NASA TECHNICAL MEMORANDUM NASA TM-75714

ANTENNA OF THE SPACE RADIOTELESCOPE KRT-3

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Translation of "Antenna Kosmicheskogo radioteleskopa KRT-3," Academy of Sciences USSR, Institute of Space Research, Moscow, Report PR-340, 1977, pp 1-20

(NASA-TM-75714) ANTENNA OF THE SPACE RADIOTELESCOPE KRT-3 (National Aeronautics and Space Administration) 22 p HC A02/MF A01 CSCL 09C N80-11280 Unclas G3/32 46137

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 NOVEMBER 1979

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Research of the structure of quasars, cores of galaxies, pulsars and areas of star formation is one of the most actual directions in contemporary experimental radioastronomy. These objects or compact components entering them have in some instances angular measurements less than 10^{-3} seconds of arc. / 3*

Reception of the detailed spacial structure of these sources is possible only by the method of radio interferometry with the use of a space radiotelescope.

Based on results of Soviet-American researches (1969-1976) [1] and taking into account the possibilities of contemporary space facilities, it is advisable to begin such studies with the objects W49 and W51 in the water vapor line (λ = 1.35 cm). These objects are the brightest and therefore it is sufficient to have the mirror of the antenna of a space radiotelescope with a diameter of 3-4 meters.

Antennas for space vehicles existing at present do not fulfill the basic requirement which is imposed for the accuracy of the reflecting surface. In connection with this, the task was set forth of creating a precision antenna for a wave of 1.35 cm. The possibility of its operation on shorter waves is also incorporated. The antenna must have minimal weight, work in the conditions of outer space, and

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*Numbers in the margin indicate pagination in the original text.

its diameter must not exceed 3 m.

Technical Requirements

One of the basic elements of the space arm of a radio-interferometer is the space radiotelescope. The antenna of this radiotelescope must meet several contradictory requirements: have minimal dimension and weight, a high precision of sighting, but at the same time a maximal effective surface and high precision of the reflecting surface. /4

The antenna must have the following parameters:

-working wave length of 1.35 cm;

-an effective antenna surface of no less than 4 m^2, which with a coefficient of antenna use of 0.5-0.6 corresponds to a mirror diameter of 3 m;

-a construction weight no greater than 140 kg;

-for more effective antenna use, the provision must be made for its use in the millimeter wave band.

Investigation of the various types of antennas has shown that it is most expedient to use a rigid parabolic system with a Cassegrainian system of exposure. In this instance the apparatus may be accommodated in the cabin, directly adjoining the primary parabolic mirror, creating a convenient arrangement of the KRT)Fig. 1). In addition, it should be relatively simple to carry out correction of error in guidance and scan of an assigned area of the sky in the boundaries of several beam patterns. This may be acheived by movement of a small mirror which is particularly attractive from an energy point of view.

On the basis of study on the choice of electrical and construction parameters, the following basic characteristics of the antenna were determined: /5

- the primary antenna mirror - paraboloid of rotation, diameter of 3.1 m;
- the secondary mirror - hyperboloid of rotation, diameter of 400 mm;
- focal distance of the paraboloid 1342 mm;
- focus of the hyperboloid set at a distance of 544 mm from the focus of the paraboloid;
- exposure angle of the primary mirror 120°;
- attachment of the secondary mirror is accomplished by mountings with a minimal shading of the antenna exposure.

Choice of the Construction Layout of the Antenna

The peculiarity of a space rediotelescope lies in the fact that it operates in the conditions of space (weightlessness, great drops of temperatures), and during transport into orbit it undergoes various forms of stress (linear, shock, and vibrational).

Upon taking these requirements into account, various variations of construction and power systems of the antenna were examined:

- solid, frameless mirror;
- thick-walled mirror, attached to a frame;
- inflatable constructions;
- thin-walled mirror, attached to a frame.

Examination of the variations showed that solid and thick-walled mirrors have a very great weight. The inflatable construction with a small weight does not have the assigned precision of the reflecting surface. And only the thin-walled mirror, attached to a rigid frame, acheived the desired precision of the reflecting surface with a small construction weight.

Of the three types of frames: /6

the first is a welded, lattice, tubular frame;

the second is a riveted cone with the assembly along the formation;

the third is a welded frame of fins and rings;

variation I has a girder weight of the order of 150 kg, and variations II and III, of the order of 100 kg.

In addition, in variation I the presence of a large number of small pieces of pipe complicates the welding of the frame and the application of the technological fixture, and in variation II after the assembling (riveting) of the frame and the installation of the elements of the reflecting surface fixture, the adjustment of the mirror is complicated.

The most preferable seems to be variation III, which was also accepted as the basis. In such a manner, a constructively sound design of the antenna, shown in Fig. 2, is as follows:

-a rigid support frame;

-a thin mirror, installed on the frame;

-four supports for the installation of the secondary mirror.

The frame consists of eight large and eight small fins. The fins are connected by three tubular rings and two ring frame supports, one of which is the base support for the placement of the form of the main mirror and the cabin with the irradiating unit, and the second - the base support for the attachment of the device network and all of the radiotelescope.

For the attachment of the reflecting surface to the framework an assembly was used with supports in the form of rigid pins, shown in Fig. 3, which was placed both on the fins and the rings.

The reflective surface is made of eight sections of aluminum sheets with a thickness of 1-3 mm. The supports of the secondary mirror are four thin-walled tubes, which pivot on the outer ring. Attachment of the supports on the outer ring is the most rational /7
from the point of view of acheiving minimal shading of the antenna. The secondary mirror is a rigid hyperboloid of rotation.

With the goal of providing for minimal construction weight of the radiotelescope and the technology of its construction, the base materials selected were aluminum and aluminum alloys (type AD-1, AMg and AMn).

Preparation of the Antenna Model for the KRT-3

For the preparation of an electric model of the projected antenna, the technology of its preparation during experimental manufacture was formulated.

