COMPACT RANGE CALIBRATION AND ALIGNMENT

M. Juretzko and E. Richter
Geodetic Institute, University of Karlsruhe, 76128 Karlsruhe, Germany
juretzko@gik.uni-karlsruhe.de
richter@gik.uni-karlsruhe.de

M. Paquay
ESA/ESTEC, 2200 AG Noordwijk, the Netherlands
maurice.paquay@esa.int

V.J. Vokurka
March Microwave Systems B.V., 5674 TM Nuenen, the Netherlands
vokurka@marchmicrowave.com

ABSTRACT

For alignment and surface accuracy testing, laser trackers became an attractive alternative during the last decade. Unlike theodolites or photogrammetry, direct absolute distance measurements are possible. Moreover, tracking flexibility allows determining the absolute position of all system components in the anechoic chamber from a single position of the laser tracker. As a consequence, the surface accuracy of reflectors, absolute position of the CATR feed, position and alignment of the positioner system including AUT, and, finally, the accuracy of the scanner can be included in these measurements.

The absolute accuracy in these measurements will mainly depend on distance and angular position of all system components. For distances up to about 10 metres, the accuracy can be kept below 30µm. Applying ray tracing to the distance pattern, a first order estimate of the amplitude and phase performance across the test zone can be calculated. It will be shown that accurate results can be realized for frequencies up to about 30 GHz. For most applications, the accuracy is still acceptable up to 100 GHz. Finally, since the mechanical deviations in the scanner have been determined accurately, the corresponding phase compensation can be applied as well.

Keywords: Compact Antenna Test Range, Surface Accuracy Determination, Range Geometry, Laser Tracker.

1. Introduction

The geometry of a Compact Antenna Test Range (CATR) with two cylindrical-parabolic reflectors is shown in fig. 1. 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).

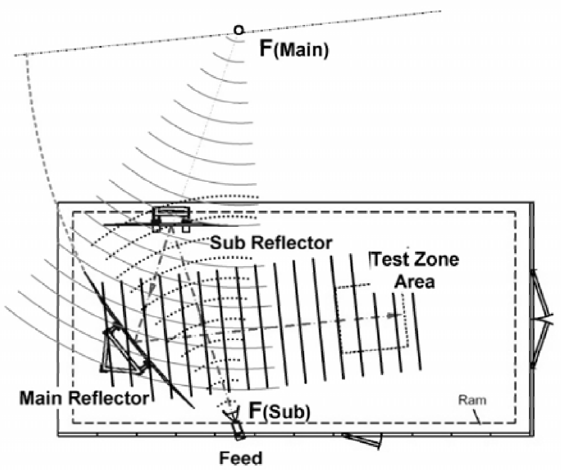

Figure 1 Compact Antenna Test Range

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

In the experimental investigation, CATR model 4838A 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. Geometry of the object

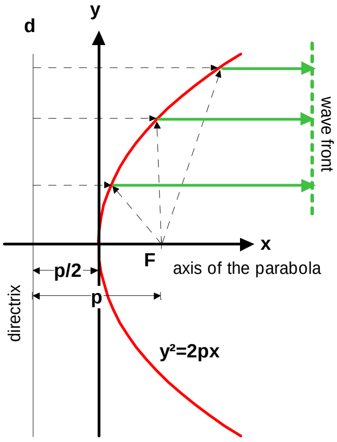

Figure 2 Parabola

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. 2). The distance from the directrix is, of course, the perpendicular distance.

Paraboloids of revolution are commonly applied in various microwave applications. A plane wave front perpendicular to the axis of the parabola will be reflected to the focus. On the other hand, spherical waves originating from the focus will be reflected as a plane wave front perpendicular to the axis of the parabola.

In case of a cylindrical parabola the wave fronts perpendicular to the "symmetry plane" of the cylindrical parabola will be reflected to the focal line (fig. 3).

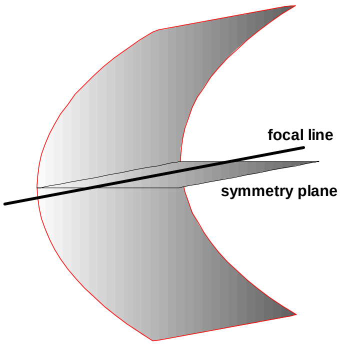

Figure 3 Cylindrical parabola

3. Data acquisition

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).

3.1 Measuring principle

In order to describe the spatial position of a point, three coordinates are required. With polar measuring systems one measures two angles and a distance (fig. 4). These polar coordinates (Hz, V, Ds) are recalculated as Cartesian coordinates (X,Y,Z) .

