Development of Optical Axis Adjustment Device for Heliostat of Beam-Down Solar Concentrator

R. Nagatomo[1], S. Tomomatsu[2] and Y. Nagase[2]
[1]Graduate school of engineering, University of Miyazaki, 1-1 Gakuenkibanadai-Nishi, Miyazaki, 889-2192, Japan
[2]University of Miyazaki, 1-1 Gakuenkibanadai-Nishi, Miyazaki, 889-2192, Japan

Abstract- A tower-type solar concentrator has a lot of devices called heliostat. They have mirrors for reflecting sunlight and can track the sun. The purposes of this study are to propose a high accuracy adjustment method for cluster-type heliostat with multiple mirrors and to investigate the influence on the divergence of the optical axis. In order to improve the accuracy of optical axis adjustment for heliostat of beam-down solar concentrator, an optical axis adjustment device was designed and manufactured. The accuracy and divergence of axes were evaluated quantitatively and theoretically. Developed optical axis adjustment device could adjust mirrors of heliostats with accuracy. The maximum divergence between the theoretical target and the axis was significantly improved by the new adjustment method.

I. INTRODUCTION

Researches for generating electricity from renewable energy [1-2] have been conducting, and concentrating solar power (CSP) is one of them. In order to improve total efficiency, various studies [3-14] were conducted, for example, receiver shape, heat storage, prime mover and so on. There are four main types of the solar concentrating method [15] for CSP. A tower-type solar concentrator has a lot of devices called heliostat. They have mirrors for reflecting sunlight and can track the sun [16]. Reflected sunlight is concentrated on a spot on the tower. Thus, a relatively high flux can be obtained at the spot. A heliostat has one mirror or multiple mirrors. By forming a cluster with multiple mirrors, heliostat is not easily affected by the wind, and it is possible to increase the concentration ratio at the focusing spot. In using the heliostats, correctly adjusting the optical axis of collecting mirror for all heliostats is the most important. The purposes of this study are to propose a new adjustment method for cluster-type heliostat with multiple mirrors and to investigate the influence on concentration ratio with the change of the culmination altitude and the direction of the sun due to the change of season and time.

II. EXPERIMENTAL DEVICES

Fig. 1 shows a schematic diagram of a beam-down solar concentrator built at the University of Miyazaki in 2012. The solar concentrator consists of a tower with a total height of 16 m and 88 heliostats, and an elliptic mirror is installed at the top of the tower to reflect the collected sunlight downward. The principle of solar concentration in this device is as follows. Firstly, the sunlight is reflected by the collecting mirror of the heliostat through the first focal point of the elliptic mirror. The reflected sunlight passing through the first focal point is reflected by the elliptic mirror and focused at the second focal point of the elliptic mirror. The concentrated sunlight at the second focal point is received by the solar receiver and converted to heat, and then used for power generation.

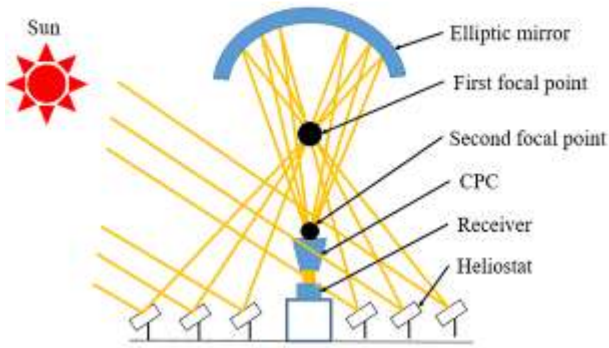

Fig. 1. Schematic diagram of a beam-down solar concentrator

Fig. 2 shows the photo of the heliostat used in this study. The heliostat consists of a tracking mirror and ten collecting mirrors, and collecting mirrors are arranged symmetrically five on each side of the tracking mirror. Each collecting mirror is a concave mirror with a diameter of 500 mm, and its focal length is determined by the distance from the tower to the heliostat. The procedure of sun tracking is as follows. First, the heliostats are roughly faced to the position of the sun at a certain time. And then the direction of heliostat is finely adjusted by using a sensor to detect the sunlight reflected by the tracking mirror installed at the center of the heliostat. After that, the sun tracking is performed while repeating the fine adjustment with the tracking mirror and the sensor. As shown in Fig. 3, 88 heliostats are installed in the area of 60 x 60 m around the tower.