The entire process was broken down into the following stages:

-preparation of the frame;

-preparation of the molds of the parabolic and hyperbolic mirrors;

-preparation of the matrix for the formation of the surface of the parabola;

-installation and adjustment of the reflecting surface of the primary mirror.

The mold of the primary mirror is intended for the placement of the supports of the reflecting surface, the implementation of the mirror adjustment and is used in the preparation of the matrix for the formation of the parabolic surface. The basic working surface of the mold is a blade made of a sheet of steel Kh18N9T with a thickness of 2 mm. The working edge is made with a precision of ± 0.05 mm (maximal tolerance deviation from the profile of the calculated paraboloid). The blade of the mold is inserted into a fin, constituted of a packet of sheets which is attached to the rotating collar. The collar terminates with a disc Ø 500 mm for the attachment of the mold to the base ring of the frame.

The mold allows for placement of the support for attachment of the antenna mirror relative to its edge with a precision of ± 0.05 mm. /8

The adjustment of the reflecting surface is carried out with the help of clockwork indicators which are additionally attached to the blade of the mold.

The mold-copy of the secondary mirror is intended for the preparation of the hyperboloid on a lathe- or lathe-copying device and is plastic with a thickness of 5-10 mm with a profile of the hyperboloid turned on it. The precision of the completed profile is ± 0.02 mm.

For the formation of the reflecting surface, special equipment was designed and prepared which incorporates a shaped cement foundation in a trough and a roller with a weight of 160 kg, which has a surface precision of ± 0.5 mm.

Precision of the Surfaces

Attachment of the reflecting surface of the primary mirror was accomplished at 1248 points. The position of these points, after the adjustment was done, was also measured. The results of the measurement are shown in Fig. 4.

The maximal error of the profile consisted of ± 0.1 mm. The root-mean-square error of deviation of the actual paraboloid at an assigned point from the theoretical equals

$$\sigma = \pm\sqrt{\frac{\Sigma \delta_i^2}{n-1}} = \pm 0.066 \text{ mm}$$

Thus the results of the measurement of the reflecting surface of the paraboloid allow one to make deductions about the accuracy of the chosen construction, the technology of preparation and method of adjustment, which allows for the creation of an antenna mirror with a surface precision no worse than ± 0.1 mm.

The prepared mold-copy of the secondary mirror and the hyperboloid itself were measured with the aid of a clockwork indicator of 0.01 mm on a coordinate-borer, type 2V440A with a step of 3 mm along /9
the radius (at 68 points). Charts of the measurement of the mold-

copy and the hyperboloid are shown in Fig. 5.

The maximal error of the profile of the hyperboloid consists of ± 0.05 mm.

The Expected Coefficient of Surface Use

In a general case when the distribution of surface areas conforms to the normal law and the representative measurement of discontinuities at the surface of the mirror is significantly less than its aperture, the coefficients of use of the actual and ideal antenna with even exposure are connected by the relation [2]

$$\eta_A / \eta_{Ao} = \exp\left(-\frac{16\pi^2\sigma^2}{\lambda^2}\right)$$

Then, substituting in this relation the value σ, we receive $\eta_A/\eta_{Ao} = 0.996$ and $\eta_A/\eta_{Ao} = 0.840$ for waves of 1.35 and 0.2 cm respectively. Consequently, with the accepted assumption, the loss of effectiveness for waves > 2 mm does not exceed ~ 15%.

For actual exposure of the antenna and the received errors of the surface, the value of the effectiveness of the area may be made in the following assumption.

Let the element of the surface be the area

$$\Delta S = 5\Delta\Theta R_i = 0.655 R_i$$

where $\Delta\Theta = 0.131$ rad is the angular aperture of the element with a length of 5 cm.

The deviation of this element from the theoretical position of the paraboloid at a value of $\pm \Delta\rho$ is accepted in the direction of the normal to the surface. In this case the change of phase equals

$$\Delta\psi = \frac{2\pi}{\lambda}\Delta\rho\,(1+\cos\varphi)$$

In addition, the contribution of each element of the surface /10
to the effective area of the antenna depends on the form of distribution of the field in the aperture of the paraboloid. Two types of the form of distribution were examined:

a) the law of mode distribution

$$E=E_0\cos\beta$$

where $\beta = \frac{\pi}{2}$ with R = 1550 mm;

b) distribution of the field with a 10% overexposure

$$A(\rho) = \left[1 - (1-\varkappa)\left(\frac{\rho}{R}\right)^2\right]^P$$

where $\varkappa$ is the level of exposure of the edge, $\varkappa = 0.1$;

ρ is the actual value of the radius, and P = 1.

Hence

$$A(\rho) = 1 - 0.9\left(\frac{\rho}{R}\right)^2.$$

Finally, with the determination of the actual effective area of the antenna, each element of the surface introduces a contribution to the energy flow, which is proportional to

$$P_i \propto \begin{cases} \dfrac{2\pi R_i \Delta\rho \cos\beta_i}{\lambda}(1+\cos\varphi) \\[2ex] \dfrac{2\pi R_i \Delta\rho}{\lambda}(1+\cos\varphi)\left(1-0{,}9\dfrac{\rho^2}{R^2}\right) \end{cases}$$

The results of the calculation of antenna effectiveness by the derived method are shown in Figs. 6-8. As follows from these data, the actual errors in the preparation of the surface of the KRT-3 give rise to effectiveness loss of no more than 10% for waves 2 mm.

<u>Conclusion</u>

Thus the derived results attest to the fact that the suggested method of design, preparation and adjustment of rigid mirrors for a space telescope permits the creation of precision antennas with a diameter of 3-4 m which work effectively in the millimeter wave band. /11

Performance of terrestrial experiments in the future will allow for the determination of the electrodynamic characteristics of the antenna and to make deductions about the interaction of electrical and mechanical parameters of mirrors of a given type.

