical axis. The beam is converted to spherical wave by an objective lens and moving toward the focal point. At this time, if a spherical mirror (metal sphere) is placed in the position of which center falling on the focus, incident angles of all rays become right angle and reflected rays go back on the incident paths. On the other hand, if the spherical mirror moves from the point in the small distance, return path of each reflected ray is changed large. This change can be detected with the astigmatic method using a condenser lens and a CCD.

The relationship between displacement along three axes and the change of the spot radius made by astigmatic method was calculated using a ray tracing code. As a result, the change of the spot shape was simulated only with the motion along one axis. This result shows the feasibility of three dimensional displacement detection by the proposed method.

Keywords: Astigmatic method, Micro-probe, Tactile probe, Coordinate measuring machine

1. INTRODUCTION

The dimensional measurement of mechanical components has been conducted with coordinate measuring machine (CMM) with tactile probe. As mechanical components getting smaller, various types of micro CMMs and micro tactile probes were developed [1-4].

For measuring small mechanical components, miniaturization of spherical probe and reduction of contact force is required. Therefore, high resolution displacement detection of a small sphere is required.

In this research, a new technique has been proposed for detecting small displacement of a small sphere with a sort of astigmatic method.

2. OPTICAL SYSTEM AND PRINCIPLE

2.1 Basic Layout and Principle of Displacement Detection

Figure 1 shows the schematic of the optical system of the proposed method. In the optical system, three eccentric collimated beams are generated first. A beam from a He-Ne laser source is enlarged diameter by a beam expander and a multi aperture stop, a plate with three circular apertures, make three eccentric collimated beams shown on Fig. 2(a). Each beam move parallel to the optical axis. These beams pass through a polarizing beam splitter (PBS) with quarter wave plate (QWP) and incident on an objective lens. By the objective lens, the beam is converted to spherical wave moving toward the focal point. At this time, if a spherical mirror, which is a polished metal sphere is placed in the position of which center falling on the focus, incident angles of all rays become right angle and reflected rays go back on the incident paths. On the other hand, if the spherical mirror moves from the point in the small distance, return path of each reflected ray is changed large. This change is converted with

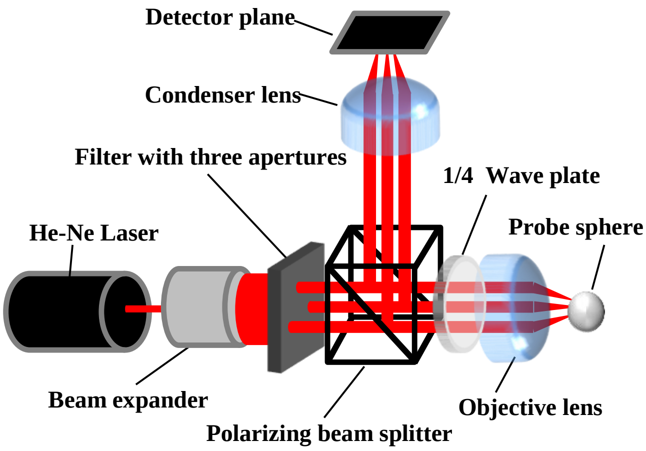


Fig.1 Schematic of optical system for detecting displacement of probe sphere

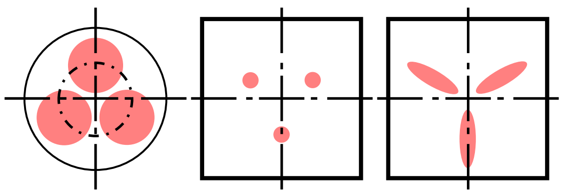


Fig.2 Shape of incident beam and spot shapes on detector plane
(a) Three collimated eccentric beams
(b)Spot shapes on detector plane (initial position)
(c)Spot shapes on detector plane (after displacement)

astigmatic method using condenser lens: On the detector plane, the shapes of the spots change from circles like Fig. 2(b) to ellipses like Fig. 2 (c).

These changes of shapes and sizes of the focused spots are acquired by a CCD image sensor on the detector and a minute motion of the sphere was detected.

2.2 Optimization of Eccentric Distance

At the next step of optical design, we carried out the optimization of the eccentric distance. In the proposed method, the spot size on the detector plane should be minimized when the probe is at the initial position. Therefore, we decide the eccentric distance with the ray tracing simulation using a commercially available software, CODE V (Synopsys Inc.). Fig. 3 shows the simulated optical system and Table. 1 shows the parameters used in the simulations. Because three beams incident on the PBS has rotational symmetries through 120 degrees, simulation was carried out with one beam. As shown on Fig. 3, two coordinate systems were defined. One is geometrical coordinate system (X, Y, Z) based on the optical axis of incident laser and another is coordinate for analysis (X', Y', Z') based on the optical axis of the focused beam. Same lenses, of which diameter is 12 mm and the focal length is 8.5 mm (01LAG000, Melles Gliot) was used as the objective lens (L1) and condenser lens (L2). The surface of the probe was defined as a spherical mirror. The diameter of the beam was set to 3 mm and eccentric distance was changed from 2 mm to 3 mm with 0.1 mm increments at the first step. Fig. 4(a) shows the spot size as a function of eccentric distance. Moreover, best eccentric

