'95 KACC (1995. 10. 23 ~ 25)

# A THREE-DIMENSIONAL MEASURING TECHNIQUE APPLIED TO FORGING PRESS MACHINE

Sun Xiao, Yoichi Shimomoto, Takakazu Ishimatsu

Mechanical Systems Engineering, Nagasaki University, Japan
Bunkyo-machi 1-14, Nagasaki City, Japan 852

Abstract. This paper describes a 3-dimensional measuring method for cylindrical huge ingot pressed with forging machine. Target ingot we consider here is rotated around a fixed axis during measurement. Using an image processing technique every profile of cross-section is obtained, and 3D image is reconstructed. One method to calibrate the system setting is also presented. Experimental results reveal that the method are applicable and the algorithm is feasible.
Key word: 3D measuring system, cross-section, image reconstruction, forging

## 1. INTRODUCTION

Three-dimensional information is important in order to promote automation of production and inspection systems. While three-dimensional measuring system with mechanical contact have been widely used so far, demand of non-contact three-dimensional measuring technique is increasing in many fields like designing fields, semi-conductor industries and so on. Also in the factory of forging press, a three-dimensional measuring technique is needed. However, in this field, scale of target objects are often over a few meters. Furthermore, environment of measurement is often unacceptable for conventional three-dimensional measuring system because of dusty air, humidity and heat. In this paper we present an original three-dimensional measuring system for recognizing profile of red-hot ingot during the forging task.

One free-forging press system which we consider is shown in Fig.1.1. In this figure one pull-down type forging press is shown. In order to upgrade the speed and precision of the free-forging press, a manipulator is employed. The manipulator grasps an ingot with fingers, then moves and rotates the ingot on the forging press machine so that the ingot is pressed to have a desired shape. The movement and rotation of the forging manipulator is remotely controlled by an operator. For a high accurate forging, three-dimensional information of the ingot is highly required. However, only the diameter of ingot can be measured manually. Usually the task is executed under extremely inhospitable operating condition because of radiant heat from measured red-hot ingot. Therefore, some non-contact three-dimensional measuring technique will be very significant and has been widely needed in this field.

Some techniques are already presented to get a 3D data by means of slit-ray projection method.[1] For an ingot during forging, the slit-ray projection method can be used for recognizing profile of cross-section[2]. Also another trial was reported that cross-section profile of ingot was measured by means of stereo images. Some points on target ingot are computed through two images obtained by two camera. Images of profile are obtained during rotation of the target ingot. Some of irregular pattern was searched in two contiguous pictures so that every part of profile can be connected together to produce a global one[3].

In our research, the target ingot is measured during the rotation around a fixed axis centrally or eccentricly. Considering practical situation in factory, measuring technique is requested to be robust to the hazardous working condition. In order to simplify the procedure of system setting, a method is used to calibrate system setting with a known radius cylinder. The relation between CCD camera and manipulator is established during the calibration. CCD camera can be fixed beside target ingot at any position in any posture if only the part of target ingot can be viewed in film plane. Global profile of target ingot can be viewed on film plane during the ingot rotating step by step. At every rotating angle, image of the target ingot is viewed on film plane

