USE OF THE CALIBRATION METHOD DURING MULTI-ELEMENT SURFACES ASSEMBLY ON THE EXAMPLE OF COMPOSITE MIRRORS

Demin Anatoliy Vladimirovich, +7(812)292-59-71, dav_60@mail.ru
Mendeleeva Liliya Michailovna, +7(911)751-34-09, mendeleevalm@gmail.com

Abstract: adjustment features of compound mirrors of high NA large-size telescopes are described. The model and algorithm of adjustment of main mirrors made as compound mirrors using the method of calibration is suggested.

Introduction. Modern development of space technologies aimed at creating a multispectral highaperture mirror-lens telescope (HaT) for the collection and processing of information from the ultraviolet to the infrared emission spectrum, which forms an extension of astrophysical research and improving information capabilities of space systems for remote sensing of the Earth surface.

One of the challenges of creating HaT is reducing its surface density (mass per unit area), which is achieved by the design and technological implementation of the primary mirror (PM) as the main component of weight and size telescope. Today, advanced technology of lightweight mirrors, but in spite of this the development of mirrors with a diameter of more than 2.5 m with a suitable space for the HaT surface density is almost impossible. In this regard, the most promising way to solve this problem is to create PM a composite of mirror segments (hereinafter segmented mirrors - SM) [2,3,4,5,6].

The main problems in the creation of segmented mirrors linked to the development of methods and creation means:

• positioning of mirror segments during assembly SM;

• provide the desired control of image quality in service.

The main part. Segmented mirror assembly by positioning mirror segments (MS) on the base surface (BS) in accordance with the calculation is carried out in two stages:

1. Geometric positioning of MS on the BS.
2. Optotechnical position - Adjustment the position of MS on the BS on the comparison of image quality segmented mirror to the estimated value.

For the completion both stages it is necessary that each segment has six degrees of freedom - three linear shifts to ensure implementation of the 1st stage, and two or three angular shifts, ensuring the implementation of the 2nd stage (the required number of angular motions is determined by image quality control). In this paper we consider the first problem, the second will be considered next.

In order to solve the first problem of positioning of MS regarding BS and the calculation results, we introduce a coordinate system XYZ, whose origin coincides with the top surface of the mirror rotation of order 2, and the x-axis coincides with the optical axis of the mirror. Any surface of the second order can be determined by the tangent plane and the normal to the top, the equations of which are [1.10, 11]:

$$\begin{cases} F(x,y,z,\rho_0,e^2) = x - \rho_0 / 2[u+(1-e^2)x^2] = 0 \\ u = y^2 + z^2 \end{cases}$$

$$\left(\frac{\partial F}{\partial x}\right)_N \times (x - x_N) + \left(\frac{\partial F}{\partial y}\right)_N \times (y - y_N) + \left(\frac{\partial F}{\partial z}\right)_N \times (z - z_N) = 0 \qquad (1)$$

$$\frac{(x - x_N)}{\left(\frac{\partial F}{\partial x}\right)_N} = \frac{(y - y_N)}{\left(\frac{\partial F}{\partial y}\right)_N} = \frac{(z - z_N)}{\left(\frac{\partial F}{\partial z}\right)_N}$$

where ρ_0 - the radius of curvature at the top surface; e^2 - the square of the eccentricity forming surface.

As a prerequisite, we assume that the composite mirror consists of N equal hexagonal mirror segments, and from a technological point of view, their parametersaccord with the required accuracy, and have accordingly activators (piezo) with accuracy of 30 nm.

With the development of information and computer technologies evaluation KI on mathematical models, of course, wins the rapidity compared with the hardware, but it certainly cannot completely replace them. In this regard, we consider the process of positioning of each MS on the BS regarding the rated model by comparisonmethod. As a measure of comparison we choose rated reflecting surface, then the condition of the correct production of the mirror is provision ofmaximum coincidenceof the shape and parameters of the design and segmented surfaces, corresponding to the following conditions:

$$\left\{F_i(x_i, y_i, z_i, \rho_{0i}, e_i^2) = 0\right\}_1^N \cap \\ \cap \left\{R_{Fi}(x_{Ri}, y_{Ri}, z_{Ri}, \rho_{0Ri}, e_{Ri}^2) = 0\right\}_1^N = \max \tag{2}$$

where $\left\{R_{Fi}(x_{Ri}, y_{Ri}, z_{Ri}, \rho_{0Ri}, e_{Ri}^2) = 0\right\}_1^N$ - the set of linear equations of the surface segments adjustable dimension mirrors; $\left\{F_i(x_i, y_i, z_i, \rho_{0i}, e_i^2) = 0\right\}_1^N$ - set of linear equations of the surface which is divided into N equal segments of hexagonal shape - the estimated model.

