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Formation of Focusing Flat Composite Heliostats and Fresnel Mirror Concentrating Systems

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ABSTRACT: In this work, methods for adjusting the facet of large-sized flat and focusing heliostats and concentrators of various types are considerstheir accuracy and complexity are evaluates. In the case of mirror-concentrating systems (MCS) and heliostats with flat facets (Fresnel mirrors, composite linear concentrators), high alignment accuracy is achieved using a screen and a telescope with a linear light source.

KEYWORDS: Concentration, solar energy, focus, linear focus, mirror-concentrating system, alignment, facet, heliostat, concentrator, screen.

I. INTRODUCTION

Currently, solar technology using concentrated solar energy (CSE, CSP technology) along with the use of photoconverters is developing rapidly. According to some estimates, the total capacity of solar installations in the world based on concentrated solar energy in 2016 was 4815 MW, which increased from 354 MW in 2005. At the same time, Spain is a world leader in this field, having generated almost half of the world figure - 2300 MW. The leading countries in the use of solar technology using concentrated solar energy are also the United States, India, China and other countries. In most cases, SSC technologies in terms of price do not compete with photoconverters. The main reason for this situation is the need for direct solar radiation, CSE technologies, while in the case of photoconverters, there is no such requirement, and theyalsois generate electricity with diffuse radiation. According to the global report of REN21 for 2016 [1], the share of photoconverters in world production of electricity is 1.2%, and according to the technology of SSC, geothermal and ocean energy is 0.4%. Despite these drawbacks, the SSC technology has several advantages, primarily due to the thermal nature of the physical processes occurring in it. This circumstance allows us to expand the field of their scientific and practical application - not only electricity is generate, but also thermal energy, as well as other applications are possible. It should be note that in the world many powerful power plants are build using CSE technology, for example, as hub-type concentrators [2]. Another advantage is the simplicity of their application in the individual sector of the use of solar energy.

CSE technologies are mainly classifies into hub-type concentrators, parabolic cylindrical, tower-type concentrators and Fresnel reflectors. In this paper, a linear-focus concentrator with Fresnel reflectors located on a parabolic profile is considered. To develop such facilities, we thoroughly studied the state of research in this area. In general, an optical-geometric approach is considers to determine the main characteristics of a concentrator, such as the number of reflectors, their coordinates and orientation, degree of concentration, and others, depending on configuration parameters. Based on the research results, it is possible to determine the parameters of an arbitrary configuration of linear-focal concentrators with flat Fresnel reflectors located on a parabolic base. Based on numerical calculations, the features of the energy density distribution at the receiver were determined, the course of sunlight in the system and the features of the optical formation of transverse focal lines of radiation concentration were graphically analysed [3].

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II. RELATED WORKS

To control the flatness of the faces of the heliostats and the concentrator prior to their deformation, the developed geodetic method is used, based on accurate measurement of deviation angles from flatness [2]. The authors used the following methods to align the planar faces of BSP heliostats:

Adjust the heliostat facet using the screen. To adjust the facet of the heliostats, a screen was used, made of a dense material stretched over a frame whose dimensions exceed the dimensions of the heliostat, and a light source located in the upper part of the hub frame [1].

Nightly adjustment of the bevel of the concentrator using a laser source. The nightly alignment of the BSP concentrator facet, unlike other alignment methods, allows you to align the reflective elements regardless of the errors of the reflective elements of the heliostat itself and its tracking system. When aligning the concentrator, the reflecting rays from the heliostat are not used, and the heliostat is used as a screen onto which the reflected rays of the concentrator facet fall [2].

Adjust the heliostat facet using the auto-reflection mark. During BSP operation, the alignment of individual reflective surfaces of the ZKS heliostat facet is disturbed due to the dynamic overload of its frame measuring 6.5x7.5 m during normal operation of the tracking system. Alignment becomes noticeable (3-4 minutes) in two to three weeks of their normal operation. Therefore, one of the difficult problems of the BSP is to maintain the original alignment, that is, a systematic assessment of accuracy and, if necessary, adjustment of the facet of 62 heliostats. The control and adjustment of the heliostat facet is carried out using the auto-reflection tag installed on the BSP hub [3].