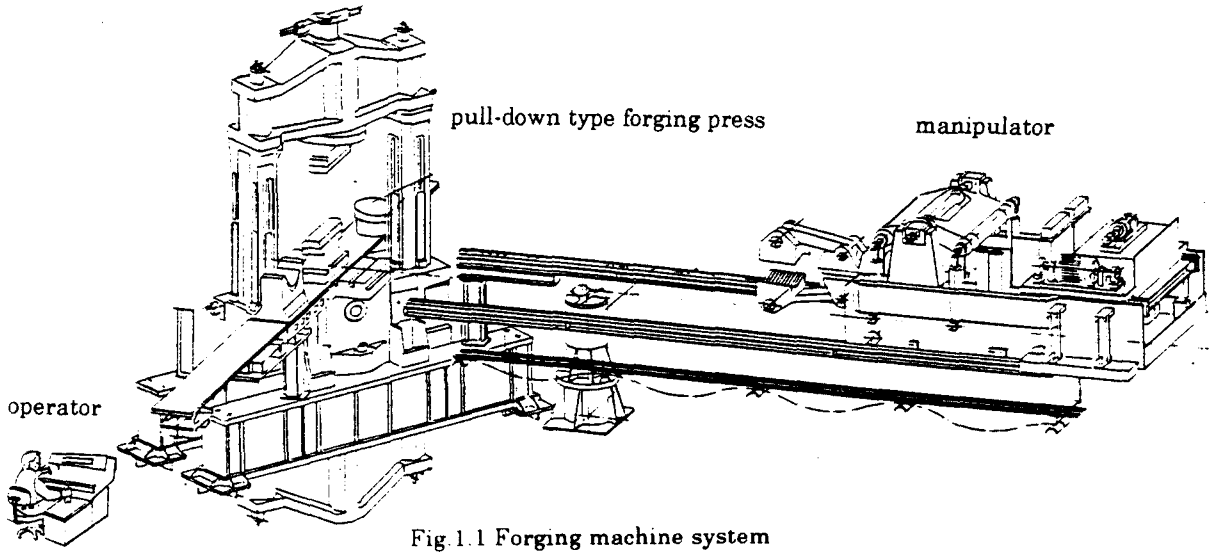


Fig.1.1 Forging machine system

and contour of the target is obtained. After that, according to the variation of every profile of the target ingot, every profile of cross-section is calculated. Finally, a 3D image of target ingot is reconstructed on computer screen. During measurement, only the outline of target ingot image is considered, so that measuring system configuration is simplified than that of slit-ray projection method and stereo picture method.

## 2. MEASURING SYSTEM CONFIGURATION

Fig.2.1 shows the system configuration. A CCD camera is fixed beside the target ingot. The measuring part of target ingot needs to be viewed on film plane of CCD camera. The position and posture of CCD camera can be arbitrary if only contour of target ingot is viewed at any time during its rotation. Relation of position and posture is recognized by a calibration method before measurement. An image processing computer system (NEC PC9801RA) performs 8-bit gray scale image data processing with 512*480 pixels per frame obtained by the CCD camera. Also all necessary computing for measuring algorithm is carried on by the computer. Manipulator can hold target ingot with fingers moving forward and backward and rotates during the ingot is pressed by the forging machine. The rotating movement is controlled by the computer step by step with a desired rotating angle during measurement. The movement of manipulator is controlled through a manipulator driver.

