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A.R. KHACHATRYAN

SPHERIACAL RADIOTELESCOPE SURFACE ADJUSTMENT USING ARBITRARY LOCATED LASER RANGEFINDER

Surface deviations from the given form in a reflector antenna reduce the aperture efficiency. In this paper we have developed a mathematical foundation and modeled a method of measuring the reflector roughness of a radio telescope. This approach was used to measure a set of points and estimate the mean surface deviation of a spherical reflector. In particular, we have considered the case when the measuring apparatus (laser rangefinder) is located in the arbitrary point within the scope of the reflector. All the calculations and software were developed for the ROT-54/2.6 antenna.

Keywords: antenna measurements, surface adjustment, roughness estimation, optical method.

Introduction. The radio astronomy antennas usually have large dimensions and generally consist of a set of surface panels with supported structure (also known as a backup structure) [1]. The radio-optical telescope ROT-54/2.6 located in Armenia has been designed by P.M. Herouni [2]. The antenna of the telescope has a spherical shape and its surface consists of 3716 solid panels [3]. In order to obtain maximum antenna gain it is necessary to locate the panels accurately in the shape of a sphere. The influence of the reflector surface roughness on the antenna gain analyzed by Ruze [4] indicates that the RMS error should be less than about one-sixteenth of the wavelength for acceptable performance. The telescope deployment in mm wavelength requires surface panel adjustment greater then 100 μm.

At the moment of ROT-54/2.6 antenna construction, the mean-square error of the main reflector's surface was ±0.308 mm which is an acceptable accuracy for the ROT-54/2.6 to operate in 5 *mm* wavelength [3].

The existing modern methods of surface roughness measurement such as Radio Holography [1] are unacceptable for ROT-54/2.6 due to the structural characteristics of the antenna.

Taking into consideration the fact that panel adjustment should be done on the field, since telescope is mounted on the ground and can not be disassembled or rotated, another problem arises. The telescope's Cartesian center is not available for carrying out measurements. Given the above statements, this paper examines the surface panel deviation error measurement from any arbitrary point (hereinafter off-center) within the scope of the reflector.

In this work, the environmental influence, such as the changing temperature, wind etc are not examined and are taken as constants.

The method description. Axial-symmetric reflector antenna surface adjustment usually means detection of divergence the between the antenna's electrical and geometric axes. The surface error influence on the antenna gain analyzed by Ruze [4] indicates that an error of $\lambda/40$ is required to limit the gain loss to 10% and with an error of $\lambda/16$ the gain is decreased to about half of the maximum achievable.

The relative decrease in the aperture gain can be expressed by a simple formula:

$$\frac{\eta_A}{\eta_{A0}} = e^{-\left(\frac{4\pi\epsilon}{\lambda}\right)^2}, \quad (1)$$

where, ϵ is the surface error distribution with RMS value; λ the wavelength; η_{A0} is the aperture efficiency of the perfect reflector.

Fig. 1 shows the reduction of the gain of a reflector antenna as a function of $\frac{\epsilon}{\lambda}$ [5].

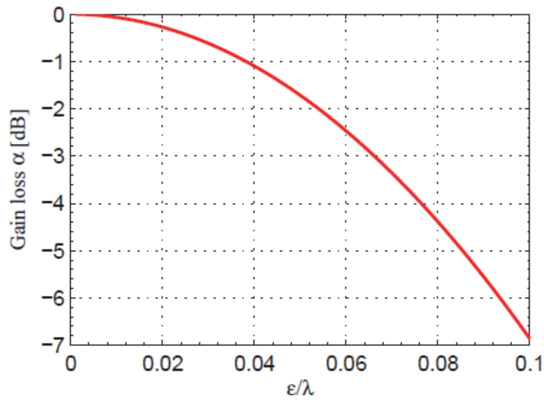

Fig. 1. Antenna gain reduction as a function of surface error

In order for the ROT 54/2.6 to operate in cm wavelength, particularly in 2 *cm*, the antenna's reflector panels should be adjusted with about 1.2 mm accuracy. The important point is that the reflectors' adjustment should be performed in the field since the antenna itself is mounted on the ground and can not be disassembled or rotated. To accomplish this, a laser rangefinder has been selected as a measuring device which can be placed in any point within the scope of the reflector. The mathematical calculations could be simplified in the case when the measuring device is placed in the center of the sphere, but because the center of ROT is not accessible for placing the measuring device, this paper studies the case when the measurement is carried out from any convenient point within the sphere.