III. MATERIAL AND METHODS

The main characteristic of concentrators is the accuracy of its reflective (refractive) surface. For facet *MCS*, it also includes accuracy of facet adjustment. There are many methods for adjusting the facet of concentrators and heliostats of the *MCS* [4-5]. Table 1 shows a generalized adjustment scheme for the compound facet *MCS* and heliostats.

Table 1.
Classification of adjustment methods for facet *MCS* and heliostats.

Facet adjustment methods			
Compound *MCS*		Heliostats	
Immediate methods for adjusting the facet of the composite *MCS*	Block methods for adjusting the facet of concentrators	Flat heliostats	Focusing heliostats, Fresnel mirrors, composite parabolic trough concentrators
Facet alignment methods using the optical structure of the *MCS*	Methods for adjusting the facet of concentrators using scanning devices	Geodesic triangulation and level adjustment methods	Adjustment methods for superimposing facet images in the focal plane
Facet adjustment methods based on the properties of aberration points of the *MCS*	Facet adjustment methods based on the use of the normal properties of the reflecting surface of the *MCS*	Autocollimation methods	Alignment methods for superimposing facet images on the screen
Methods of facet adjustment by superimposing the image of the Sun in the focal plane		Methods for adjusting for kinked image.	Facet adjustment methods based on the properties of aberration points of focusing heliostats and Fresnel mirrors

Note that some of these methods can also be uses to control the non-flatness of the substrates of the flat facets of the heliostats and the concentrator, for example, the geodetic method developed by us, based on the accurate measurement of the angles of deviation from flatness [6]. To evaluate these adjustment methods, we examined at the Big Solar Furnaces (BSF):

In the case of large faceted flat heliostats and Fresnel *MCS* with dimensions of 10x10 m, surface accuracy is determined by the roughness of the surface itself and the state of alignment of individual elements - facet. The standard deviation of the incident rays is define as

$$2\sigma_1 + 2\sigma_2 \approx 4\sigma_1 = \Delta\alpha \quad (1).$$

Where σ_1 are the errors of the reflecting surface of the manufacture of individual facets of the *MCS*, σ_2 are the errors of the installation of individual facets on the common surface of the *MCS*, and $\Delta\alpha$ is the standard deviation of the incident rays.

One of the main points in the implementation, the calculation of the energy capabilities of the optical specular reflection of the radiant flux from the Sun with a visible angle of $2\gamma_0$, is the laws of change after reflecting the density of the radiant flux at various distances depending on the concave or flat shape of the mirror elements. The elementary point of the reflecting surface, unchanged, reflects a beam with a visible angle of $2\gamma_0$. Spatial is symmetrical with respect to the normal to this point (Fig. 1 a, b).

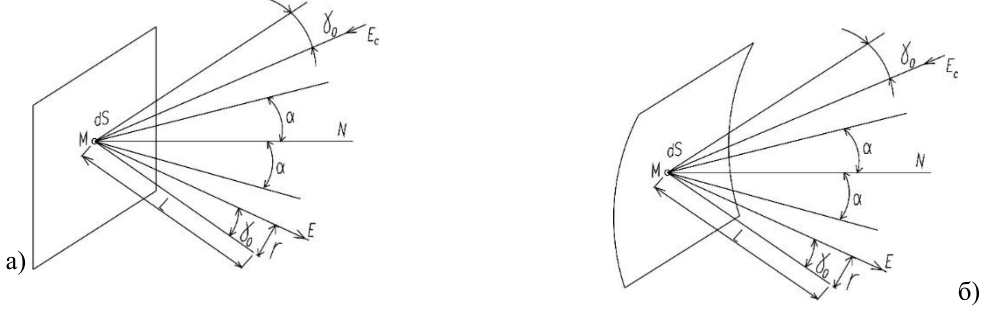

Fig. 1a, b. Highlights of the optical reflection of radiant fluxes from various mirror surfaces. a) Reflecting flat surface. b) Concave optical reflective surface.