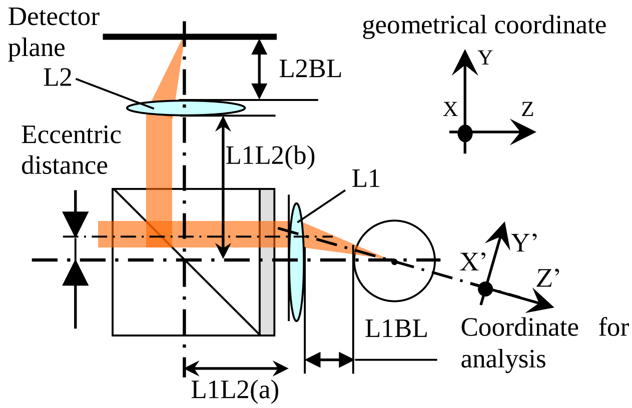
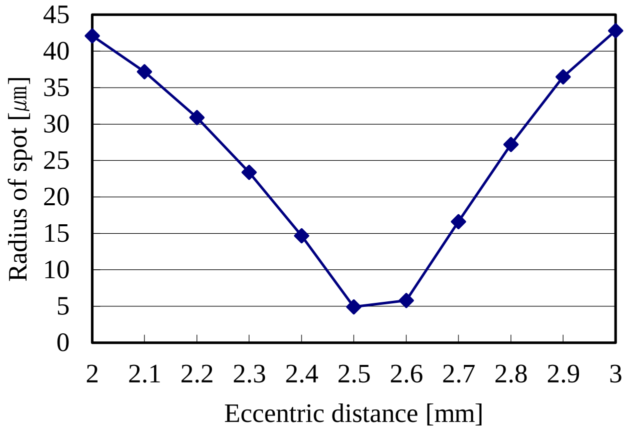


Fig. 3 Simulation settings and coordinate systems

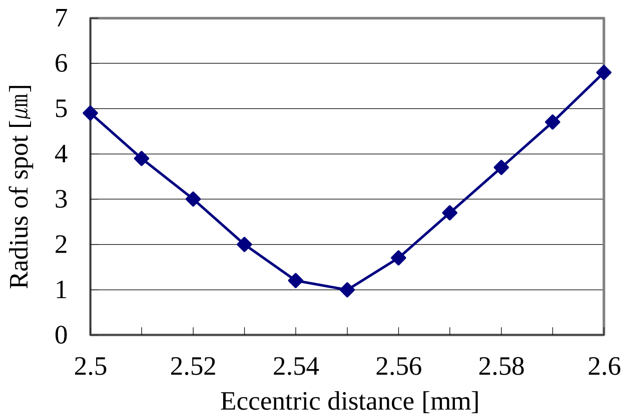
Table 1 Parameters used in ray tracing simulation for optimization of eccentric distance

Wavelength	632.8 nm
Beam diameter	3 mm
Eccentric distance	2 – 3 mm (with 0.1, 0.01, 0.001 increments)
Objective lens (L1), Condenser lens (L2)	01LAG000 Melles Gliot d=12 mm f = 8.5 mm
Diameter of probe ball	1 mm
L1L2(a) + L1L2(b)	100 mm

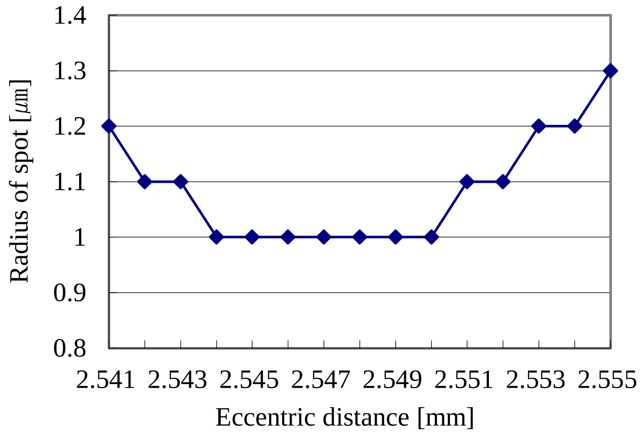
distance was investigated near the bottom of the line chart with increments of 0.01 mm (Fig. 4(b)) and 0.001 mm (Fig. 4(c)). From these results, we determine the best eccentric distance as 2.547 mm under these conditions. In the eccentric distance, the optical axis of the beam focused by the objective lens, namely, the coordinates for analysis incline approximately 17 degrees to the geometrical coordinate.