Let's consider three points from the antenna's reflector, (Fig. 2) The points are:

M_c – the center point of the reflector. The surface roughness estimation should be considered relative to this point;

M_s – the measured point of the reflector. Mathematical calculations should be performed for this measurement;

M_l – the arbitrary point within the scope of the reflector, also referred as an off-center point in this paper. It is assumed that the laser rangefinder is placed here and actual measurements are performed from this point.

One of the importent points of the adjustment procedure is the antenna's geometric center identification. The detailed procedure for ROT 54 / 2.6 is discussed in paper [6].

Mathematical foundation. The laser rangrfinder measurment result would be the array of values M_s, showing the distances of the reflector point relatively to point M_l. Let's apply the mathematical calculations to one of these measurments (Fig. 2).

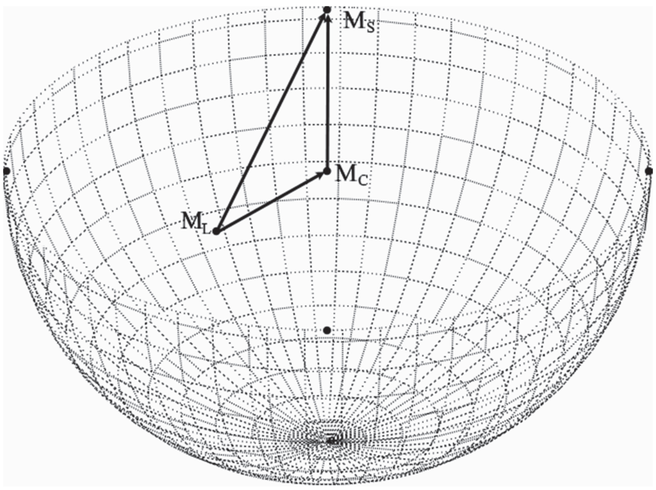

Fig. 2. A single point measurement scheme from the reflector surface using an off-center laser rangefinder

Relative to point M_l which is assumed as a relative point from which the reflector surface roughness measurements are performed, the points of interest (M_c, M_s) can be defined in the Cartesian coordinate system in the following way:

$$M_l\ (0, 0, 0),$$
$$M_c\ (r\cos\theta\sin\varphi\,, r\sin\theta\sin\varphi, r\cos\varphi),$$
$$M_s\ (l\cos\theta\sin\varphi\,, l\sin\theta\sin\varphi, l\cos\varphi),$$

where r and l are distances between points (M_l , M_c) and (M_l , M_s) respectively; θ – the azimuth angle; φ – the polar angle.

Vectors $\overrightarrow{M_lM_c}$ and $\overrightarrow{M_lM_s}$ take the following forms:

$$\overrightarrow{M_lM_c} = \hat{\imath}r\cos\theta\sin\varphi + \hat{\jmath}r\sin\theta\sin\varphi + \hat{k}r\cos\varphi, \tag{2}$$

$$\overrightarrow{M_lM_s} = \hat{\imath}l\cos\theta\sin\varphi + \hat{\jmath}l\sin\theta\sin\varphi + \hat{k}l\cos\varphi. \tag{3}$$

Vector $\overrightarrow{M_cM_s}$ can be defined as a difference between vectors $\overrightarrow{M_lM_c}$ and $\overrightarrow{M_lM_s}$:

$$\overrightarrow{M_cM_s} = \overrightarrow{M_lM_c} - \overrightarrow{M_lM_s}. \tag{4}$$

The surface roughness of the measured point M_s relative to point M_c can be defined as follows:

$$Surface\ error = R - \left|\overrightarrow{M_cM_s}\right|, \tag{5}$$

where R is the theoretical (ideal) radius of the ROT and equals 54 m.