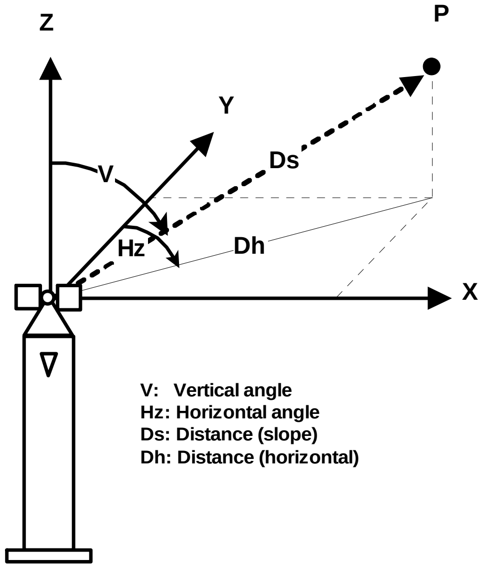

Figure 4 Polar measuring system

3.1.1 The laser tracker

A laser tracker is a polar measuring system that works with a cooperative target (fig. 5). The used laser tracker Leica LTD500 contains two different distance measuring systems (laser interferometer and absolute distance meter ADM), two precision angle encoders and appropriate software (Leica Axyz) to calculate, store and display 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 reference systems defined by object points [2]. 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 times per second. 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 called CCR (Corner Cube Reflector). In the following one the term "target" is used.

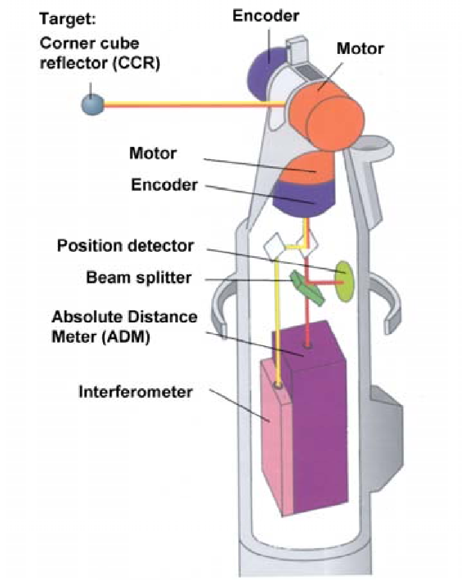

Figure 5 Laser tracker

The target is guided by hand or machine over features to be measured and reflects the beam back along the same path to the tracker. The tracker follows every move, taking 1000 measurements per second. Precision encoders report the horizontal and vertical angles while the laser interferometer reads the distance. The computer stores data when instructed by infrared controller, remote control or by striking a key on the computer.

The general measurement uncertainty is specified as a function of the distance between the laser tracker and the measured point. It is ±10 ppm for static measurements and ±20-40 ppm for dynamic measurements (2σ, manufactures' instructions). This uncertainty mainly depends on the uncertainty of the angle measurement and the uncertainty of the measurement of the atmospheric conditions.

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

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 trackers line of sight), one gets an accuracy which nearly equals the specification of the interferometer.

3.1.2 Reflector offset

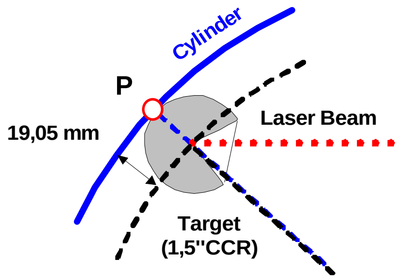

Figure 6 Cylindrical offset

The tracker is not able to measure direct to the surface of an object. The tracker always measures to the centre of a target. The most precise targets are so called "corner cube reflectors" (CCR): They consist of 3 precise mirrors, arranged perpendicular to each other. In consideration of the targets offset it is possible to derive the coordinates of the contact point P between the target housing and the object surface from the measurement to the centre of the target (fig. 6). 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.

3.2 Measuring process

3.2.1 Definition of the grid

As mentioned above, a laser tracker enables coordinate acquisition while the reflector 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 reflectors surface is too sensitive and this method cannot be applied.

Therefore we decided to acquire the surface data point by point by using a marked grid (fig. 7). 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 target was positioned directly on the reflectors surface carefully in the region of a marking. It should be noted that 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.