In accordance with (1) the positioning algorithm of adjustable dimension of MS on the BS can be defined as a sequence of actions to ensure coplanarity of each component of the tangent planes and normal settlement and adjustable dimension segments, which is presented in Figure 1.

Figure 2 shows the display screen on which the image of the model, the calculated mirror surface of revolution, which is divided into N equal hexagonal segments and adjustable dimension surface during positioning. Attitude control of adjustable dimension segments is performed by setting the values of the coordinates of each of MS on screen computer monitor, and activators for the positioning of the control circuit.

Centers of symmetry of MS defined as nodes, are located on rings width equal to the diameter of the MS and in steps of $\Omega = 30°$.

For the coordinates of the vertices of such a partition segments are defined [9]:

$$\begin{cases} z_i = 2 \cdot R_i \cdot \sin\left(6 \cdot \arcsin\left(\dfrac{a/2}{\sqrt{R_i^2 + (a/2)^2}}\right)\right) \cdot \cos\left(6 \cdot \arcsin\left(\dfrac{a/2}{\sqrt{R_i^2 + (a/2)^2}}\right)\right) \cdot \cos\varphi_i \\ y_i = 2 \cdot R_i \cdot \sin\left(6 \cdot \arcsin\left(\dfrac{a/2}{\sqrt{R_i^2 + (a/2)^2}}\right)\right) \cdot \cos\left(6 \cdot \arcsin\left(\dfrac{a/2}{\sqrt{R_i^2 + (a/2)^2}}\right)\right) \cdot \sin\varphi_i \\ x_i = 2 \cdot R_i \cdot \sin^2\left(6 \cdot \arcsin\left(\dfrac{a/2}{\sqrt{R_i^2 + (a/2)^2}}\right)\right) \end{cases} \quad (3)$$

where R_i - the radius of the i - th ring; φ_i - angle "turn"; a - the size edge segment.

The value of the linear shifts of segments if determined by the solution of the system of linear equations involving N (similar to the relations (1)), the parameters of which are data on the spatial position of the adjustable dimension segments generated positioning sensors, and design.The criterion for the solution of the geometrical positioning is χ^2,notably:

$$\chi_R^2 - \chi_F^2 = \left\{ \sum_{j=1}^{N} \frac{\sum_m A_{jm} p_m - s_j}{\sigma_{Rj}^2} \right\}_R - \left\{ \sum_{j=1}^{N} \frac{\sum_m A_{jm} p_m}{\sigma_{ji}^2} \right\}_F \Rightarrow 0 \quad (4)$$

wheres_j - the sensors; σ_j- sensor errors; p_m - solution m - th of N equations; $A_{jm}= B_{jm}^{-1}$, and B-matrix, which completely determined by the geometry controlled mirror segment; R and F - indicate affiliation with adjustable dimension and settlement segment.

Thus, the quality of the geometric positioning of mirror segments, i.e. the first task is determined by the measure of mismatch vertex coordinates adjustable dimension segments relative to estimates and the measure of mismatch of the corresponding coplanar normals.

Conclusion. The proposed method is applied to the calibration of the assembly of composite mirrors allows to solve the problem of the geometric positioning of mirror segments on the base surface without the need for optical control devices that can solve the problem of maintaining the quality of the autonomous highly segmented mirror aperture space telescopes. The second task - the task of optical and technical positioning is also solved using the method of comparison withoutusing means of optical control, but this will be the subject of a subsequent publication.

References and Published Papers.

1. *Александров П.С.* Курс аналитической геометрии и линейной алгебры// М.: Наука, 1979. 512 с.
2. *Демин А.В., Рабыш А.Ю.* Алгоритм компоновки составных зеркал (на примере зеркала) // Научно-технический вестник СПбГУ ИТМО. - 2008. - № 58. - Оптотехника, оптоинформатика, оптические материалы. - 6 с.
3. *Лахтиков В.Б., Серегин А.Г.* Оценка оптимальной конфигурации разреженной апертуры для составного главного зеркала адаптивного телескопа. Оптический журнал, 1997, том 64, № 3, с. 127-128.
4. http://www.jwst.nasa.gov/ - The James Webb Space Telescope
5. *Parkinson, C. L.,* 2003: Aqua: An Earth-observing satellite mission to examine water and other climate variables, *IEEE Transactions on Geoscience and Remote Sensing*, 41 (2), 173-183.
6. http://aqua.nasa.gov/ - NASA Goddard Space Flight Center, Greenbelt, Md.20771
7. *Родионов С.А.* Об описании оптических поверхностей в программных расчетах оптических систем на ЭВМ. Изв. вузов. Приборостроение ТXXI №5 с.105-109
8. *Feder D.P.* Optical Calculations with Automatic Computing Machinery. Journ. Opt. Soc. Of America, vol. 41, №9, 1951, p.630
9. *Рабыш А.Ю., Демин А.В.* Алгоритм компоновки составных объектов. Научно-технический вестник СПбГУ ИТМО. - 2008. - № 58. - Оптотехника, оптоинформатика, оптические материалы.