Fig. 2. The photo of the heliostat

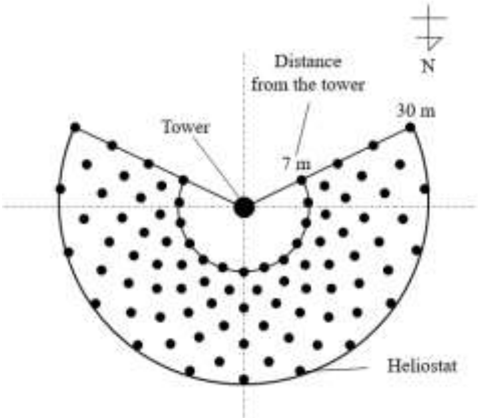

Fig. 3. Placement of heliostats

In general adjustment method, the optical axis is adjusted by superimposing the reflected sunlight from the individual collecting mirrors on the target plate at the top of the tower when the heliostat is kept tracking the sun. There were three problems with this method. Firstly, the accuracy of mirror adjustment is not high. Because the reflected sunlight from the individual collecting mirrors is superimposed on the target plate, but it is not at the first focal point of the elliptic mirror. Secondly, the adjustment can be only conducted when direct solar radiation is available. Thirdly, when the optical axis adjustment of collecting mirror is conducted, the posture of a person who conducts adjustment is severe. Because the adjustment work is conducted at the back of the heliostat, but in the conventional method of adjustment the mirror surface of the heliostat is inclined almost horizontally on the ground at a low position. In order to solve these problems, an optical axis adjusting device for heliostat are developed and the adjustment accuracy of the device is investigated.

The photo of the optical axis adjustment device is shown in Fig. 4. The device mainly consists of a laser for collecting mirror adjustment and a laser for tracking mirror adjustment. The former is installed on a traverse device for parallel moving and the latter is directly fixed on the rotation axis of the traverse device. The axes of the two lasers are adjusted in parallel. The laser for collecting mirror adjustment is fixed to a block on the linear guide and can be moved on the guide while keeping parallel to the optical axis of another laser. And traverse device can be rotated around the laser for tracking mirror adjustment. By using this adjustment device, it is possible to conduct the optical axis adjustment regardless of day and night and with higher accuracy than the conventional method.

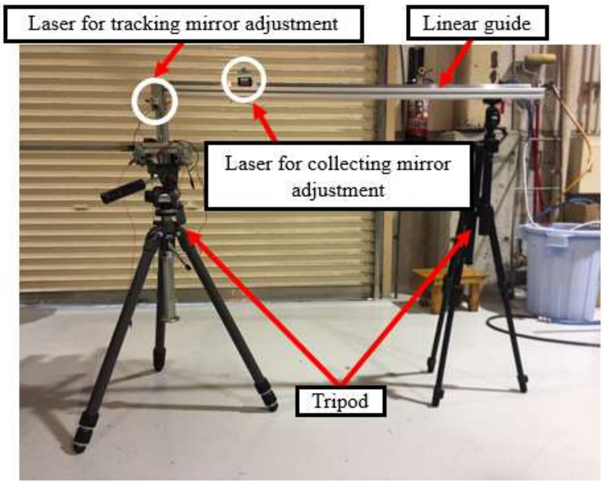

Fig. 4. The photo of the optical axis adjustment device

III. Experimental Method

The image diagram of the new adjustment method is shown in Fig. 5. In conventional adjustment method, the optical axis adjusted by superimposing the reflected sunlight from the individual collecting mirrors and tracking mirror on the target plate at the top of the tower. In this method, the accuracy of optical axis adjustment is not able to evaluate quantitatively at the actual first focal point of the elliptic mirror, because the overlap of each reflected sunlight is not able to measure in actual solar collecting condition. On the other hand, in the new method, the laser beam reflected by the collecting mirror hit directly the target which is installed the first focal point of the elliptic mirror. It is possible to quantitatively evaluate the accuracy of optical axis adjustment as the divergence of the reflected beam because the new optical axis adjustment is conducted in the almost actual solar collecting condition

IV. Results and Discussion

To evaluate the accuracy of optical axis adjustment, the theoretical angle of collecting mirror is calculated in the case of the actual culmination altitude of the sun and the case of using the optical axis adjustment device.

