GEOMETRICAL SURVEY OF COMPACT ANTENNA TEST RANGES USING LASER TRACKER TECHNOLOGY

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Abstract: For the testing of antenna properties compact antenna test ranges (CATR) are used to an increasing degree. They consist of a system of two large parabolic mirrors. To inspect the geometry of the mirrors' surfaces, a laser tracker was used. In this paper, the results of a feasibility study are shown, focussing on the appropriate measuring techniques for surveying large sensitive structures. Furthermore, the deviations between the CATR-design data and actually produced parabolic mirror surfaces are presented.

1. Introduction

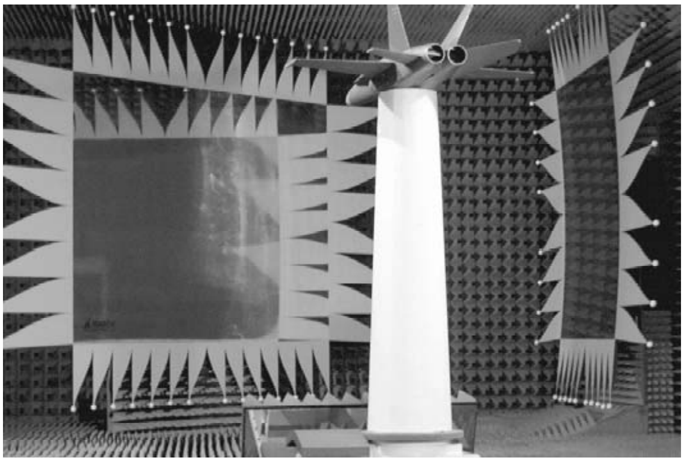

Fig. 1: CATR

Fig. 2: Collecting data

Compact antenna test ranges (Fig. 1) serve for the surveying of radar components with respect to electromagnetic properties. With a CATR, a spherical wave is transformed to a plane wave by using two cylindric-parabolic mirrors with a surface of several square metres, placed in an anechoic chamber. In this way, a very large distance between feed and antenna under test can be simulated in a relatively small range. Antenna measurements are carried out directly under similar conditions as in the far field. Due to the high requirements of the far-field properties of the antenna system, the specifications of the mirrors' surfaces are challenging, too. The easiest way to prove the far-field characteristics is to check the surface accuracy. Optical surveying techniques with theodolites have been utilized for many years for static measurements of reflector antennas [1]. Because of the required geometrical measuring accuracy of 0.030 mm and the structure´s dimensions, for this task the appropriate measuring tool is a laser tracker. In particular, its mobility and its range make it the preferential technique for the measurement of large construction units, which cannot be handled by coordinate measuring machines (CMM).

2. Geometry of the object

To characterise the functionality of a CATR first some essential properties of the parabola should be described:

A parabola is the locus of all points in a plane equidistant from a fixed point, called the focus, and a fixed line, called the directrix (Fig. 3). The distance from the directrix is, of course, the perpendicular distance. Paraboloids are found very commonly as reflectors of waves. Each part of a plane wave front perpendicular to the axis of the parabola will be reflected to the focus. On the other hand, each signal from the focus will be reflected as a plane wave front perpendicular to the axis of the parabola.

The characteristic of a cylindrical parabola is comparable to a plane parabola: Wave fronts perpendicular to the symmetry plane of the cylindrical parabola will be reflected to the focal line (Fig. 4).

