Manufacturing Engineering of Surface Panels for the 64-m Antennas

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The procurement of two 64-m antennas for the overseas deep space stations was authorized with new vendors. These changes engendered new procedures to insure quality manufacturing of the surface panels for maximum RF performance. The new checking procedures are described including the mathematical formulations and functional aspects of the checking fixtures. A computer program was developed to solve the parameters. Notes on the computing of arc lengths along the parabolic curve are included.

I. Introduction

One of the major factors affecting the RF performance of the 64-m antennas is the accuracy of the contoured shape of the surface panels for the paraboloidal primary reflector. The change in the vendor for the surface panels for the overseas antennas and the use of new methods of checking the contour tolerances imposed the generation of new procedures to insure quality control. Independent checks on the shop procedures and the checking algorithms were considered advisable because of the importance of obtaining the specified accuracy tolerances.

The overall problem is first reviewed, followed by functional descriptions of the checking tools and fixtures and a schematic procedure of their use. The mathematical algorithm used is then described including some notes on the calculation of arc lengths along a parabola.

II. Program Description

The paraboloidal reflective surface of the 64-m antenna consists of 552 separate surface panels separated by 3.3-mm (0.125 in.) to 9.9-mm (0.38 in.) gaps and individually secured to the top chord of the reflector structure by screw-type adjustable means accessible from the reflective surface side. By use of an accurate angle-measuring theodolite and targets at known arc distances from the vertex of the paraboloid, the corners of the panels can be accurately positioned in a paraboloidal shape. It follows that the contoured surfaces of the individual surfaces must be checked for manufacturing accuracies in reference to these targeted positions. This was done by using contour checking fixtures which, in turn, must be checked by master measurements.

The distortions from the paraboloid, one per 645 cm^2 (100 $in.^2$) of surface, are measured normal to the zero plane determined by the four corners of the panels where the optical targets for the theodolites are located. These distortions are analyzed for the root-mean-square value not to exceed 1.52 mm (0.06 in.) rms. After all the panels are measured, specifications allowed a calculation of the mean and the standard variation about the mean surface from all of the distortion data. This value was set not to exceed 0.89 mm (0.035 in.) rms in the specifications. The actual value attained for the overseas antenna was 0.76 mm (0.030 in.) rms.

Figure 1 shows a perspective view of a typical panel surface outlined on the side edges by equally spaced radial planes $OZP'Q'$ and $OZP''Q''$ by the azimuth angle intervals of 2 times Ψ angles. The top and bottom edges are intersection lines of the paraboloid and the two cylindrical surfaces of RAD_{IN} and RAD_{OUT} radii. In practice, the intersection points of the cylinders, the paraboloid, and the radial planes (P', P'', Q', and Q'') were used to determine the corners of the panel surface and straight cuts of the developed flat surfaces formed the eventual edges. The surface of a panel could also be considered as an equally divided part of a frustum of a paraboloid. Dependent on the panels' distances to the symmetric axis, each frustum segment was divided by 48 or 96 equally spaced radial planes.

III. Contoured Surface Checking Fixture

To avoid the third-dimensional problems, it was logical to use as a measuring base a two-dimensional template that rotates about the symmetric axis of the paraboloid. This was done, as shown on Fig. 2, by providing on the panel holding fixture two flat surfaces which are perpendicular to the symmetric axis and intersect points P and Q of the parabola. The checking template or the transducer beam as finally evolved was located to the holding fixture by the two planes and pins R and S. By locating the holes for these pins in the flat planes at the same radii, the transducer beam was effectively rotated about the symmetric axis of the paraboloid. This checking system has been successfully used by antenna manufacturers. Figure 3 shows a photograph of the actual checking fixture in use.

The template shape replaced by transducer points provides a fast, accurate, and permanent printout record of the readings for each radial position checked. Figure 4 shows the method of zeroing the transducers using the calibration rods.

The panels are located in the fixture by stops on the top surfaces above the panels' mounting points on the antenna itself and at the lower-end edge. Pneumatic pressure applied by cylinders holds the panels in place as transducer beam readings are made.

IV. Formulation Data

A. Paraboloidal Surface

The working points of the surface panels are P', P'', Q', Q'', (Fig. 1) on the parabola and define the chords $P'Q'$ and $P''Q''$. We have the problem: (1) of finding the distance between the chord and the normal distance to the parabola as shown on Figure 5, and (2) of finding the distance between the plane $P''Q''$ that is normal to the XZ plane and the surface of the paraboloid. The plane $P''Q''$ on Fig. 5 would be the same as plane $P'P''Q'Q''$ of Fig. 1.

It is obvious that direct solution of the normal distance is available by transforming the coordinate axis to coincide with either the chord or the plane.