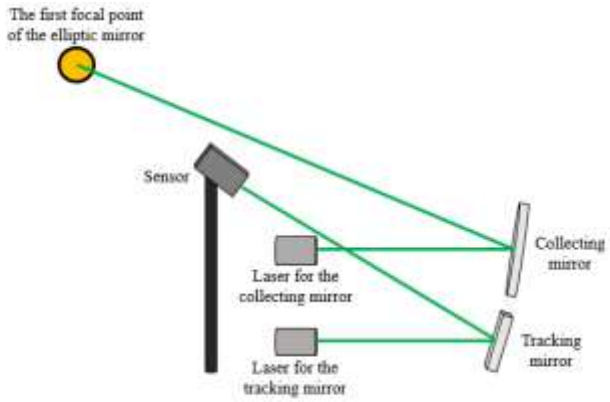

Fig. 5. The image diagram of the new adjustment method

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Then, the divergence of the optical axis is calculated from the difference of angle under each condition. The culmination altitude at the latitude of the University of Miyazaki is 81.61 degrees at the summer solstice and 34.76 degrees at the winter solstice. Furthermore, in the case of using the optical axis adjustment device, it has the same meaning that the culmination altitude is approximately 0 degree. The theoretical angle of the collecting mirror of the heliostat at these culmination altitudes was calculated as follows.

The position coordinate of collecting mirrors is shown in Fig.6 and ε which means the angle of the collecting mirror is defined as Fig.7. The maximum divergence which was obtained by the above conditions are shown in table 1. In conventional adjustment method, the divergence between the summer and winter solstice was 31 mm at the optical axis at the first focal point. On the other hand, in the new optical adjustment method, the divergence between the summer solstice and using the optical axis adjustment device is 36 mm.

Here, in the conventional method, the allowable divergence of the optical axis at the first focal point is considered as follows. The actual collecting mirror is a concave mirror which has curvature, but it is assumed to be a plane mirror for simplicity. In addition, if sunlight is assumed a parallel beam, the reflected image of sunlight reflected by the collecting mirror can be assumed to a circle with a diameter of 500 mm. When the reflected image of sunlight completely covers the target sphere with a diameter of 300 mm at the first focal point, the optical axis of the collecting mirror can be assumed correct.

Therefore, the allowable divergence of the optical axis at the first focal point is 200 mm in diameter as shown in Fig.8. From above, when we conduct optical axis adjustment in the conventional method, it is predicted that the divergence of the optical axis at the first focal point of 100 mm or less occur. In addition, as shown in Table 1, the divergence between the summer and winter solstice is 31 mm. Therefore, in conventional adjustment method, the conceivable maximum divergence is 131 mm. On the other hand, the maximum divergence in the new method is only 36 mm, and it is smaller than the conventional method. Thus, the new method of optical axis adjustment for heliostat using the optical axis adjustment device is more theoretical advantage than the conventional method.