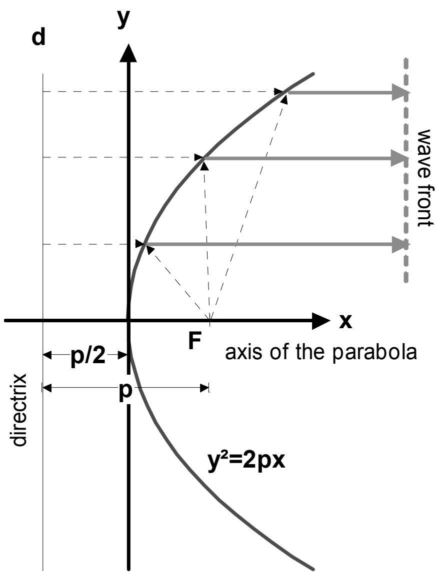

Fig. 3: Parabola

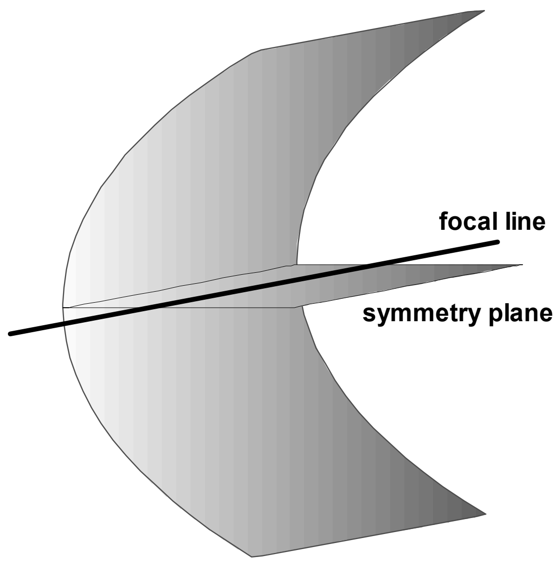

Fig. 4: Cylindrical parabola

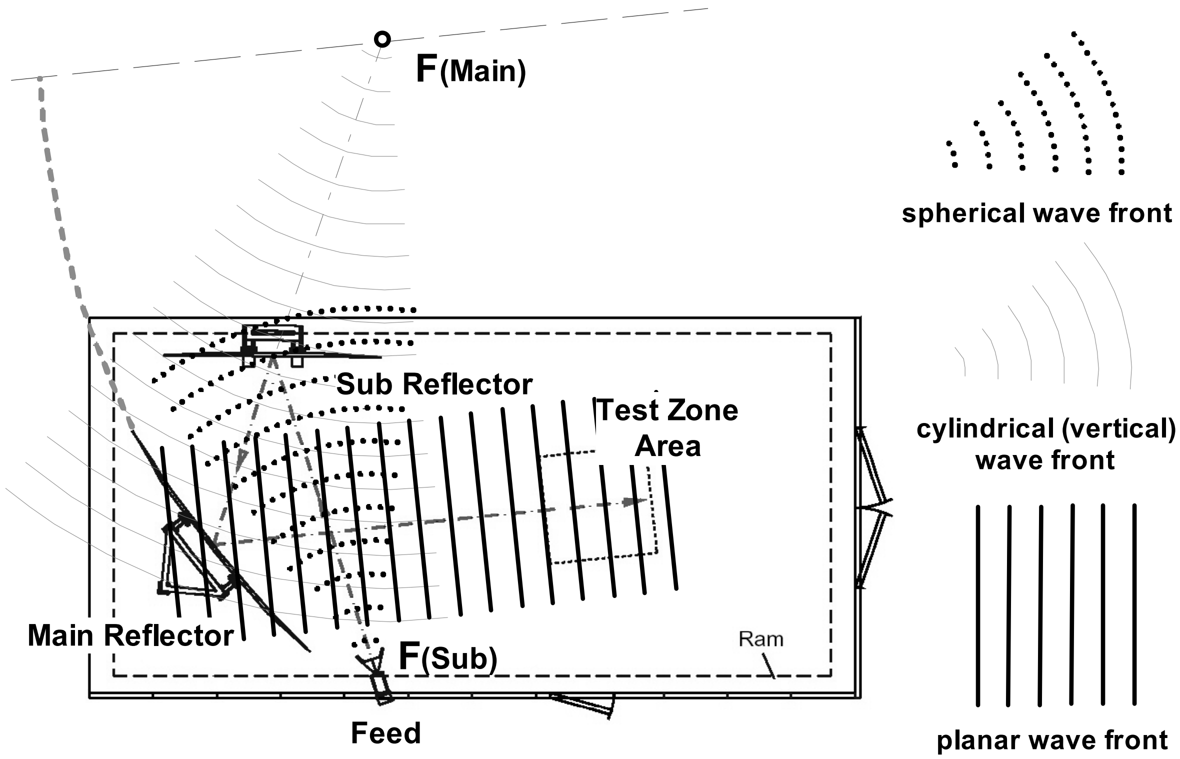

Fig. 5: Compact antenna test range

The geometry of a CATR with two cylindrical-parabolic reflectors is shown in Fig. 5. The sub reflector has the form of a parabolic cylinder with horizontal axis. The compact range feed is placed on the focal line of the sub reflector F(Sub).