Depending on the manufacturing accuracy, σ (where σ is the spatial deviation of the normal N from its nominal direction), the elementary zone dS at the point M of the reflecting surface, without changing the structure of the incident beam of rays, deviates by $\Delta\alpha = 4\sigma$ [8-9]. In this case, the density in elementary beams after reflection from the dS zone of the mirror surface decreases depending on the distance where this reflected beam is considered by the value $E=E_c R_z L tg\gamma_0$. Where E_c is the density of the incident radiant flux, (see table 2). The table shows the changes in the density of the incoming radiant flux after reflection as a function of reflection.

Table 2.

Experimental changes in the density of the reflected radiant flux depending on the distance.

№	Facet size axb, m	E_c, Wt/m^2	R_z	L, m	E_1, Wt/m^2	E_2, Wt/m^2	r,m
1	0.5x0.5 m	803	0.79	20	638	627	0.3
2	0.5x0.5 m	803	0.79	75	638	308	0.5
3	0.5x0.5 m	847	0.79	100	669	187	0.7
4	0.5x0.5 m	847	0.79	230	669	33	1
5	0.5x0.5 m	847	0.79	340	669	22	1.63

R_z is the coefficient of specular reflection, E_1 is the density of the reflected radiant flux after taking into account the coefficient of specular reflection, E2 is the change in the density of the reflected radiant flux depending on the distance L; r-size of the scattering spot in the measured area after reflection.

The issues of contribution of mutual arrangement of optical surfaces, individual movement bevels to the general error, their elimination and fixation in the specified position are also considers in this work. It is know that alignment is an integral part of the assembly process, which imposes certain requirements on the design of composite heliostats. Therefore, two tasks need to be solves in parallel during the design phase.

1. Provide the technical characteristics of composite focusing heliostats, i.e. satisfy all requirements arising from the operating conditions.

2. Meet the requirements of production technology.

IV. TECHNICAL SOLUTIONS

A. ADJUSTMENT PROCEDURE FOR FACET FLAT HELIOSTATS

The principles of initial adjustment, control and pre-adjustment of bevels with size 500x500x20 mm of composite flat reflector with total size 10x10 m, with total accuracy of reflecting surface (RS) not more than 3 angular minutes for turning of incoming radiation, are based on the fact that normal of nominal flat surface are collinear. If the

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flat surface of the reflector is set horizontally, then all the normal from the individual elements should be parallel to each other and perpendicular to the horizon plane. If you set two levels on the facet to be adjusts, which are perpendicular to each other, and then when these levels are brings to zero using the facet adjustment screws, the normal to the surface is perpendicular to the horizon plane. The direction of the normal is controls with the help of a reflected laser beam sent to the center of the aligned facet using flat reference mirrors. In this case, the reflected laser beam should come to the center of the corresponding mesh cell (Fig. 2.b.). Adjustment and measurement of deviation of flat bevels of composite focusing heliostats is performs at the installation, the diagram of which is given in Fig.2.a. The plant consists of a radiation source and visual tubes. The generated laser beam, reflected from the reference mirror of the adjusted bevel, should create a point trace in the center of the corresponding grid cell installed under the reflector. Support extreme bevel located in frame angle is selects, and collimated laser beam is direct to center of its surface by means of reference mirror. For double check, a device with two mutually perpendicular levels can be install on the reference bevel from the reverse side. Zero positions of two mutually perpendicular levels are obtains by means of adjusting screws of support chamfer. The laser collimate beam reflected from the facet is monitored [9]. The center of the reflected beam must align with the center of the cell corresponding to the adjusted bevel. Thus, the bevels are ready for further alignment and control.