The authors consider it their pleasant suty to express thanks to A.Y. Bor-Ramenskiy, L.I. Volkov, M.I. Grigor'yeva, G.N. Khramov and V.N. Shchepem'yev who took an active part in the creation of the antenna.

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2. Ruze, T., Proc. I.E.E.E., vol. 54, P. 633, 1966.

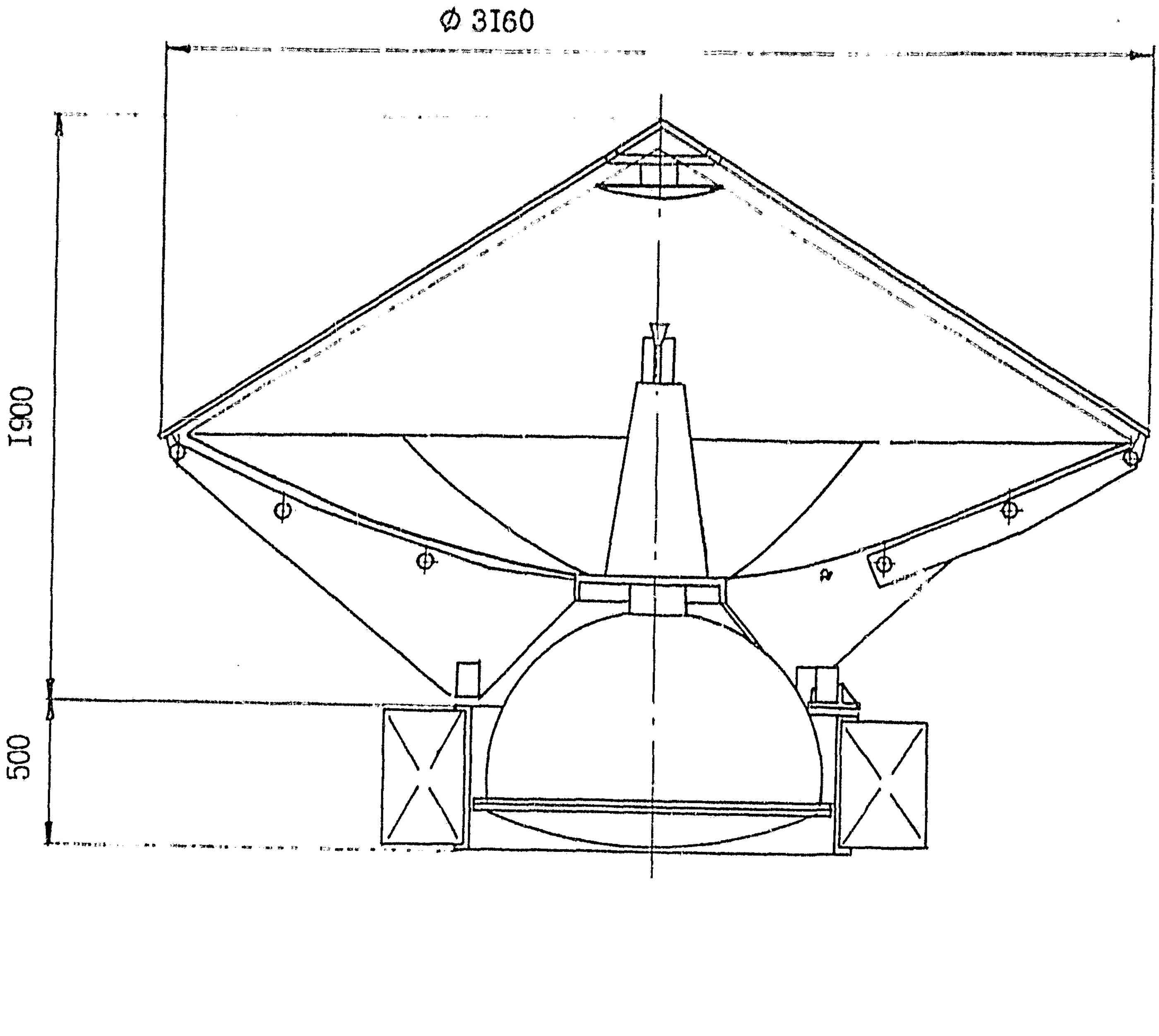


Figure 1. Layout of the radiotelescope.