The feed produces a spherical wave front which is transformed to cylindrical wave front after the reflection from the sub reflector. Consequently, the cylinder axis of the transformed wave front is vertically oriented. Furthermore, it coincides with the focal line of the main reflector. The main reflector transforms the cylindrical wave fronts to a pseudo plane front. In this way, far-field conditions can be realized indoors.

In the experimental investigation, CATR model 4838A from MARCH MICROWAVE SYSTEMS has been used. This compact range operates between 2 GHz and 40 GHz and the test zone size is approximately 2 metres in diameter [2].

3. Data acquisition

3.1. Laser tracker

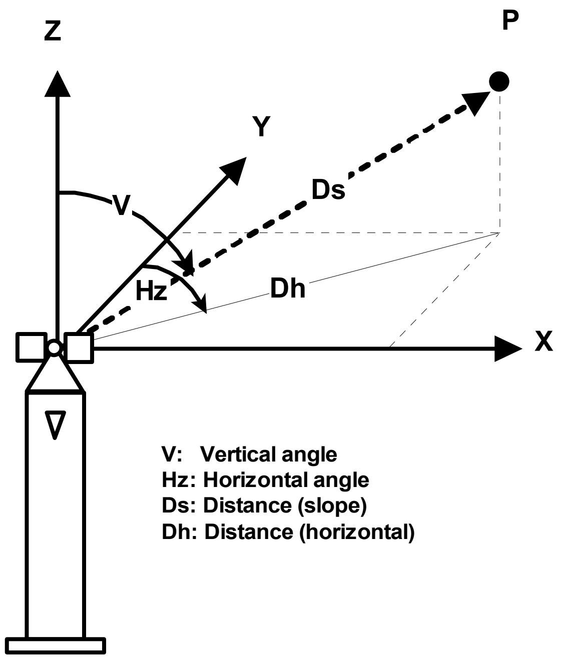

Fig. 6: Polar measuring system

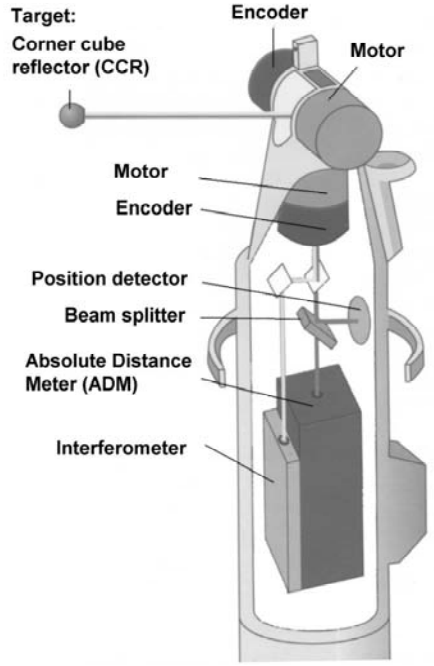

Fig. 7: Laser tracker

A laser tracker is a polar measuring system (Fig. 6) that works with a cooperative target. The used laser tracker Leica LTD500 (Fig. 7) contains two different distance measuring systems (laser interferometer and absolute distance meter ADM) and two precision angle encoders. An appropriate software (for example Leica Axyz) calculates, stores and displays the 3-dimensional position of a mirrored target. The software is used to calculate the transformation from polar coordinates to Cartesian coordinates (x,y,z) as well as the transformation to the reference system defined by object points [3]. A beam steering system senses movements of the mirrored target and directs two servo motors to track the target. The tracker follows the mirrored target over features, updating the position at a rate of 1000 Hz. The abundance of data collected yields good statistical redundancy, permitting excellent accuracy and repeatability. The laser tracker emits a beam from a laser to a mirrored target. The most precise targets are so called "corner cube reflectors" (CCR), consisting of three orthogonal mirrors. The mirrors are centred in a metal sphere and their reflective surfaces have a special coating.