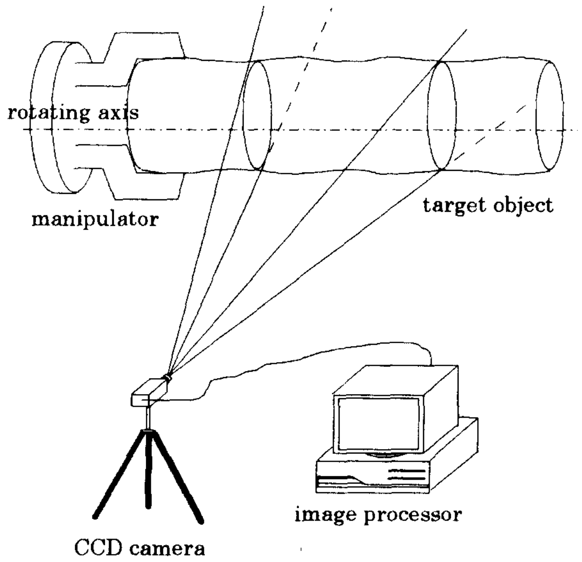


Fig.2.1 Measuring system configuration

## 3. CALIBRATION

In order to calibratie the geometrical relation between the rotating axis of the manipulator and the camera coordinate, the calibration model with known radius R is cramped by the manipulator as shown in Fig.3.1. Firstly, the vector to represent the direction of rotating axis is determined as follow. Suppose the outline of the calibration model is observed on the film plane as shown in Fig.3.1, where length $|\vec{p}_5| = |\vec{p}_6| = l$. It should be noted that the vectors $\vec{p}_1 \sim \vec{p}_4$ are tangant to the cylindical surface of the calibration model, and also that the vectors $\vec{p}_5$ and $\vec{p}_6$ are parallel with the rotating axis. From the image on the film plane, the vector $\vec{p}_1 \sim \vec{p}_4$ can be determined as follows. The relation between $\vec{p}_1 \sim \vec{p}_4$ and $\vec{q}_1 \sim \vec{q}_4$ are discribed by Eq.(3-1) with constant $k_1 \sim k_4$ and relation amoung $\vec{p}_1 \sim \vec{p}_4$ discribed by Eq.(3-2).

$$\vec{p}_j = k_j \vec{q}_j \quad (j=1,2,3,4) \tag{3-1}$$

$$\vec{p}_1 + \vec{p}_4 = \vec{p}_3 + \vec{p}_2 \tag{3-2}$$

Substituting Eq.(3-1) into Eq.(3-2) we obtain

$$k_1 \vec{q}_1 + k_4 \vec{q}_4 = k_3 \vec{q}_3 + k_2 \vec{q}_2 \tag{3-3}$$

From the above equations $k_i$ is obtained as

$$k_1 = \frac{l}{\sqrt{t^2 \vec{q}_2^2 - 2t(\vec{q}_1 \cdot \vec{q}_2) + \vec{q}_1^2}} \tag{3-4}$$

$$k_2 = \frac{l\ t}{\sqrt{t^2 \vec{q}_2^2 - 2t(\vec{q}_1 \cdot \vec{q}_2) + \vec{q}_1^2}} \tag{3-5}$$

where

$$t = \frac{\vec{q}_3 \cdot (\vec{q}_4 \times \vec{q}_2)}{\vec{q}_3 \cdot (\vec{q}_4 \times \vec{q}_1)} \tag{3-6}$$

and l is the length of $\vec{p}_5$. So that we obtain

$$\vec{p}_5 = \vec{p}_2 - \vec{p}_1 = k_2 \vec{q}_2 - k_1 \vec{q}_1 \tag{3-7}$$

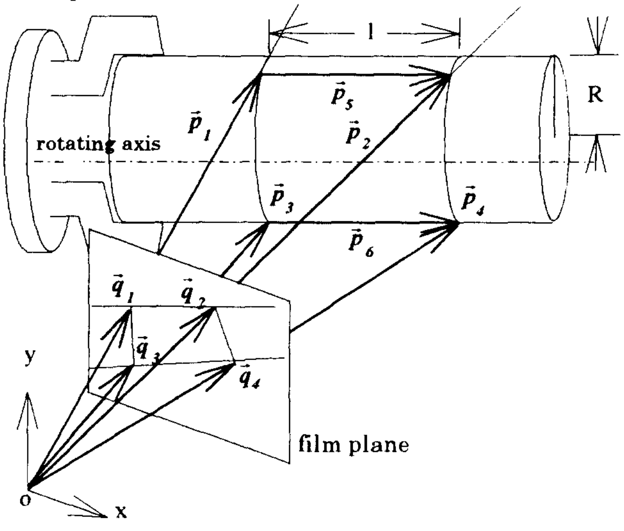


Fig.3.1 Computation of the direction of the rotating axis

Secondly, as shown in Fig.3.2, the point $o_c$ which is defined as cross point of vector $\vec{r}$ and rotating axis is determined, where vector $\vec{r}$ is vertical with rotating axis. The point $o_c$ will be used as base point for deciding position of cross-section where a cross-section is measured. A plane $S_0$ at the point $o_c$ vertical with the rotating axis is shown in Fig.3.2. In the second step of the calibration, the vector $\vec{r}$ needs to be determined. Considering the eccentricity of the rotating axis, the calibration model needs to be rotated and the outline of the model needs to be measured. From the data measured, the vector $\vec{r}$ can be determined. However, we omit the explanation for short.