Figure 7 Collecting the data

3.2.2 Vibrations

For the determination of the reflectors shape it is neither necessary nor technically possible to place the target accurately on a certain position of the reflector. The target was held without further aids only with free hand to the surface of the reflector. The raster marked with tape served thereby as orientation. Although the target 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 is 20 to 30 microns. Measurements with a standard deviation over 30 microns were rejected and the measurement was repeated. For the determination of the reflectors shape this inaccuracy is however unimportant, because the target is pressed against the surface of the reflector. So a movement of the target 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 target with 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

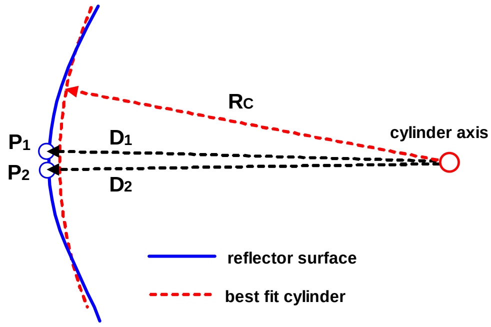

Figure 8 Point differences

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 target to identical 3D-position on the reflector during both measurement sessions. In fact, 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 target, 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. 8, the position P1 of a point measured in the first session lies very closely apart from the position P2 of the second session. The difference of the distances D1 and D2 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 measurement sessions were used. The standard deviation of an individual determined distance to the cylinder axis Di, derived from double measurements, amounts 0.015 mm for the main reflector and 0.012 mm for the sub reflector.

4. Evaluation of the surfaces shape

The coordinates of all points on surfaces of both reflectors originally refer to a right-angled three-dimensional coordinate system defined by the axes of the laser tracker. In the following it will be presented, which transformations are necessary, in order to make statements about the accuracy of the reflector surfaces. The evaluation of the measurement to the (symmetrical) sub reflector was accomplished in two different ways:

1.: Deviation to the cylindrical parabola with the focus length f = 5915 mm (in accordance with specifications). From the measurements of the first session a best fit cylinder was computed according to the method of the least squares.

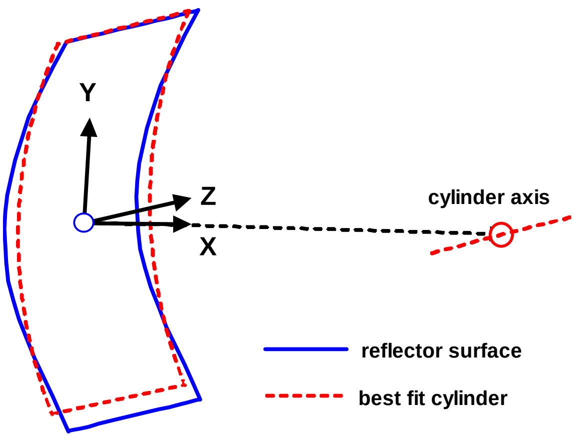

Figure 9 Coordinate system of the cylindrical parabola

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 (fig. 9). 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. The deviations are represented in fig. 10.

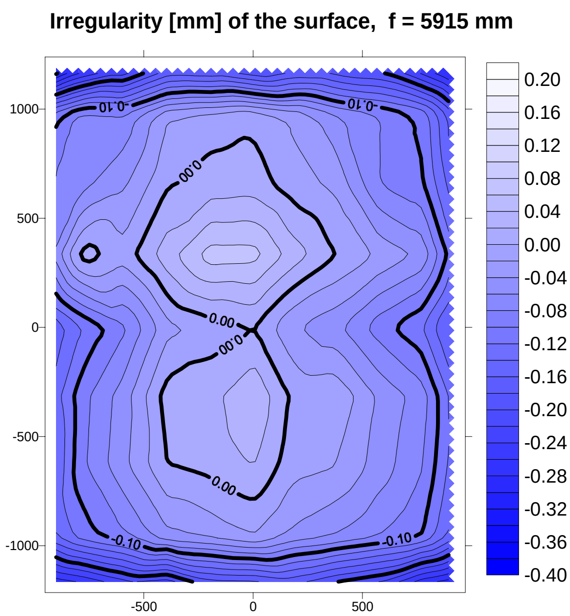

Figure 10 Deveations f = 5915 mm

2. Computation of the actual focus length according to the method of the least squares.

The focus length became estimated to f = 5935 mm according to the method of least squares with one of Dr. Kupferer at Geodetic Institute of the University of Karlsruhe developed form analyzer. The deviations to the parabola with this estimated focus length took place similarly to the form comparison described above via computation of the nominal values (using f = 5935 mm) at the individual measuring positions.

