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ON THE STATISTICAL EVALUATION OF THE EFFECT OF ACCURACY AND RIG--ETC(U)
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

8. ON THE STATISTICAL EVALUATION OF THE EFFECT OF ACCURACY AND RIGIDITY OF THE ANTENNA OF RADIOTELESCOPE ON ITS PARAMETERS

by

A. Ye. Salomonovich

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10 By: A. Ye. Salomonovich

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh^{-1}
cos	cos	ch	cosh	arc ch	cosh^{-1}
tg	tan	th	tanh	arc th	tanh^{-1}
ctg	cot	cth	coth	arc cth	coth^{-1}
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

8. On the statistical evaluation of the effect of accuracy and rigidity of the antenna of radiotelescope on its parameters.

A. Ye. Salomonovich.

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The parameters of the antenna of radiotelescope (radiation pattern, effective area, etc.) depend on an inaccuracy in its production and various kinds of strains [1].

FOOTNOTE [1]. On the effect of scattering on the thrusts/rods and others of construction/design see [1]. ENDFOOTNOTE.

The effect of the random errors for the production of the surface of antenna on its radiation pattern, front-to-rear factor (derictive gain) and effective area are examined in works [2, 3, 4, 5]. In particular, in [5] are obtained the expressions, which connect dispersion and radius of the correlation of the random phase errors on the aperture of line-source antenna, caused by an inaccuracy in its production, with the distortion of diagram and worsening/deterioration in efficiency. Work [6] examines analogous task for the aperture systems. The examination, which was being carried out in indicated and some other works, must be supplemented with the consideration, apparently, which were not being considered earlier. The fact is that surface distortions of the real antenna, which lead to the phase distortions of field, are the result of action, at least, two different reasons.

The surface of antenna can be prepared only with certain final accuracy, characterized by the value of maximum relative tolerance $\varepsilon_{\tau}/L = 10_{4}^{-m_{\tau}}$ (where L - diameter of antenna aperture), the being determining dispersion σ_{τ}' phase, and with a radius of correlation These parameters can be measured after the termination of the ρ_{τ}. production of antenna and usually they relate to the specified ambient conditions, under which are conducted the measurements.

In the process of operation the antenna undergoes different effects: test/experience weight, wind and thermal deformations. As a result its surface is changed. These changes cause the phase distortions of field, which leads to further worsening/deterioration in the characteristics of antenna. A difference in the distortions as a result of the strains from the distortions due to an inaccuracy in the production lies in the fact that the first are always more smooth

- the equally deformed sections are commensurated with the diameter of antenna. Furthermore, strains do not usually remain constant/invariable.

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In the overwhelming majority of the cases we do not have the capability to in detail investigate the character of phase distortions as a result of the strains, since the latter in a complicated manner are distributed by the constructions/designs of antenna and do not remain constants. Therefore phase distortions on the aperture of this antenna, caused by its strains, cannot be described analytically, for example with the help of the power-series expansion. In connection with this such distortions it is expedient to examine (similar to distortions as a result of an inaccuracy in the production) as random ones. In this case we can examine the group of the possible layouts of the deformed surface of antenna or the layout, which randomly depends on the time. Just as in the examination of the effect of inaccuracy, at small strains the average parameters of antenna differ little from the parameters of separate realization. With this approach we consider the surface of antenna as deformed randomly; however, with the assigned characteristics: by maximum strain $\varepsilon_\text{д}/L = 10^{-m_\text{д}}$, by determined dispersion $\sigma_\text{д}$ and by a radius of correlation $\rho_\text{д}$.

The statistical characteristics of phase error distribution as a result of an inaccuracy in the production and due to the strains, as a rule, essentially differ from each other; usually $\rho_{\text{т}} \ll \rho_{\text{д}}$. Concerning values $\sigma_{\text{т}}$ and $\sigma_{\text{д}}$, are possible the most varied relationships/ratios. A precise, but insufficiently rigid mirror is characterized by the fact that $\sigma_{\text{д}} > \sigma_{\text{т}}$. meanwhile in rough, but rigid mirror $\sigma_{\text{д}} < \sigma_{\text{т}}$. Generally speaking, phase distortions due to strains depend on time. However, during more or less prolonged time intervals antenna can be considered as that possessing the constant shape of surface which to us is accurately unknown and which we to characterize statistically.