The equation defining the circular paraboloid is (Ref. 1)

$$Z = b_3 + b_4 x + b_5 y + b_9 (x^2 + y^2) \tag{1}$$

For an on-axis paraboloid, the equation reduces to

$$Z = b_9 (x^2 + y^2)$$

where

$$b_9 = \frac{1}{4F}$$

$$F = \text{focal length} \tag{2}$$

By substituting the transformation equations limited to the X and Z parameters

$$X = X' \cos\theta - Y' \sin\theta + X_0$$

$$Z = X' \sin\theta + Z' \cos\theta + Z_0$$

into Eq. (2), we get

$$X' \sin\theta + Z' \cos\theta + Z_0 =$$
$$b_9 [(X' \cos\theta - Z' \sin\theta + X_0)^2 + Y^2]$$

which reduces to

$$(- b_9 \sin^2\theta)(Z')^2 + (2X' b_9 \sin\theta \cos\theta$$
$$+ 2X_0 b_9 \sin\theta + \cos\theta) Z'$$
$$+ (Z_0 + X' \sin\theta - b_9 Y^2 - b_9 (X')^2 \cos^2\theta$$
$$- b_9 X^2 - 2X' X_0 b_9 \cos\theta) = 0$$

Thus, Z' or the normal distance between the plane and the paraboloid is computed by the quadratic formula

$$Z' = \frac{- B \pm \sqrt{B^2 - 4AC}}{2A}$$

where

$$A (Z')^2 + BZ' + C = 0$$

and the negative result is output from the program.

B. Arc Length

The arc length along the parabola is used as a parameter for field measuring of distortions with theodolite angles as previously described. Two different formulations for computing the arc lengths may be of interest for checking purposes:

(1) Equation (2) reduces to

$$Z = \frac{1}{4F} x^2$$

for a parabola, and using

$$ds^2 = dx^2 + dy^2 \text{ and } s = \; ds$$

where s = arc length, after integrating, the solution is

$$s = \frac{X}{2}\sqrt{1 + \frac{1}{4F^2} X^2} + F \ln\left(\frac{X}{2F} + \sqrt{1 + \frac{1}{4F^2} X^2}\right)$$

(2) The arc length is also equal to

$$S = D\left[1 + \frac{2}{3} M^2 - \frac{2}{5} M^4 + \cdots\right] \text{(from Ref. 2)}$$

D = diameter of the antenna

$$M = \frac{X}{Z}$$

Since the number of terms supplied in the reference did not provide sufficient precision in the answer, the Numerical Analysis Group of the Computation and Analysis Section was the source of the following equation, which checked with the 8-digit accuracy of the answer from Eq. (1) for the 64-m antenna values, using the double-precision mathematics of the 1108 computer:

$$S = D\left[1 + \frac{2}{3} M^2 - \frac{2}{5} M^4 + 4/7\, M^6 - 10/9\, M^8 + 28/11\, M^{10} - 84/13\, M^{12} + 264/15\, M^{14} - 858/17\, M^{16} + 2860/19\, M^{18}\right] \quad (3)$$

It should be noted that the series converges only for $M < 0.375$, and close to this value the convergence will be very slow. The value of M for the 64-m antenna is 0.295.

References

1. Lawson, C. L., "Paraboloid Fitting to Minimize Pathlength Error," in *Supporting Research and Advanced Development*, Space Programs Summary 37-32, Vol. IV, pp. 22–24. Jet Propulsion Laboratory, Pasadena, Calif., April 30, 1965.
2. Hudson, R. G., *The Engineers' Manual*, Second Edition. John Wiley & Sons, Inc., New York, August 1945.