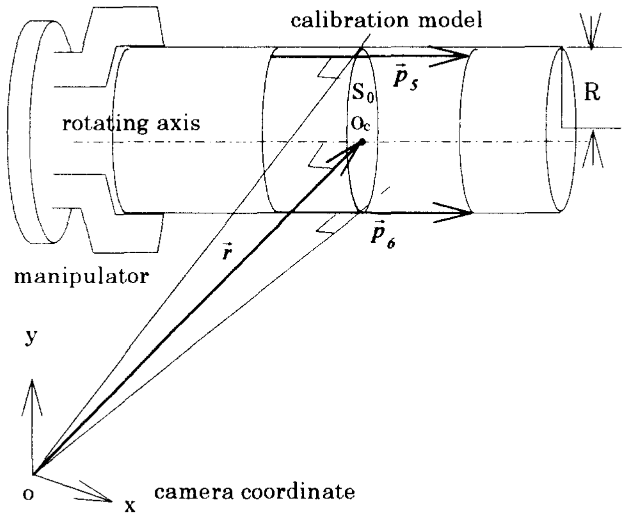


Fig.3.2 Featuring parameters of calibration

## 4. MEASUREMENT

In order to obtain a 3D image of target ingot, a set of measuring plane $S_d$ ( d=1,2,3... ) are fixed on rotating axis vertically, whose position is represented by a vector $\vec{v}_{rd}$ as shown in Fig.4.1. $\vec{v}_{rd}$ is stating from base point and ending at the position where measurement will be carried on. The number of d is depending on the number of measuring plane that we are going to measure for profile of cross-section.

As shown in Fig.4.1 $\vec{q}_n$ (n=1,2,3...) is built through a point on the outline of target ingot projection on film plane. The extended line crosses measuring plane $S_d$ at cross point $H_n$ (n=1,2,3...). $\vec{p}_n$ is defined as a vector to point at point $H_n$ on measuring plane $S_d$. $\vec{v}_{od}$ is defined as a vector to point at point $o_d$ from origin, at where rotating axis crosses measuring plane $S_d$. The relation between the vectors satisfied the following equations.

$$\vec{r} + \vec{v}_{rd} = \vec{p}_n - \vec{v}_h \qquad (4\text{-}1)$$

$$\vec{v}_h \cdot \vec{v}_{rd} = 0 \qquad (4\text{-}2)$$

$$\vec{p}_n = k_n \vec{q}_n \qquad (4\text{-}3)$$

From the above equations we have

$$k_n = \frac{(\vec{r} + \vec{v}_{rd}) \cdot \vec{v}_{rd}}{\vec{q}_n \cdot \vec{v}_{rd}} \qquad (4\text{-}4)$$

where $\vec{q}_n$ (n=1.2,3...) can be obtained through detecting the outline of target ingot on the film plane.