Since both mentioned effects are not depended, for small distortions we can determine the value of the real derictive gain of this antenna D by the expression

$$\overline{D} = D_0 (1 - \Delta_{\text{т}}) (1 - \Delta_{\text{д}}), \qquad (1)$$

where D_0 - value derictive gain of ideal antenna [1], and $\Delta_{\text{т}}$ and $\Delta_{\text{д}}$ - relative decreases of derictive gains, which must be determined on the basis of known values $\sigma_{\text{т}}, \rho_{\text{т}}$ and $\sigma_{\text{д}}, \rho_{\text{д}}$ respectively.

FOOTNOTE [1]. For simplification in the calculations we accept, that $D_0 = \pi^2 h^2 \simeq 10h^2$, where $h = L/\lambda$, i.e., we consider that the coefficient of the use of a surface of aperture is equal to one. ENDFOOTNOTE.

For the certainty we will consider that the distribution of distortions as a result of the inaccuracy is close to the normal, so that $\varepsilon_\text{т} \simeq 2{,}6\lambda/4\pi\sigma_\text{т}$, and therefore $\sigma_\text{т}^2 \simeq 25(\varepsilon_\text{т}/\lambda)^2$. Furthermore, usually $\rho_\text{т} = n\lambda$, where for highly directional n=1-20.

For the evaluation/estimate of order of magnitude $\sigma_\text{д}$ and $\rho_\text{д}$ it is possible to consider that the displacement along the normal of the points of surface from the assigned profile/airfoil as a result of the strains is described by the equation of elastic curve. Calculation shows that for approximate estimates $\varepsilon(x) = \varepsilon_\text{д} x^2$, where x=2r/L (r - distance from the center of circular opening). Excluding constant along the surface displacement, we obtain the effective average/mean value of the dispersion:

$$\sigma_\text{д}^2 = \overline{\varphi_\text{д}^2(x)} = \int_0^1 \varphi_\text{д}^2(x)\,dx \simeq 14\,(\varepsilon_\text{д}/\lambda)^2. \qquad (2)$$

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The distortion of phase $\varphi_\text{д}$ (x) reverses the sign when $x = 1/\sqrt{3} \simeq 0{,}6$. We respectively accept approximately $\rho_\text{д} \approx 0{,}3L$. In the case of the pencil-beam antennas, as noted above, $\rho_\text{т}/\lambda = 1-20$. Furthermore, λ/L=$10^{-3}$-$10^{-4}$. At such values of the parameters we obtain according to [5]

$$\Delta_\text{т} \approx \sigma_\text{т}^2 = 25\,(\varepsilon_\text{т}/\lambda)^2. \qquad (3)$$

On the other hand, when $\rho_\text{д}/\lambda > \frac{1}{\pi}$, as shown in [5], value $\Delta_\text{д} = F\sigma_\text{д}^2$, where F - function, close to linear, changing from 1 when $\rho_\text{д}/L \to 0$ to 0.4 when $\rho_\text{д}/L = 0{,}75$.

Having expressed $\sigma_\text{т}$ and $\sigma_\text{д}$ through introduced above parameters $m_\text{т}$ and $m_\text{д}$ and being limited to the first-order terms of smallness relatively $\sigma_\text{т}^2$ and $\sigma_\text{д}^2$, we will obtain

$$D = 10h^2\,[1 - 0{,}25\,(10^{2(1-m_\text{т})} + 0{,}6F\cdot 10^{2(1-m_\text{д})})\,h^2]. \qquad (4)$$

The maximally attainable value derictive gain, obtained with prescribed allowances for accuracy and rigidity, proves to be equal to

$$D_\text{макс} = 10^{2m_\text{т}-1}/(1 + 0{,}6F\cdot 10^{2(m_\text{т}-m_\text{д})}) \qquad (5)$$

or in the decibels

$$N_\text{макс} = 20m_\text{т} - 10 - 10\lg\,[1 + 0{,}6F\cdot 10^{2(m_\text{т}-m_\text{д})}]. \qquad (6)$$