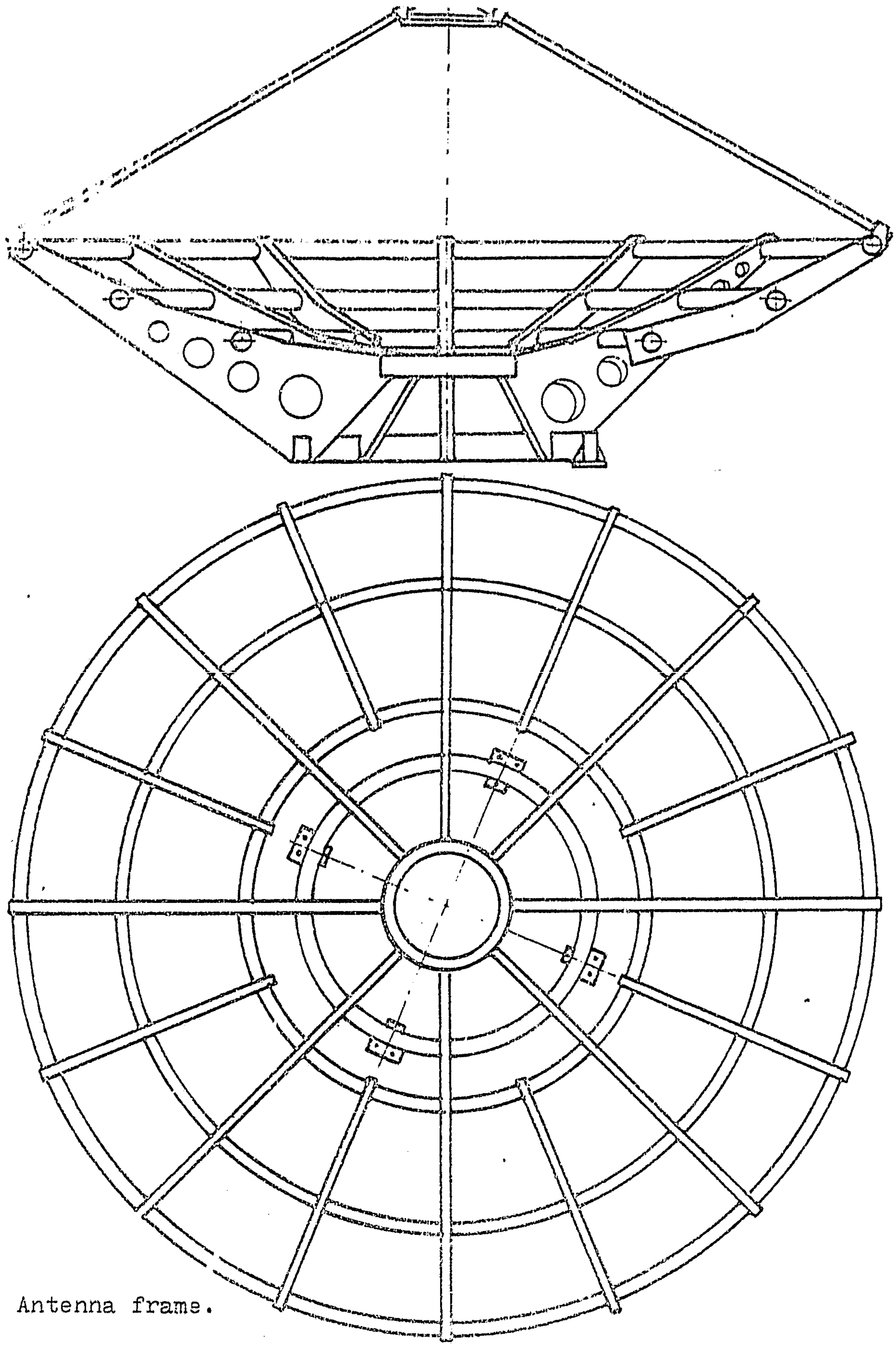


Figure 2. Antenna frame.