The CCR is guided by hand or machine over features to be measured and reflects the beam back along the same path to the tracker.

The general measurement uncertainty is specified as a function of the distance between the laser tracker and the measured point. The 2σ-accuracy is ±10 ppm for static measurements and ±20-40 ppm for dynamic measurements [4]. This uncertainty mainly depends on the uncertainty of the angle measurement and the uncertainty of the measurement of the atmospheric conditions.

Distance	2,5 m	5 m	7,5 m	10 m	15 m
2σ Accuracy	0,025 mm	0,050 mm	0,075 mm	0,100 mm	0,150 mm

Table 1: Measurement accuracy

Due to the very high accuracy of the laser interferometer it is possible to enhance the accuracy of the results for special configuration between laser tracker and object: If the angle measurement has only low influence on the result (for example movements along the laser tracker's line of sight), one gets an accuracy responding to the interferometers' uncertainty. Therefore it was indicated to place the laser tracker between both mirrors to aim more or less orthogonal to the mirrors' surfaces.

3.1.1. Reflector offset

The tracker is not able to measure direct to the surface of an object. The tracker always measures to the centre of a target. In consideration of the CCR's offset it is possible to derive the coordinates of the contact point P between the CCR housing and the object surface from the measurement to the centre of the CCR (Fig. 8). For that it is necessary to define the kind and the size of the offset. To measure cylindrical parabolas with very long focal length, a cylindrical offset should be selected. For the definition of the dimensions of the offset cylinder at least 5 points are necessary. It is also possible to create a best fitting cylinder to a set of multiple points using the method of least squares.

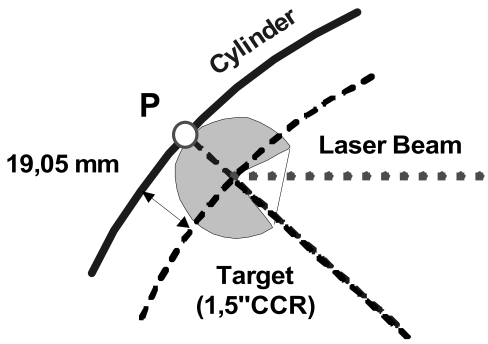

Fig. 8: Cylindrical offset

3.2. Measuring process

3.2.1. Definition of the grid

As mentioned above, a laser tracker enables coordinate acquisition while the target is moving, using the dynamic mode of the tracker: In short temporal or linear distances the position of the moving target is detected automatically. Unfortunately the reflector surface is too damageable to apply this method.

Therefore we decided to acquire the surface data point by point by using a marked grid. The grid was oriented in reference to the serrations of the reflector. In this way a raster of 9 lines and 15 columns was created for the main reflector, and a raster of 9 lines and 11 columns for the sub reflector. The raster was marked by adhesive tape, but the CCR was positioned directly on the reflectors surface carefully in the region of a marking. However, it is not strictly necessary to measure at predefined absolute positions on the reflector. The procedure was done to generate more or less equidistant points.

3.2.2. Vibrations

As mentioned above, for the determination of the reflector's shape it is neither necessary nor technically possible to place the CCR accurately on a certain position of the reflector. The CCR was held without further aids only with free hand to the surface of the reflector (Fig. 2). The raster marked with tape served as orientation. Although the hand was pressed carefully against the reflector, a stable position is not guaranteed during the measurement. Since the acquired coordinate date is averaged from 100 individual samples, a standard deviation can be computed immediately for each displayed and stored value. The mean repetition standard deviation was 0.020 to 0.030 mm. Measurements with a standard deviation over 0.030 mm were rejected and the measurement was repeated. However for the determination of the reflectors shape this inaccuracy is unimportant, because the CCR is pressed against the surface of the reflector. So a movement of the CCR during the measurement is not effective toward the surface-normal but only perpendicularly to it. Before we started measuring the surface, the reflector's deformation due to the pressure was examined by holding the CCR with low and strong pressure against the surface. It showed that the coordinates and the surface remain stable. Thus it can be assumed that this also applies during the measurement.