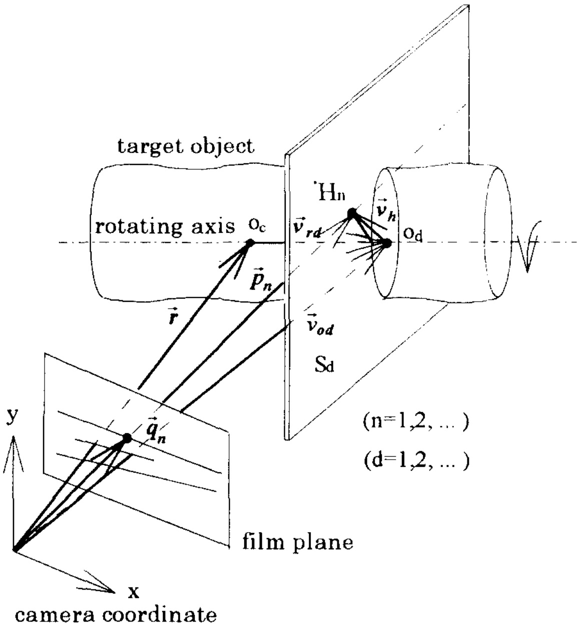


Fig.4.1 Cross point on the measuring plane

Choosing image point along the outline of target ingot projection properly, $\vec{p}_n$ is computed by Eq.(4-4) and Eq.(4-3), and cross points $H_n$ can be obtained on measuring plane $S_d$ through vector $\vec{p}_n$. Connecting all of points $H_n$, a curve $M_i$ is completed at rotating angle $\omega = \omega_i (i = 0,1,2...I)$, on which it must has a point at where the curve is tangent to profile of cross-section of target ingot. It is shown in Fig.4.2.

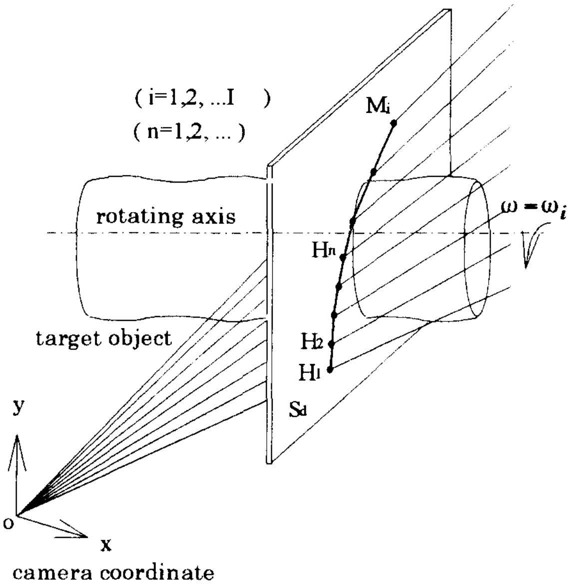


Fig.4.2 A curve tangent to the profile of cross-section

Once the curve $M_i$ are obtained at various rotating angles, cross-section on the plane $S_d$ can be estimated. Therefore, the target ingot is turned i times and we can get i ( i=0,1,2...I ) curves $M_i$ during measurement. Rotating angle for one time is $\Delta\omega$ , so that the number of curves is 360/ $\Delta\omega$ . Cross point between two curves $M_i$ and $M_{i+1}$ is searched after curve $M_{i+1}$ is turned for an angle $\omega_i + \Delta\omega$ around rotating axis $o_d$ on the measuring plane $S_d$ .

Finally, linking all cross points of neighboring curves $M_i$ , a closed curve which representing the profile of cross-section of target ingot at position $o_d$ is obtained. For a 3D profile, measuring plane is moved along rotating axis with distance $\Delta d$ step by step.

## 5. SIMULATION EXPERIMENT AND RESULTS

The experiment was carried out with ordinary temperature. A plastic bottle with irregular shape is measured as a target object as shown in Fig.5.1. Calibration was carried on with a known radius-cylinder. The radius is 49.33[mm]. The relative position of camera and rotating axis of manipulator is measured by the calibration as mentioned above. As results measured direction cosine of rotating axis in x, y, z direction are 0.029, 0.997 and -0.072. The components of vector $\vec{r}$ that points to the base point on rotating axis are 29.602[mm], -0.690[mm] and 695.260[mm] in x, y, z axis.