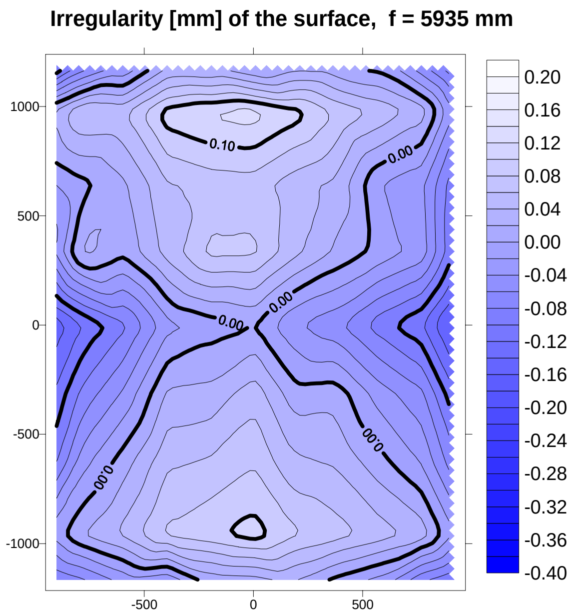

Figure 11 Deviations f = 5935 mm

It is observed that the deviations are smaller with the computed focus length of 5935 mm at the upper and lower edge of the parabola than at the construction value of 5915 mm (fig. 11). The illustrations show also that the geometrical deviations of the surface from the theoretical parabola almost on the entire reflector surface are smaller than ±0.1 mm. For the central area of the reflector which corresponds to the projected test zone area, the maximum deviation is less than ±0.05 mm.

Similarly, a best fitting cylindrical parabola was estimated for the main reflector. It should be noted that the main reflector is an asymmetrical (offset) 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.

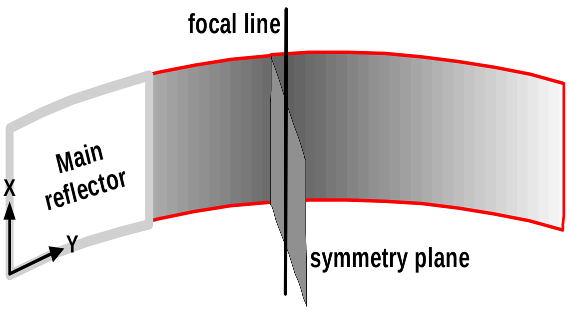

Figure 12: Offset main reflector

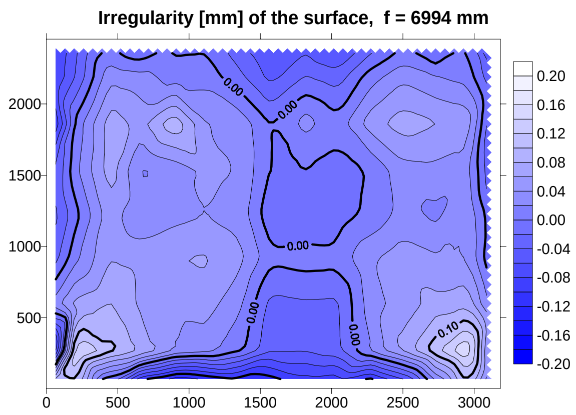

Figure 13: Deviations of the main reflector

The focal length was estimated as 6994 mm. Analogue to the results of the sub reflector, the geometrical deviations on the largest part of the reflector surface are smaller than ±0.1 mm (fig. 13).

5. Conclusions

It has been shown that laser trackers are capable to determine the surfaces of Compact Range reflectors accurately. Measurement errors of approximately 0.02 mm or less are considered as realistic. This means that this method will provide satisfactory results for frequencies up to about 100 GHz. It has been demonstrated that after the surface coordinates are determined, the focus length can be recalculated by the method of the least squares. Consequently, the deviations of the reflector surface will decrease further. In the future not only the individual reflectors but the geometry of the entire CATR system can be determined by this method. This can include both reflectors, CATR feed, positioner, scanner and an RCS reference target. The laser tracker can thus provide additional data for advanced range evaluation [3, 4]. For instance, it will be possible to apply ray tracing from the CATR feed over the actual reflector surfaces up to the test zone area in order to estimate the uniformity of the wave front across the test zone. These data can be directly compared to those collected by probing or application of RCS reference targets. Furthermore, the alignment of the reflectors could be checked periodically and adjusted if necessary. For further accuracy increases, at present a pressure system for the tracker target is developed. Such a system aims at fixing the target by vacuum cups at the reflector's surface and ensures more stability during the measurement process.

6. References

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