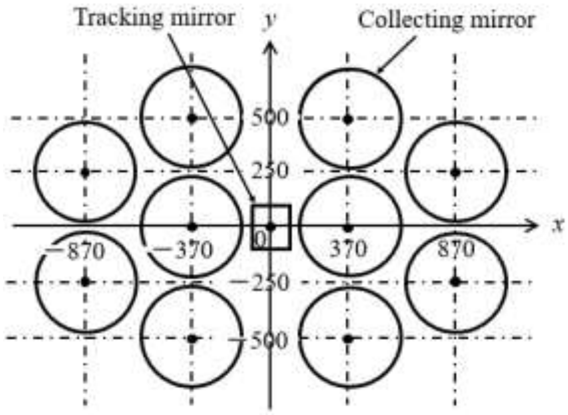

Fig. 6. The position coordinate of collecting mirrors

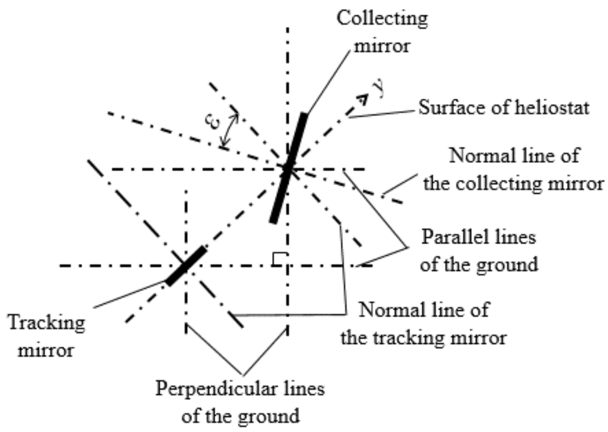

Fig. 7. The *ε* which means the angle of the collecting mirror

TABLE 1. THE MAXIMUM DIVERGENCE OF THE OPTICAL AXIS AT THE FIRST FOCAL POINT

Condition	The divergence [mm]
In the conventional method	31
In the new method	36

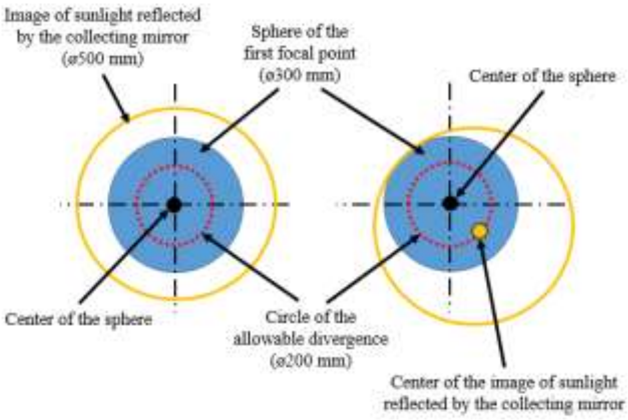

Fig. 8.Considered allowable divergence of the optical axis at the first focal point

The optical axis adjustment using the optical axis adjustment device was conducted in the actual heliostats. Furthermore, sunlight reflected by the heliostat which was adjusted by the new method passed the first focal point of the elliptic mirror correctly. In addition, the adjustment device solved two problems. One is adjustment time. The conventional method needs direct solar radiation. But the new method does not need it and is available to conduct optical axis adjustment in day and night. Furthermore, adjustment is not affected by the weather. Another is the angle of heliostat which uprose like upright during the adjustment. It is not only very helpful for improving the posture of operator but also reducing the adjustment time. From above, the purposes of this study are achieved.

In the next study, heat flux measurement at the condensing spot should be done.

V. Conclusion

In order to improve the accuracy of optical axis adjustment for heliostat of the solar concentrator, an optical axis adjustment device was designed and manufactured. And the accuracy and divergence of axes were evaluated quantitatively and theoretically. The major conclusions are as follows:

(1) An optical axis adjustment device was designed and manufactured. It was confirmed that sunlight reflected by the heliostat which was adjusted by the new method passed the first focal point of the elliptic mirror correctly.
(2) The adjustment device is available without direct solar radiation and improved the posture of the operator.
(3) The maximum divergence between the theoretical target and the axis in the conventional method was able to include within 131 mm and it was able to theoretically decrease within 36 mm in the new method.

In the future study, heat flux measurement should be conducted under the conventional and the new adjustment condition. And then the accuracy of optical axis adjustment will be evaluated from the viewpoint of heat flux distribution on the concentrating spot.

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E-mail of the author(s): s-tomo@cc.miyazaki-u.ac