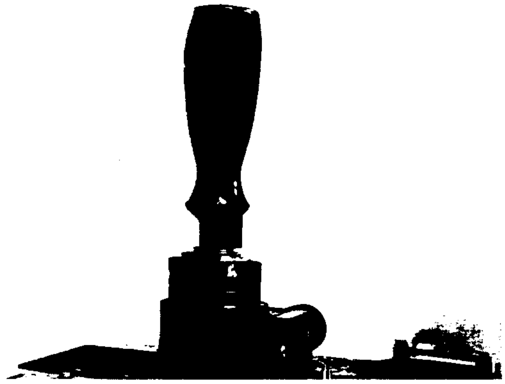

Fig.5.1 Target object

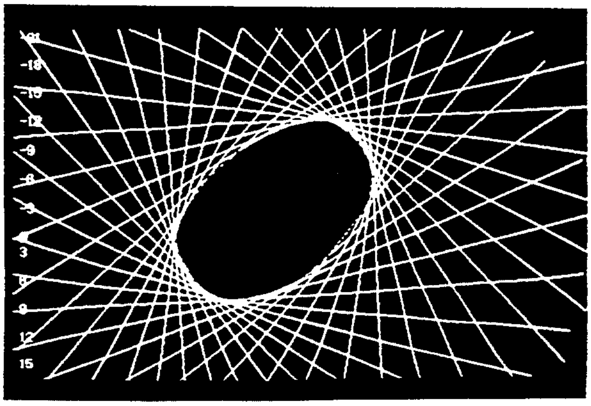

Fig.5.2 Cross-sectional profile tangent to all curves

Fig.5.2 shows idea how the cross-section is calculated. A cross-section profile is tangent to all curves on the plane. Interval of rotating angle $\Delta\omega$ is 10.0 degree so that the number of curves is equal to 36. Profile is obtained by linking the cross points between two contiguous curves. The distance of measuring plane was 15.0[mm] from base point along rotating axis.

Three-dimensional image was reconstructed as shown in Fig.5.3. The interval of two measuring planes is 3.0[mm] and measuring height was from -90.0[mm] to 30.0[mm] according to the position of base plane.

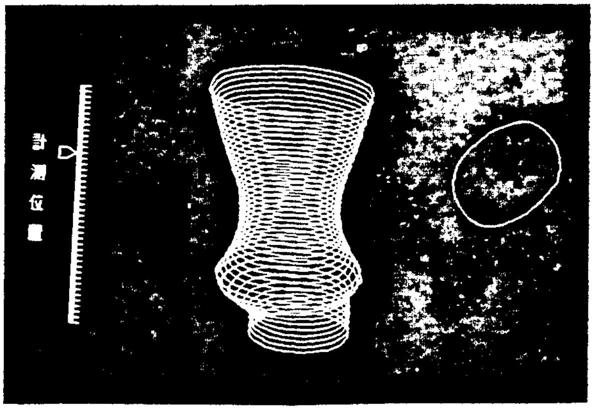

Fig.5.3 3D image reconstruction

## 6. CONCLUSION

We have developed a three-dimensional measuring system of ingot pressed with forging machine. Using a original algorithm, profile of cross-section on a certain position along rotating axis is determined by a set of curves. Shape of target object is reconstructed on screen of computer. A feature of our method is that the system configuration is simple enough to apply in the practical field and also that reliable data are obtained since image processing is quite simple without using special light sources. The basic assumption of this method is that bending of the target ingot during the rotating is negligible. This assumption needs to be considered when the target ingot is relatively long. The results of experiment show that the system is applicable and the algorithm to measure three-dimensional profile of ingot is feasible.

## 7. REFERENCE


[1] Ishimatsu T. et al, "Fast 3-dimensional Measuring Technique Using a Look-Up Table( Measurement of Human Head) ", Transactions of the Japan Society of Mechanical Engineers, vol.57, no.538(c), 1992

[2] Sun Xiao et al, "Three-dimensional Profile Measurement of the Ingot Pressed with Forging Machine", The First Asian Control Conference Tokyo, vol.3, pp. 623, 1994

[3] Furuhashi H. et al, "One Fast Computing Technique of Image Registration", 11th Pattern Measurement Division, Yokohama, Japan, 1991