Software implementation. As it was discussed in the previous sections, the measurement of the surface can occur from any point within the scope of the sphere. The goal of this paper is the interpretation of the measurement results as they were taken from the center of the sphere. The software modeling has been used in conjunction with mathematical foundation to achieve this. Particularly, a case has been modeled when the laser rangefinder was placed in point M_l, and the measurements where taken from 60 points of the reflector surface. Note that in the real case, at least 3 measurements should be taken from a single panel to correctly build the virtual surface. Fig. 3 shows the measurement points in the map of the sphere. The values demonstrate the deviation of the measurement result from the ideal sphere surface. The sign "-" shows that for that particular measurement surface, deviation has an opposite direction relative to other measurements. In Fig. 3, the top view is achieved by plotting distance $\left|\overrightarrow{M_cM_s}\right|$ (4) projection on the XY plane by calculating the $\left|\overrightarrow{M_cM_s}\right|\cos\varphi$ value.

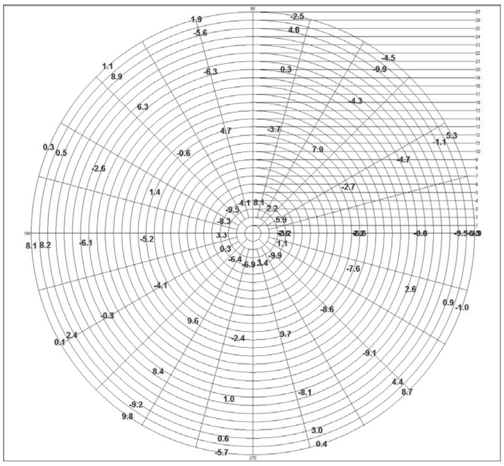

Fig. 3. Error plotting on XY plane in millimeters

Fig. 4 shows the 3D view of measurements created by the simulation software.

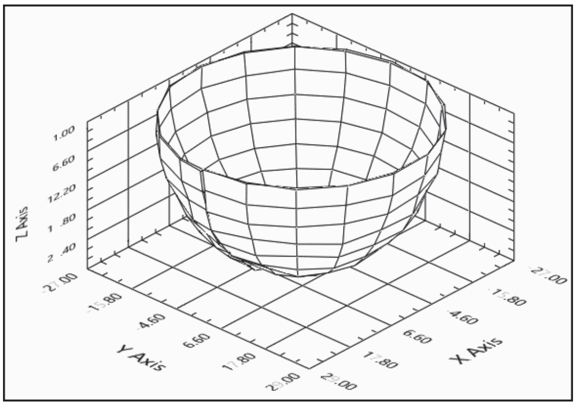

Fig. 4. Error plotting on the Cartesian system in meters

Laser rangefinder operating mode. For our measurement purposes we will use the laser rangefinder manufactured by OEM Laser Systems. The model of laser is LDM. This laser can perform measurements from up to 100 *m* providing +/- 1.0 *mm* accuracy. Each single measurement time can take 50 *ms* – 1 *sec*. This is also an advantage because all surface measurements can be accomplished within a short time period during which environmental changes will not vary too much. Also, the instrument has a serial port that can be connected to the computer where all software algorithms are implemented for evaluating the roughness.

The distance measurement process of laser rangefinder is shown in Fig. 5. Note, that we do not use the reflected laser beam (5) for distance calculation. The following notations are used in Fig. 5.