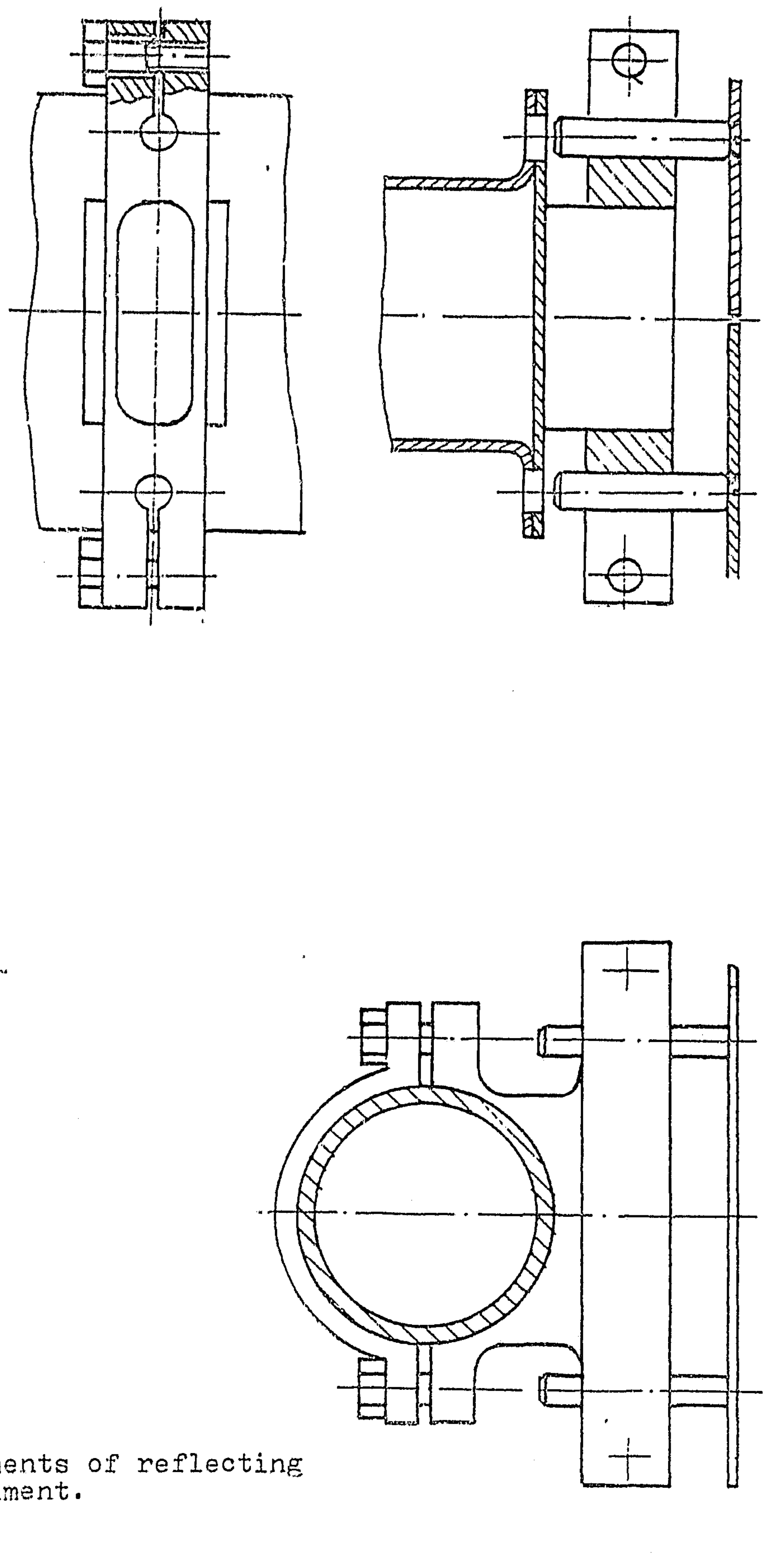
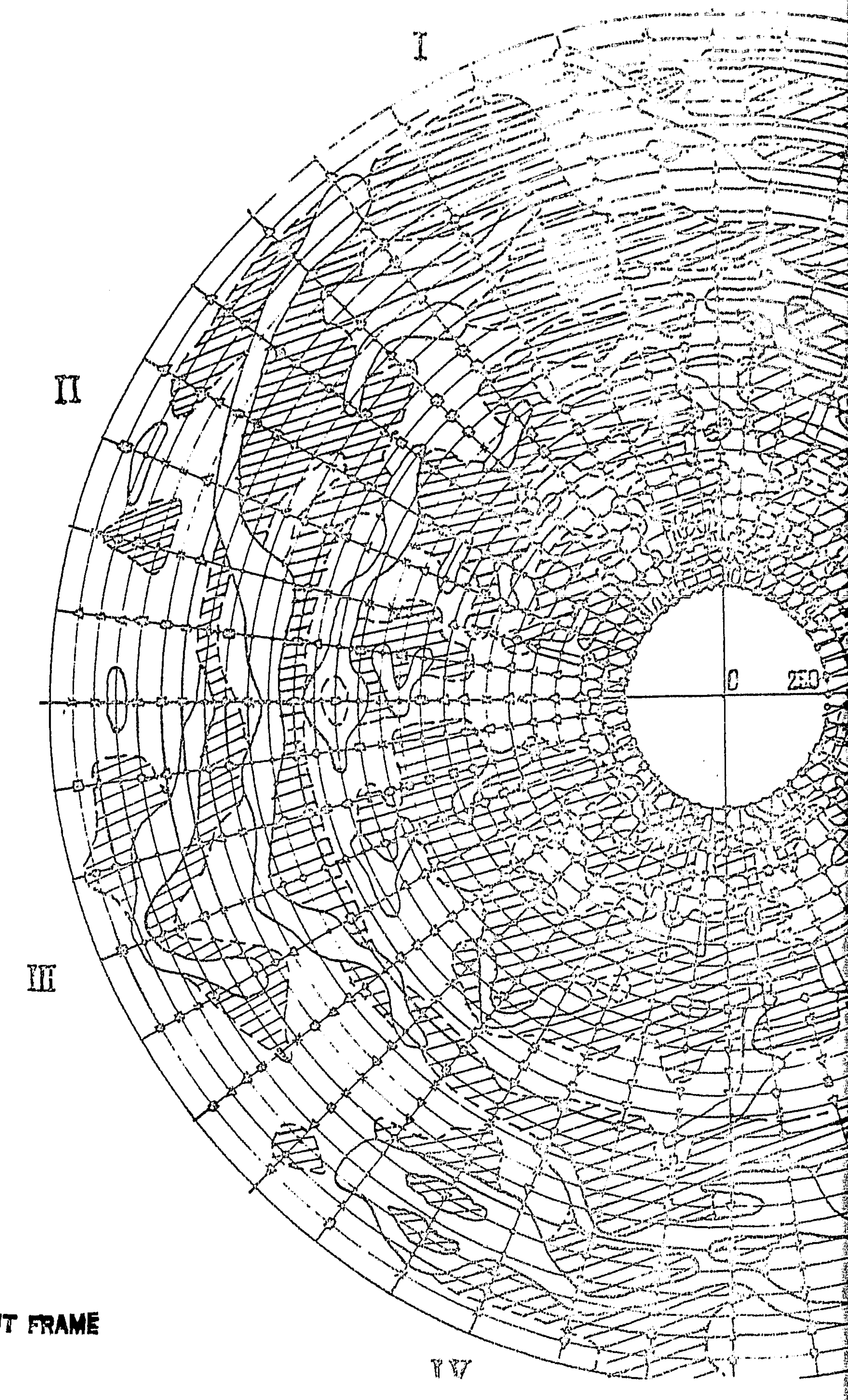


Figure 3. Elements of reflecting surface attachment.