3.2.3. Overall accuracy

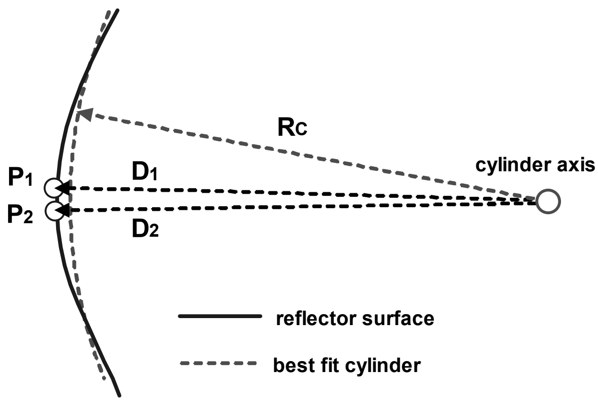

Fig. 9: Point differences

To estimate the accuracy of the acquired data points, both reflectors were measured in two independent sessions. As described in section 3.2.1, it was not possible to bring the CCR to identical 3D-position on the reflector in both sessions. Actually the touched positions lay apart about a few millimetres. For the comparability, the two data series can be used but not the absolute spatial position of the CCR, only the distance from the point of surface to the axis of a best fit cylinder delivers an acceptable measure for comparison. As represented in Fig. 9, the position P_1 of a point measured in the first session lies very closely apart from the position P_2 of the second session. The difference of the distances D_1 and D_2 is therefore the actual indicator for the repetition accuracy of one point. For the computation of the best fit cylinder of each reflector the values from both sessions were used respectively. The standard deviation of an individual determined distance to the cylinder axis D_i, derived from double measurements, amounts 0.015 mm for the main reflector and 0.012 mm for the sub reflector. Drift of the interferometer can be excluded due to previous examinations [5].

4. Evaluation of the surfaces shape

In the following we present the calculations necessary to make statements about the accuracy of the reflectors' surfaces.

The coordinates of all points of the surfaces originally refer to a right-angled three-dimensional coordinate system defined by the axes of the laser tracker as shown in Fig. 6. To compare the design form of the reflector with the actually measured form these coordinates have to be transformed to a coordinate system defined by the reflector:

4.1. Sub reflector

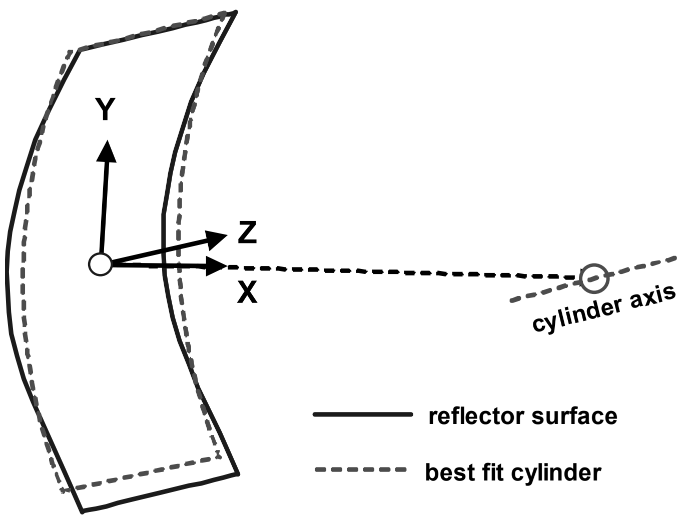

Fig. 10: Coordinate system of the cylindrical parabola

From the measurements of the first session a best fit cylinder was computed according to the method of the least squares. A right-angled coordinate system was defined as follows: The origin of the system is centrically on the surface of the symmetrical reflector. The Z-axis runs parallel to the axis of the best fit cylinder, the X-axis is perpendicular to the Z-axis and points to the axis of the best fit cylinder and the Y-axis is perpendicular to X- and Z-axis.