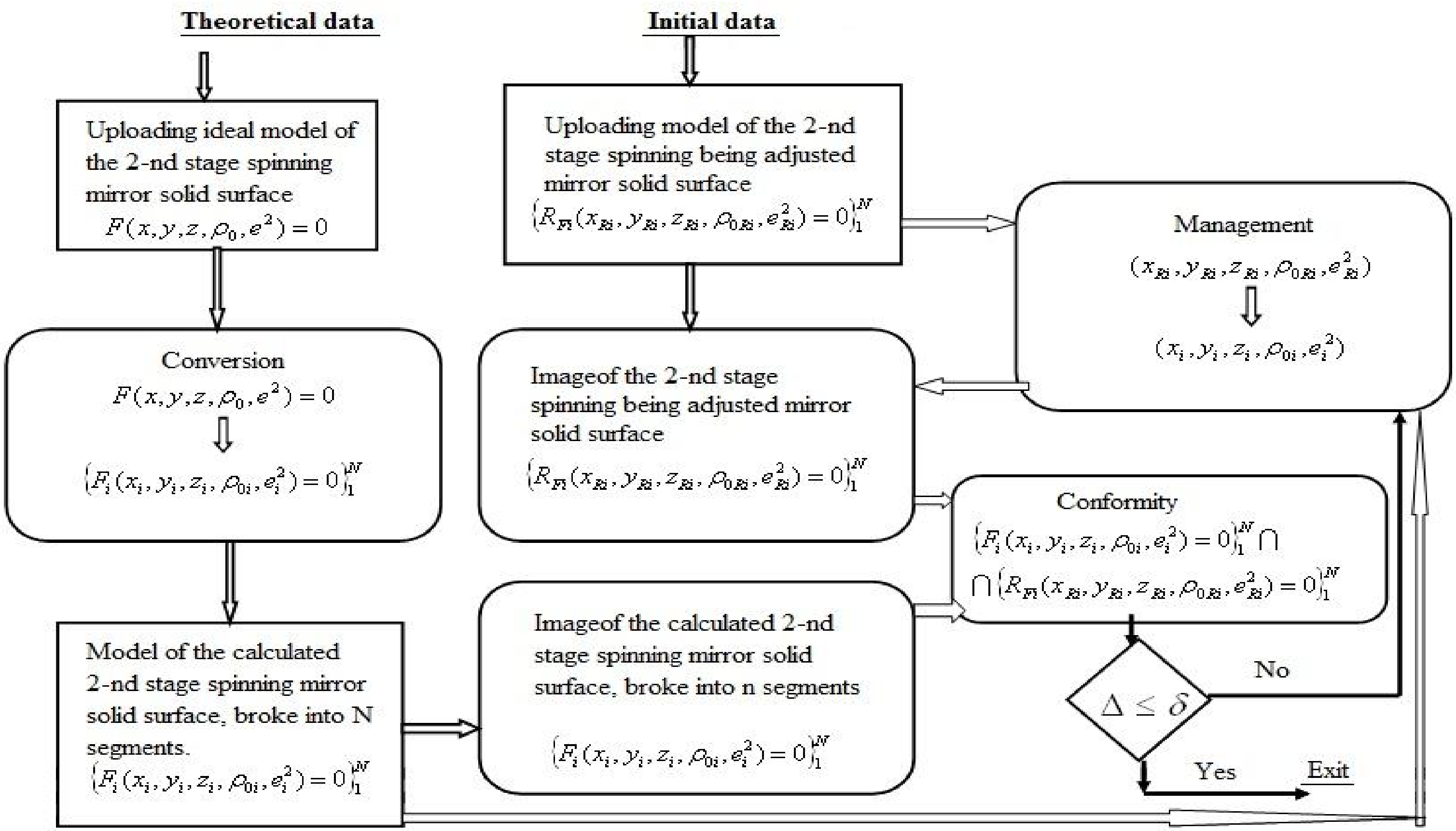
Theoretical data
Initial data
Uploading ideal model of the 2-nd stage spinning mirror solid surface $F(x,y,z,\rho_0,e^2)=0$
Uploading model of the 2-nd stage spinning being adjusted mirror solid surface $\{R_{Fi}(x_{Ri},y_{Ri},z_{Ri},\rho_{0Ri},e^2_{Ri})=0\}_1^N$
Management
$(x_{Ri},y_{Ri},z_{Ri},\rho_{0Ri},e^2_{Ri})$
$(x_i,y_i,z_i,\rho_{0i},e_i^2)$
Conversion
$F(x,y,z,\rho_0,e^2)=0$
$\{F_i(x_i,y_i,z_i,\rho_{0i},e_i^2)=0\}_1^N$
Imageof the 2-nd stage spinning being adjusted mirror solid surface
$\{R_{Fi}(x_{Ri},y_{Ri},z_{Ri},\rho_{0Ri},e^2_{Ri})=0\}_1^N$
Conformity
$\{F_i(x_i,y_i,z_i,\rho_{0i},e_i^2)=0\}_1^N \cap$
$\cap \{R_{Fi}(x_{Ri},y_{Ri},z_{Ri},\rho_{0Ri},e^2_{Ri})=0\}_1^N$
Model of the calculated 2-nd stage spinning mirror solid surface, broke into N segments.
$\{F_i(x_i,y_i,z_i,\rho_{0i},e_i^2)=0\}_1^N$
Imageof the calculated 2-nd stage spinning mirror solid surface, broke into n segments
$\{F_i(x_i,y_i,z_i,\rho_{0i},e_i^2)=0\}_1^N$
$\Delta \leq \delta$
No
Yes
Exit