I
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250

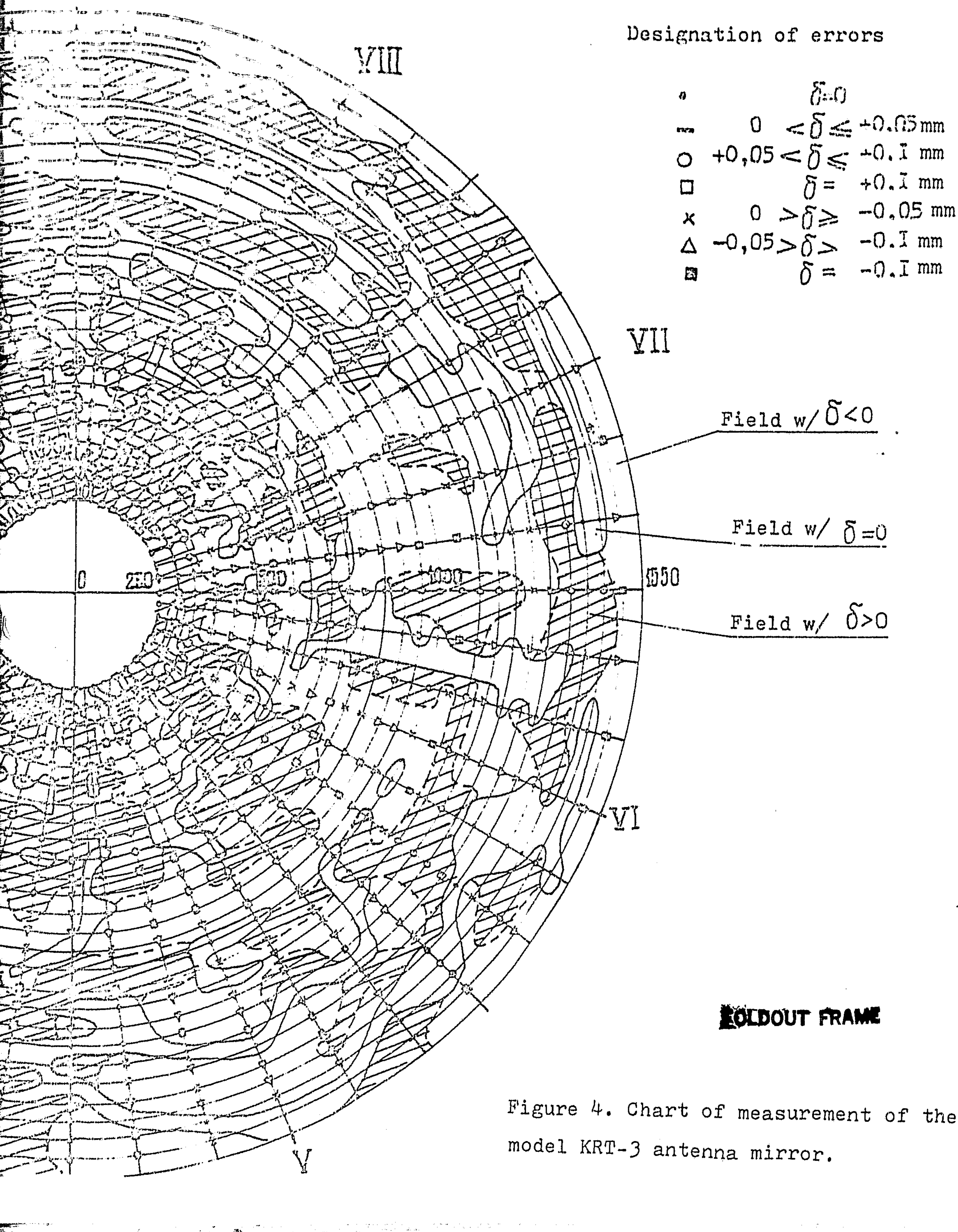

Figure 4. Chart of measurement of the model KRT-3 antenna mirror.

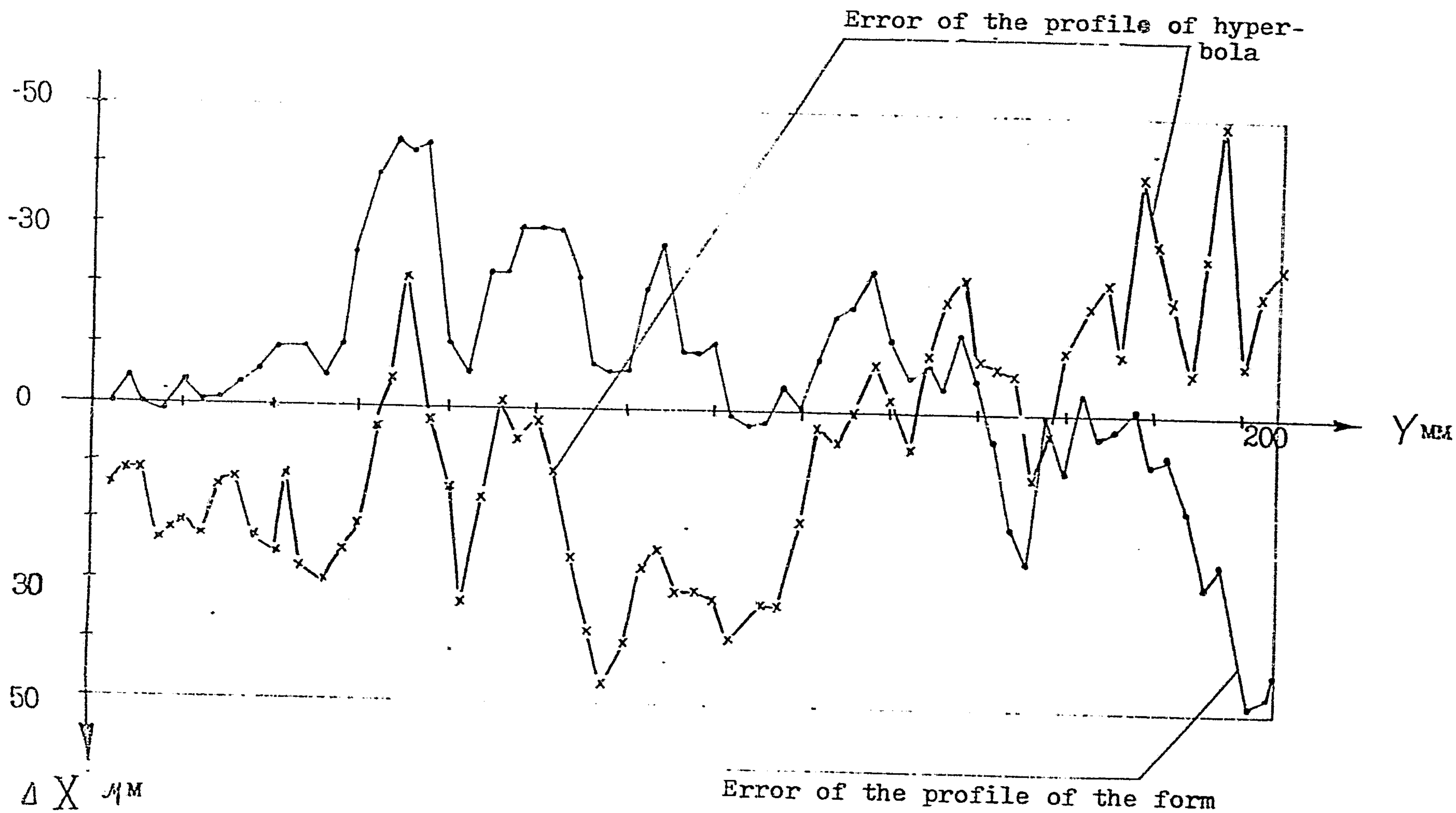

Figure 5. Chart of measurements of the mold and hyperbola.