If tolerance for the manufacturing precision is considerably more than requirements for the rigidity of mirror, i.e., if $m_\text{д} > m_\text{т}$, then

$$N_\text{макс} = 20m_\text{т} - 10, \qquad (7)$$

i.e., as can easily be seen, it corresponds to the value, obtained without taking into account strains [2.5]. If, on the contrary, mirror is prepared relatively accurately, but it does not possess the corresponding rigidity, i.e., if $m_\text{д} \leq m_\text{т}$, then (under condition

$10^{\varkappa(m_т-m_д)} \gg 1$, which usually occurs)

$$N_{макс} \approx 20m_д - 10 - 10\lg[0{,}6F], \qquad (8)$$

i.e. derictive gain is limited to the insufficient rigidity of antenna. In this case $N_{макс}$ proves to be somewhat greater than in (7). This is explained by the relatively smaller effect of distortions as a result of the strains, which have a larger radius of correlation. For example, when $\rho_д = 0{,}3L$, value $N_{макс} = 20\,m_д - 5$. When $m_т - m_д$

$$N_{макс} \approx 20m_т - 11, \qquad (9)$$

i.e. occurs only small further worsening/deterioration maximum derictive gain as a result of the effect of insufficient rigidity.

A difference in the radii of the correlations of phase distortions $\rho_т$ and $\rho_д$ makes it possible by characteristic measurements of antenna to rate/estimate the reasons for worsening/deterioration in these characteristics in comparison with the ideal ones. The decrease of derictive gain as a result of the inaccuracies, being characterized by $\rho_т \ll L$, leads to an increase in isotropic scattering, without changing the form of major lobe. However, the decrease by derictive gain due to the strains for which $\rho_д \sim L$, it leads in essence to the expansion of major lobe.

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Measuring the width of major lobe of the pencil-beam antenna [1], it is possible on the measured expansion with known $\rho_{д}$ to rate/estimate value $\sigma_{д}$, and according to it and $\Delta_{д}$:

FOOTNOTE 1. The method of measurement is presented in [7]. ENDFOOTNOTE.

The measurement of general/common/total worsening/deterioration derictive gain makes it possible to isolate then its that part which is caused by an inaccuracy in the production, i.e., $\Delta_{т}$. The latter independently can be determined by the measurement of the coefficient of antenna scattering. Observing the dependence of the width of major lobe on the ambient conditions, it is possible to further explain the character of the strains, critical for this expansion (strains weight, thermal, etc.).

The considerations, presented above, have used we with the study of the characteristics of the highly directional parabolic antenna of radiotelescope RT-22. Research of the surface of mirror RT-22 showed that $\rho_{т} \approx 200'$ mm, and $\sigma_{т}^{2} = 0{,}21$ for λ=8 mm. From the calculation it is evident that under these conditions D/D_0=0.81. Wide measurement of major lobe led to the conclusion that the relative expansion composes ~6o/o. From the analysis of elastic deformations it is evident that expected $\rho_{д} \approx 0{,}3\,L$. In similar $\rho_{д}$ to the measured expansion of major lobe corresponds $\sigma_{д}^{2} = 0{,}30$. Under the quadratic law of the increase of strains from the center to the edge of the mirror it leads to average/mean value $\varepsilon_{д} = 1{,}3$ мм, which closely coincides with the value, obtained by calculation [8]. Knowing $\sigma_{д}^{2}$ and $\rho_{д}$, it was possible to rate/estimate $\Delta_{д}$. The obtained value comprises $\Delta_{д} = 0{,}17$. Taking into account, furthermore, the effect of the nonuniform irradiation of opening and scattering on the thrusts/rods and other elements/cells [1], it was possible to rate/estimate the total losses derictive gains, as a result of which the effective antenna area of radiotelescope RT-22 on the wave λ=3 mm proved to be close to 100 m² that it composes ~26o/o of the geometric area of aperture. Obtained computed value coincided with the results of measuring effective area [7].

The statistical method of the evaluation/estimate of the total distortions of phase, as is evident from that presented, when does not succeed in producing a precise calculation of the expected strains, it proves to be appropriate both during the formulation of requirements for the construction of the large/coarse optical-type antennas of radiotelescopes and at the estimate of the magnitude of its expected parameters.

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