Figure 1. Algorithm.

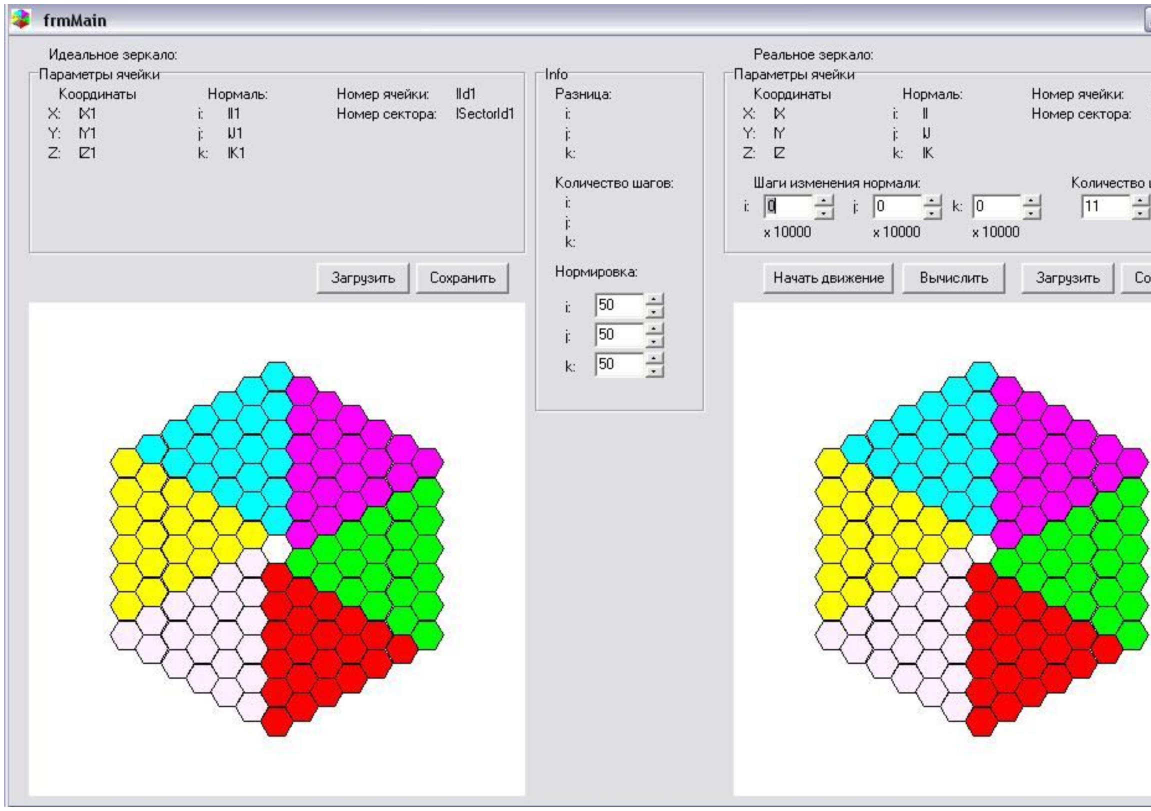

Figure 2. Operating window.