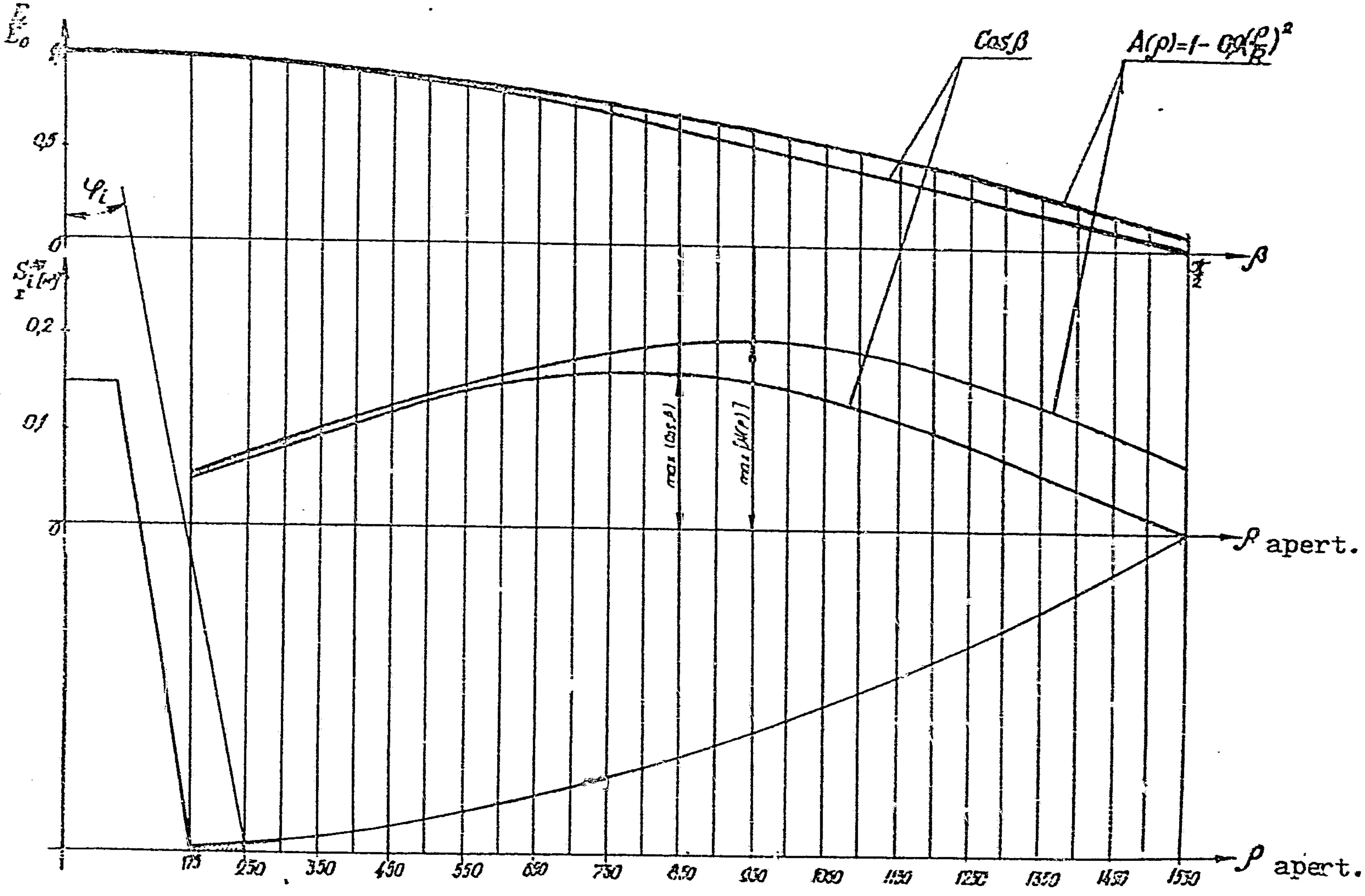

Figure 6. Dependance of the effective area of the antenna on the form of field distribution of exposure in the aperture for the mirror of the KRT-3.