(a) With increments of 0.1mm



(b) With increments of 0.01mm



(c) With increments of 0.001mm

Fig. 4 Relation between eccentric distance and radius of spot on detector plane

3. SIMULATIONS FOR DISPLACEMENT DETECTION

3.1 Simulation Conditions

In the following simulations, diameter of probe ball was set to 0.3 mm and the distance from the back surface of L1 to the surface of the probe (L1BL) was set to 5.844 mm. Eccentric distance was set to 2.547 mm. According to these changes, distance from L2 back surface to surface of the probe at initial position (L2BL) was set to 6.069 mm. Other parameters used in the following simulations were same as shown in Table. 1.

3.2 Simulation Results of Spot Radius

Figure. 5 Shows the relationship between displacement of the sphere and radius of the spot on the detector plane. Figure (a), (b), (c) show the simulation results when the sphere moved along the X' axis, Y' axis and Z' axis respectively. At the initial position, X radius and Y radius of the spot were about 0.8 µm.

In case of the X' axial motion, Y radius was almost constant and become slightly larger when the absolute value of the displacement was set larger than 0.8 µm. At the same conditions, X radius remained constant.

On the contrary, in case of the Y' axial motion, the Y radius become large sharply in proportion to the displacement and the X radius remained constant. As a result, shape of the spot changes from a circle to an ellipse with the displacement. Furthermore, by comparing with other results, it was confirmed that small spherical ball makes drastic change even if the displacement is slight.

In case of the Z' axial motion, the X radius and the Y radius kept almost constant under the displacement less than 1 µm.

From these results, we confirm that clear change of the spot shape arises only when the sphere moves along the Y' axis. This property is desirable for applying to position detection of the sphere using as the tactile probe.

3.3 Simulation Results of Spot Position

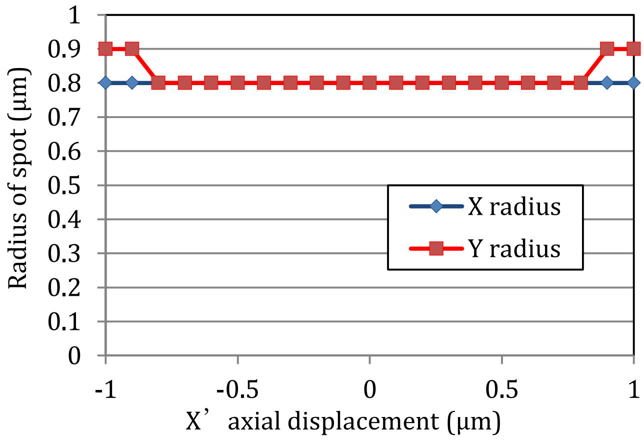
Figure 6 shows the relationship between the displacement along the each axis and the spot position on the detector plane.

Fig. 6(a) shows the change of spot position when the X' axial motion of the sphere was given. The X axial position changes slightly within ±1 µm near 0 µm and the Y axial position of spot keep constant at about -23 µm. This result shows the focused spot appears near the center of detector plane, but it does not overlap each other.

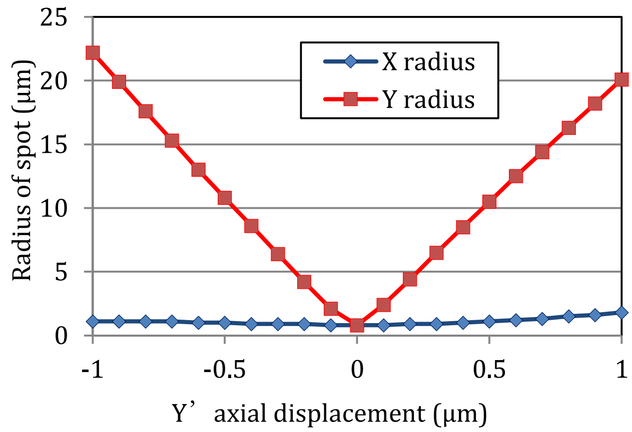
Fig. 6(b) shows the change of the spot position when the Y' axial motion of the sphere was given. The X axial position of the spot was constant at 0 µm and changes of the Y axial position was small (-23 ±1 µm).

Fig. 6(c) shows the change of the spot position when the Z' axial motion of the sphere was given. The X axial position of the spot was constant at 0 µm and changes of the Y axial position was also constant at -23 µm.