In this coordinate system for each measured Y-Z-position nominal values for X were computed (by using the parabola equation) and compared with the measured X-values. Two different focal lengths were used:

- F = 5915 mm, in accordance with the description of construction.
- F = 5935 mm, estimated according to the method of least squares with a form analyzer developed by Dr. Kupferer at Geodetic Institute of the University of Karlsruhe.

The deviations are represented in Fig. 11.

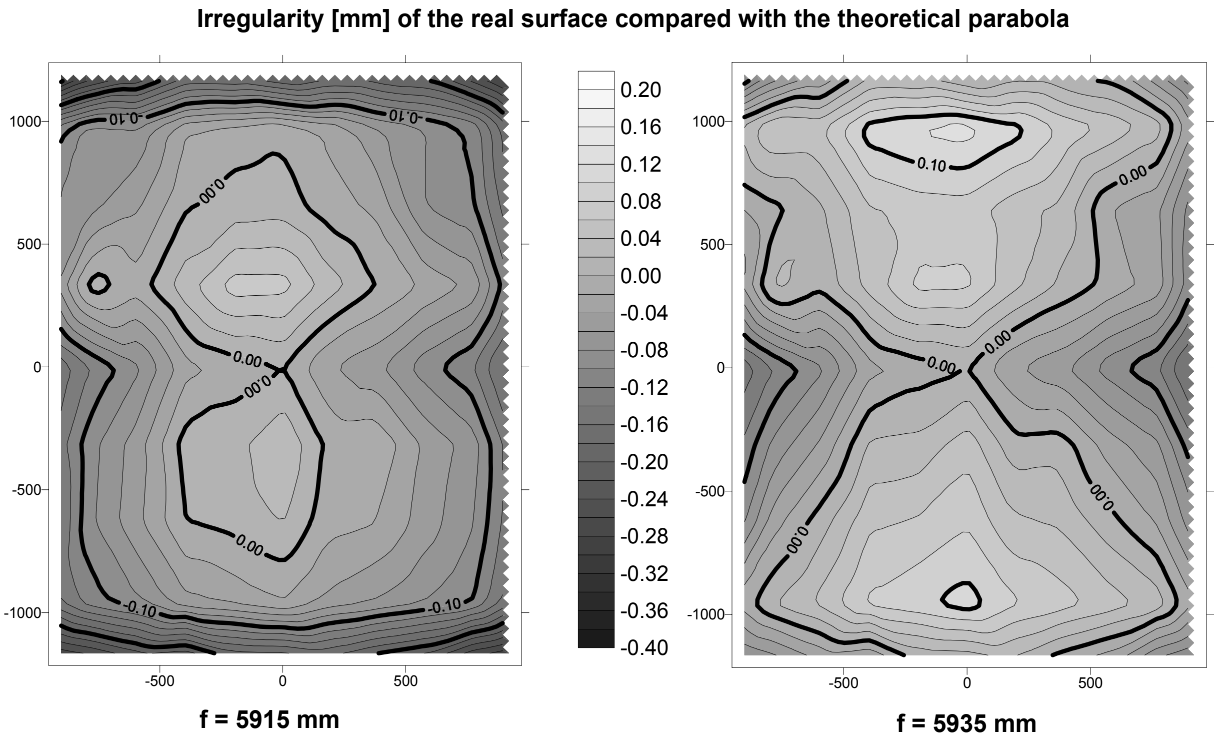

Fig. 11: Deviations of the sub reflector

It is to be recognized clearly that the deviations are smaller with the computed focal length of 5935 mm at the upper and lower edge of the parabola than at the construction value of 5915 mm (Fig. 11, right). The illustrations also show that the geometrical deviations of the surface from the theoretical parabola almost on the entire reflector surface are smaller than ±0.1 mm.

4.2. Main reflector

With the same form analyzer a best fitting cylindrical parabola was estimated for the main reflector, too. It should be reminded, that the main reflector is an asymmetrical part of the cylindrical parabola (Fig 12). To represent the deviations, the surface is mapped to the plane. The origin of the used coordinate system is located at the lower left edge of the reflector. The x-axis runs parallel to the focal line. The y-coordinate is the arc length perpendicular to the x-axis, measured on the surface.