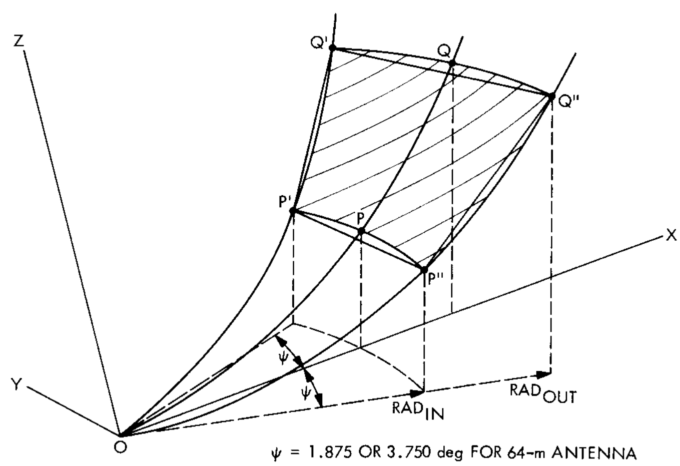

Fig. 1. Perspective view of a panel surface

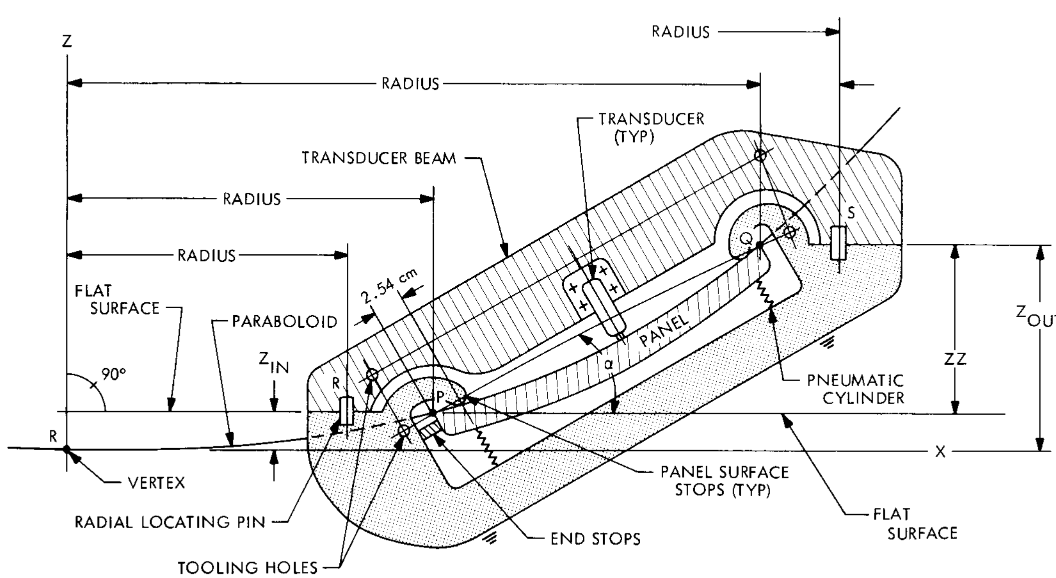

Fig. 2. Surface panel contour checking fixture side elevation view

Fig. 3. Contour checking fixture

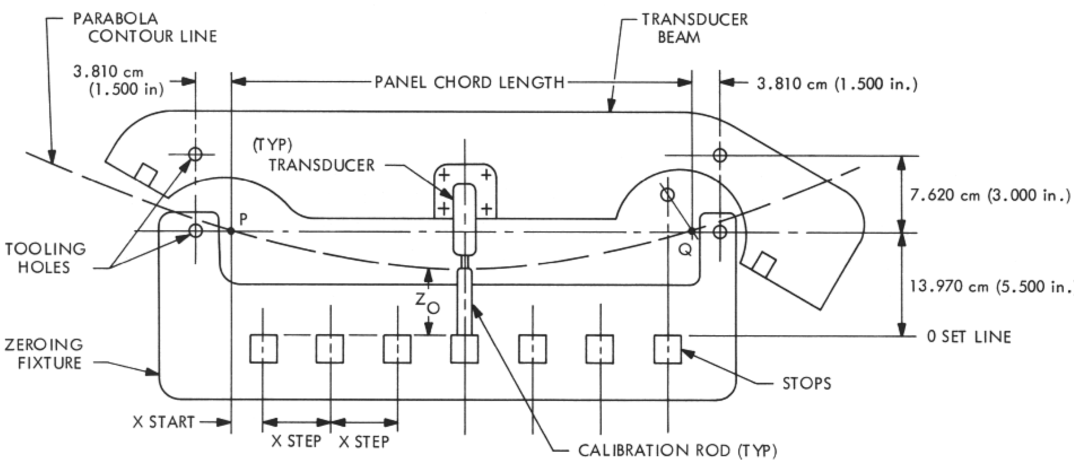

Fig. 4. Transducer zeroing fixture

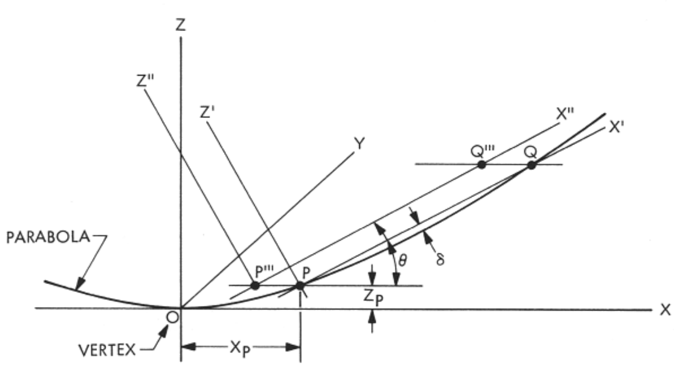

Fig. 5. Coordinate transformation scheme