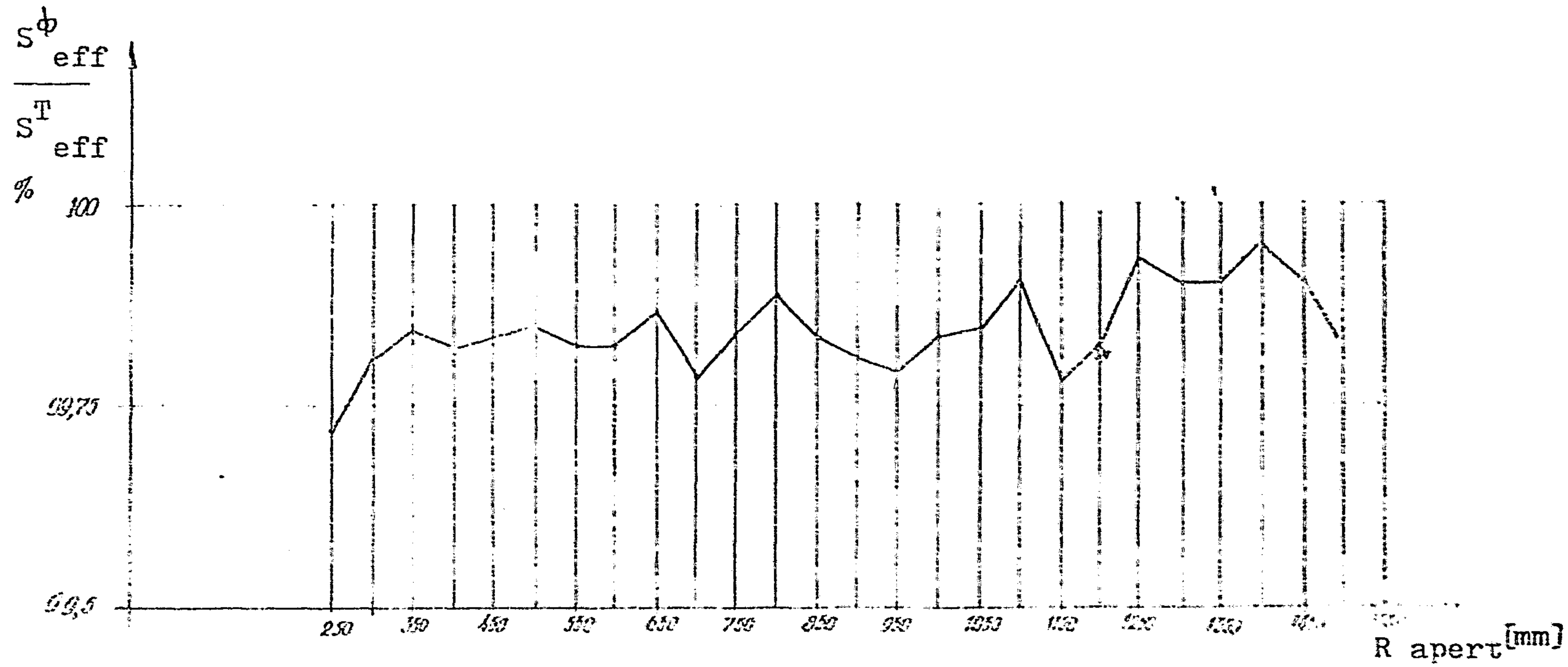

Figure 7. Effectiveness of area use of the antenna mirror by the aperture

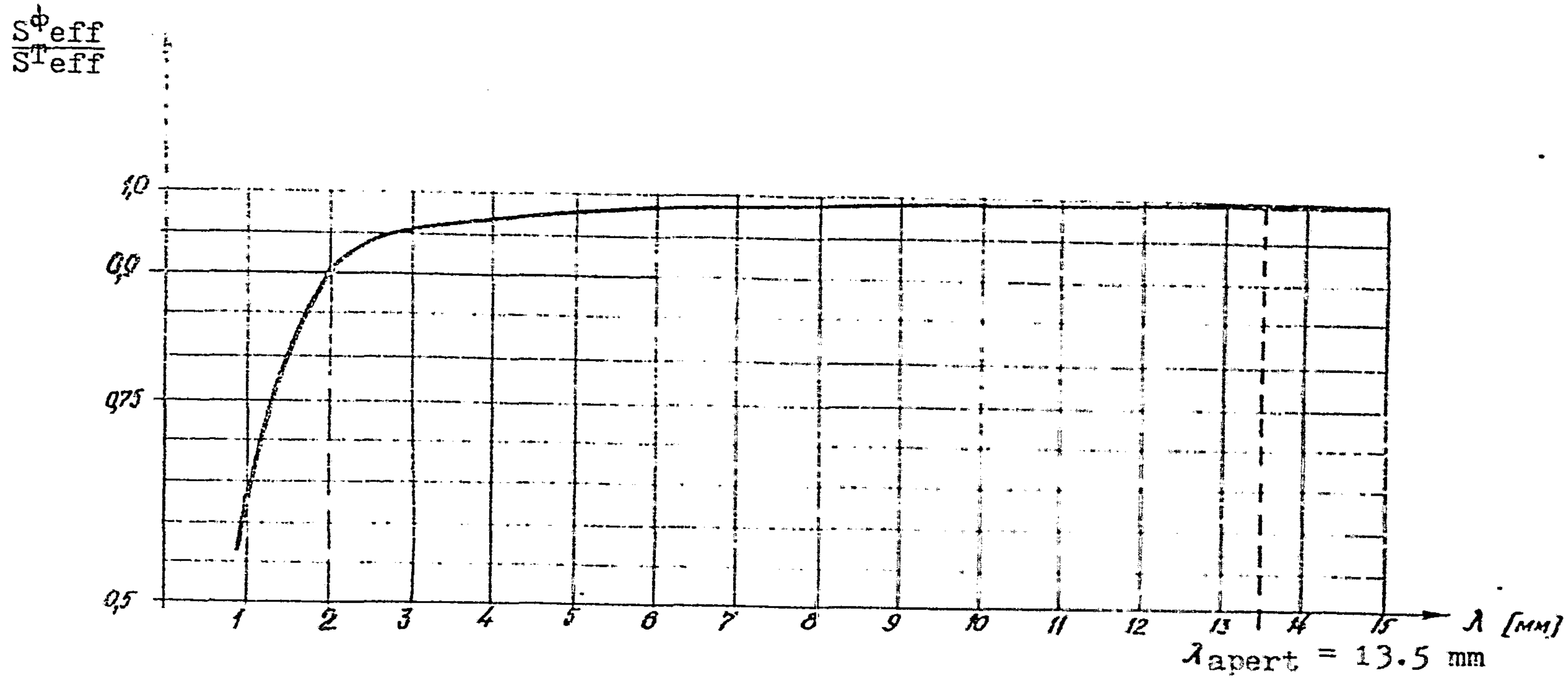

Figure 8. Change of the effective area of the KRT-3 antenna mirror in relation to the working length of the wave.