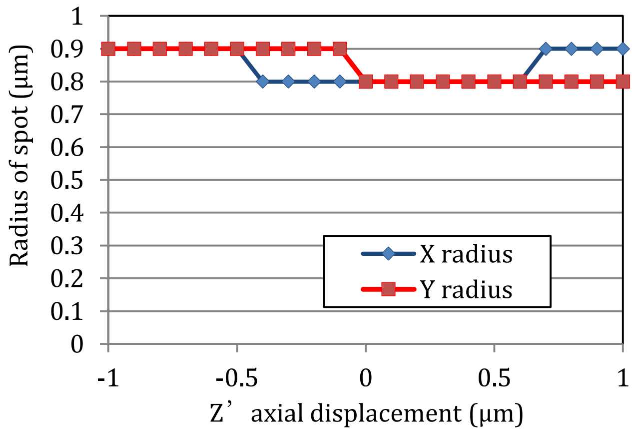
These properties, namely, does not overlap and moves only in a small area, are desirable for detecting the change of the spots simultaneously with one photo detector like CCD.



(a) Displacement along X' axis

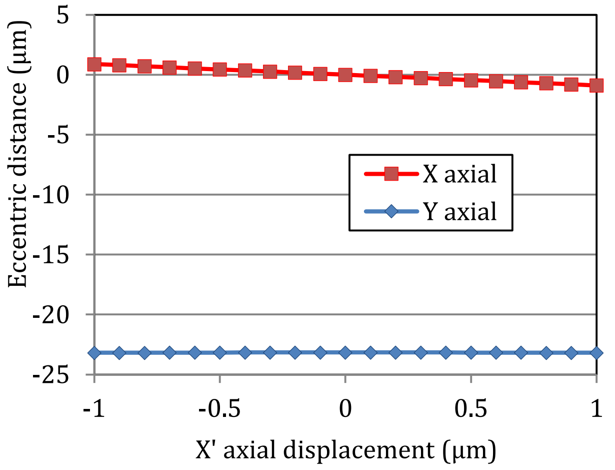


(b) Displacement along Y' axis

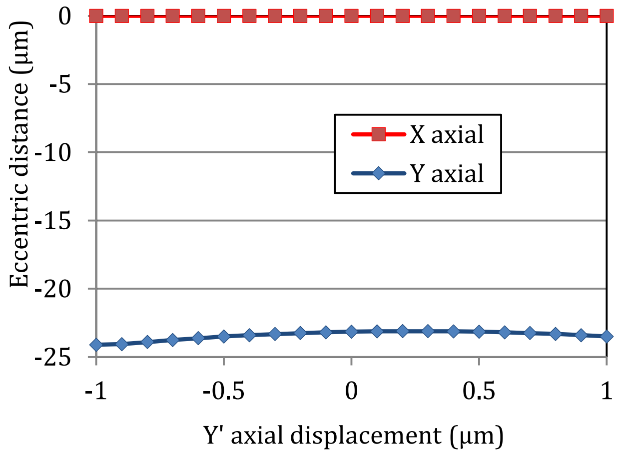


(c) Displacement along Z' axis

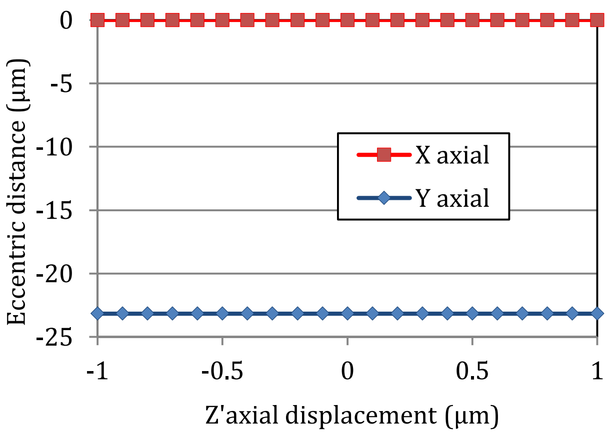
Fig. 5 Relationship between displacement of sphere and radius of spot on detector plane



(a) Displacement along X' axis



(b) Displacement along Y' axis



(c) Displacement along Z' axis

Fig. 6 Relationship between displacement of sphere and eccentric distance of spot on detector plane

4. CONCLUSION

The authors proposed the novel technique to detect a three dimensional displacement of a sphere by using a sort of astigmatic method with three beams.

By the ray tracing simulations about the optical system, the following results were obtained.

(1) By the optimization of the eccentric distance on a condition, a proper value which makes the sharp spot on the detecting plane was determined.

(2) The shape of the spot changes from a circle to an ellipse only when the sphere moves along the Y' axis: X radius of the spot become large sharply in proportion to the displacement and the Y radius remained constant. The shape and the radii keep almost constant when the sphere moves along the X' axis and Z' axis.

(3) The spot on the detector plane remains almost constant position when the sphere moves along X', Y' and Z' axis.

From these results, the proposed optical system has the feasibility of the precision position detection and desirable properties for applying to a tactile probe system.

As a future work, the authors plan to construct an experimental system based on these simulation results.

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