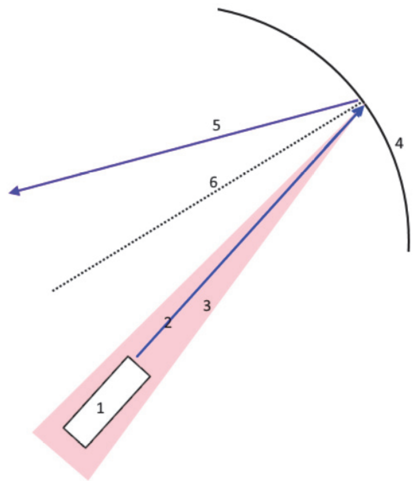

Fig. 5. The measurement process
1 – Laser rangefinder; 2 – the laser beam traveling from the laser rangefinder to the measurement surface; 3 – the scattered radiation of falling beam reflected to the direction of the laser; 4 – the measurement surface; 5 – the reflected beam from the surface; 6 – the normal of the surface

This type of laser can perform measurement using the scattered radiation energy reflecting back to the source of the beam because of roughness of the surface using the phase comparison technique to measure the distance. The ROT 54/2.6 radio optical telescope is constructed by aluminum panels which is not the ideal reflector for laser beam thus the energy of (3) would be enough for accurate measurements. This method eliminates the need when the reflected beam (5) should be necessarily captured by the measurement system.

Conclusion. Considering the structural characteristics of ROT-54/2.6, which make the direct measurement from the geometrical center impossible, the described method of the reflector surface roughness measurement is viable enough to estimate the surface deviation errors from the given form. Overall Measurement precision fully relays on the laser rangefinder measured parameters accuracy such as distance, azimuth angle and polar angle.

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Ա.Ռ. ԽԱՉԱՏՐՅԱՆ

ԳՆԴԱՁԵՎ ՌԱԴԻՈԴԻՏԱԿԻ ՄԱԿԵՐԵՎՈՒՅԹԻ ՃՇՏԱԴՐՈՒՄ՝ ԿԱՄԱՅԱԿԱՆՈՐԵՆ ՏԵՂԱԴՐՎԱԾ ԼԱԶԵՐԱՅԻՆ ՀԵՌԱՉԱՓԻ ՄԻՋՈՑՈՎ

Անտենայի հայելու մակերևութային անհարթությունները զգալի բացասական ազդեցություն են թողնում անտենայի օ.գ.գ.-ի վրա: Ստեղծվել են մաթեմատիկական հաշվարկային բանաձևեր և ծրագրային մոդելավորման մեթոդներ՝ ռադիոաստղադիտակի հայելու անհարթությունները գնահատելու համար: Վերոհիշյալ մեթոդների կիրառմամբ կատարվել է գնդաձև անտենայի հայելու մակերևութային սխալանքների գնահատում՝ միջինացնելով կատարված չափումները: Մասնավորապես, ենթադրվել է, որ չափող սարքը (լազերային հեռաչափը) տեղադրված է անտենայի հայելու բացվածքի կամայական կետում: Մաթեմատիկական և ծրագրային մեթոդների մանրամասն բացատրությունը կատարվել է գնդաձև ռադիոօպտիկական աստղադիտակի ՌՕԴ-54/2.6 համար:

Առանցքային բառեր. անտենայի չափումներ, մակերևութային ճշտադրում, անհարթությունների գնահատում, օպտիկական եղանակ:

А.Р. ХАЧАТРЯН

ЮСТИРОВКА ПОВЕРХНОСТИ СФЕРИЧЕСКОГО РАДИОТЕЛЕСКОПА ПРИ ПОМОЩИ ПРОИЗВОЛЬНО РАСПОЛОЖЕННОГО ЛАЗЕРНОГО ДАЛЬНОМЕРА

Поверхностные отклонения отражателя антенны от данной формы уменьшают коэффициент полезного действия антенн. Разработаны математические формулы и методы моделирования для измерения неровностей поверхностей отражателя радиотелескопа. Эти методы были использованы для измерения множества точек на поверхности зеркала и оценки среднего отклонения поверхности сферического зеркала от идеального. В частности, рассмотрены случаи, когда измерительный прибор (лазерный дальномер) расположен в произвольном месте в пределах сферического отражателя. Математические расчеты и методы моделирования подробно описаны для случая антенны сферического радиооптического телескопа РОТ-54/2.6.

Ключевые слова: измерения антенны, юстировка поверхности, оценка неровности, оптический метод.