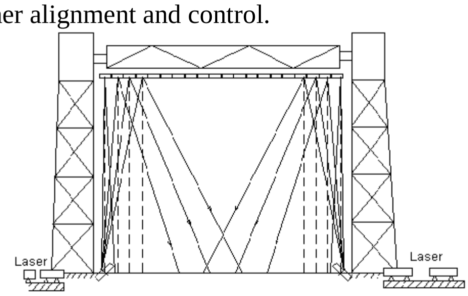

Fig. 2.a. Schematic diagram of adjustment of chamfered flat heliostats.

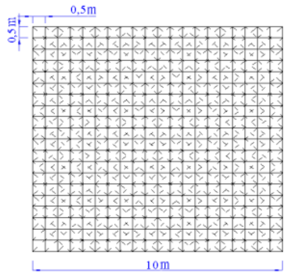

Fig. 2.b. Screen

Then the device with levels is transfers to the next adjusted bevel. Laser beam is directs to center of adjusted chamfer by turns of reference mirror. Adjustment of adjustment mechanisms of bevel is uses to achieve zero position by alignment of reflected beam with center of corresponding mesh cell. For clarity, you can use a visual tube without a laser. For this purposes adjustment of spatial positions adjusted by bevel is ensures by alignment of center of field of view with center of grid cell image. By move the device with levels and turning the reference mirror by a step equal to the distance between the chamfers, adjustment and control of the next chamfer is performs.

Based on the above procedure, the optical reflecting surface of the reflector consisting of 400 bevels measuring 500x500x6 mm was adjustsand controls. The results of the inspection show that the standard deviation of the shape from the flatness is 4÷5 angle, minutes over the entire surface of the reflector. Operational control of the surface consisting of elements of 500x500x20 mm in size is carries out with an accuracy of 2÷3 angle, minutes. Increase of accuracy is connect with surface accuracy of production of these bevels (0.5 angle, minutes).

B. Method of alignment of linear focusing of the Fresnel MCS

Adjustment of deviation of flat bevels of composite focusing heliostats and Fresnel MCS is performs at the unit, the diagram of which is given in Fig.3.a.

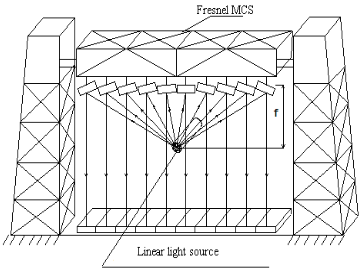

Fig. 3.a. Procedure for adjustment of Fresnel MCS bevel.

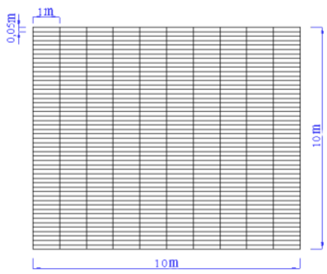

Fig. 3.b. Screen.

The installation consists of a radiation source forming a linear beam falling on mirrors of the adjusted bevel, creating in the center of the corresponding cell of the screen grid installed under the reflector, point in one direction and

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linear in the other direction of the trace. The adjusted bevel is selects and the image of the trace from the linear source is direct to the corresponding screen cell. The center of the reflected beam must align with the center of the cell corresponding to the adjusted bevel on the screen. In case the center of the reflected beam does not align with the center of the cell, this alignment is performs by means of adjustment screws [10].

V. CONCLUSION

In general, the introduction of the new above-mentioned methods at the Fresnel MCS allows are assess its optical-geometric characteristics effectively and promptly.

Summarizing the obtained results, it can be concludes that when adjusting the bevel of the case of the Fresnel MCS, as well as the bevel flat heliostats, high accuracy of adjustment is achieved by using a screen and a visual tube with a linear light source.

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