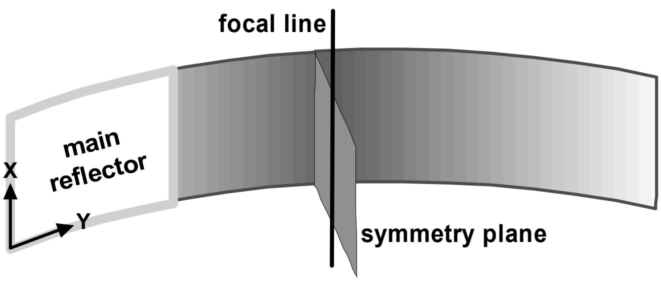

Fig. 12: Asymmetrical main reflector

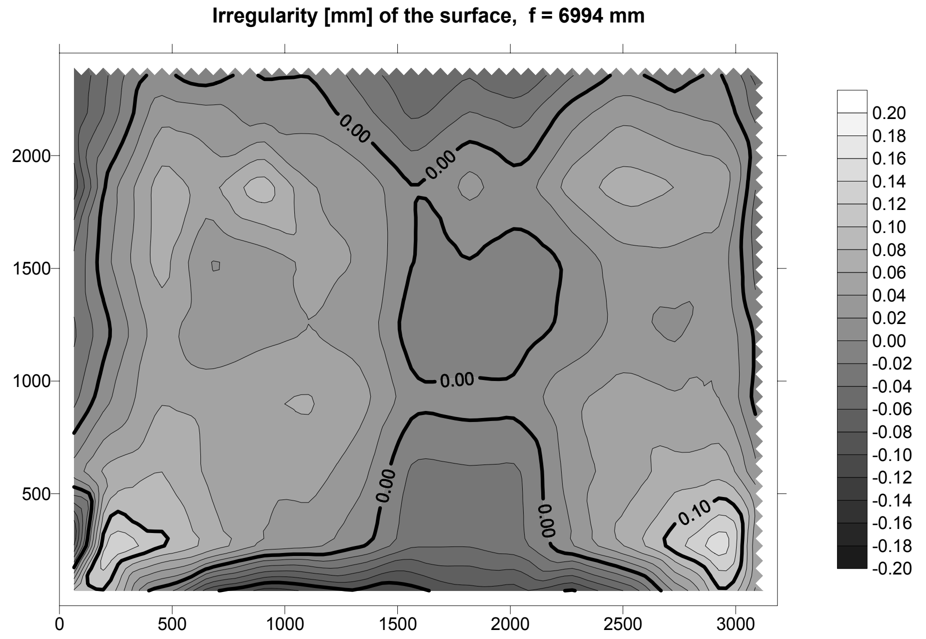

Fig 13: Deviations of the main reflector

Differing to the construction value of 7020 mm the focal length was estimated as 6994 mm. Analogue to the results of the sub reflector, the geometrical deviations of the surface from the theoretical parabola (f = 6994 mm) almost on the entire reflector surface are smaller than ±0.1 mm (Fig. 13).

5. Conclusions and Outlook

The measuring principle of laser tracker was presented and it was shown that these instruments are suitable to determine the geometry of reflector surfaces. A real case study pointed out details to be considered. The results show the evaluation of a symmetrical cylindrical parabolic sub reflector with the size of 1.8 m x 2.4 m and an asymmetrical main reflector with the size of 3.2 m x 2.4 m. The actual surfaces deviate, from the all-largest part, by less than ±0.1 mm from the required geometrical design form. In addition, if also the focal length is computed by the method of the least squares, the deviations decrease further. In the future not only the reflectors but the geometry of the entire CATR system should be measured. For that it is necessary also to survey the centre of the feed. Then it would be possible to compute a complete ray tracing of a ray from the feed over the actual reflector surfaces up to the test zone area in order to get statements about the homogeneity of the wave front. In the future also very clearly defined representative points at the reflectors should be measured, which are suitable for defining a reflector coordinate system. Then the geometrical adjustment of the reflectors could be checked and improved if necessary. To increase the accuracy in future, at present a pressure system for the tracker CCR is developed. Such a system aims at fixing the CCR by vacuum cups at the reflector's surface and ensures more stability during the measurement process.

References:

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