Geometric Variations of a Geodetic Radio Telescope

S. Bergstrand, R. Haas, M. Herbertsson, C. Rieck, J. Spetz, C.-G. Svantesson

Abstract We have measured the key deforming parameters of the Onsala 20 m telescope with laser based tracker, scanner and electronic distance meters. The parameters show both thermal and elevation dependence at an order of some millimeters, and are therefore potential significant contributors to a scale error in VLBI analysis.

Keywords radio telescope, laser tracker, laser scanner, deformation parameters

1 Introduction

Compared to previous VLBI generations, local measurements have become an increasingly important issue in connection with the tighter VLBI2010/VGOS/GGOS specifications. Signal chains and other electronic components are under constant development, and local tie methods are being improved (IERS WG, 2015; Lösler et al., 2016; Poyard et al., 2017) e.g. as a mean to better understand the scale error between SLR and VLBI in ITRF2014 (Altamimi et al., 2016) but the mechanical parts have attracted less attention. Clark and Thomsen (1988) is the standard work in the area, which in later years has been extended (Sarti et al., 2009; Artz et al., 2014). Artz et al. (2014) reported a general deformation model for the Effelsberg telescope and based an analysis on a combination of recent and historical data, and suggested a similar investigation for the more common 20 m sized telescopes in the regular IVS networks/sessions. Following the model by Artz et al. (2014), we have employed a number of contemporary laser based length measuring devices in order to characterize the deformations of the Onsala 20 m telescope. Noting that stations are identified by DOMES number and sites are geographical locations, a co-location and site surveying reference for this work is slightly misleading, as local ties provide information of the external relationships between the geometrically defined reference points (GRP) of geodetic stations on a site, whereas deformation analysis captures information of internal variations that largely have been elusive to those surveys. In this study we focus on the internal structural deformations of the telescope in order to explore the possibilities to detect the systematic effects that are, or alias as, tropospheric, temporal or vertical errors in the geodetic analysis. Quantification of these deformations therefore has potential to put valuable constraints on systematic VLBI errors.

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2 Methods and results

Clark and Thomsen (1988) characterized telescope deformation in terms of elevation dependent length changes ΔL and divided these into parts relating to focal length $\Delta F(\epsilon)$, vertex position $\Delta V(\epsilon)$ and receiver position $\Delta R(\epsilon)$, i.e.

$$\Delta L = \alpha_F \Delta F(\epsilon) + \alpha_V \Delta V(\epsilon) + \gamma \alpha_R \Delta R(\epsilon), \qquad (1)$$

where $\alpha_{F/V/R}$ are telescope specific linearly dependent scaling coefficients, and $\gamma = 1$ for primary and $\gamma = 2$ for secondary focus telescopes.

Artz et al. (2014) presented the separate contributing components that we list in Tab. 1, and which we here complement with the instrumentation that we have utilized for the measurements. Due to different telescope constructions some components have been slightly altered in the progression of the project.

Table 1: Telescope deformation category (CA), components (CO), description, measuring method and equipment used.

CA	CO	Description	Method	Instrument
V	L_1	Height of secondary axis	Invar + tracker	Electromagnetic inducer, Leica LTD800
V	L_2	Vertex separation from elevation axis	(tracker)	Leica LTD800
F	L_3	Deformation of the main paraboloid	Scanner (EDM)	Leica HDS7000, Micro-Epsilon optoNCDT ILR 1181
R	L_4	Impact of defocused optics	Gain+EDM	Micro-Epsilon optoNCDT ILR 1181
R	L_5	Effects of a second reflection	EDM	Micro-Epsilon optoNCDT ILR 1181
R	L_6	Displacement of feed horn at secondary focus	(EDM/tracker)	Micro-Epsilon optoNCDT ILR 1181

3 Invar

The main constituent of L_1 is the monument height, whose near 1:1 correlation with temperature has been monitored continuously for more than twenty years (Johansson et al., 1996). Additional movements have been observed during geodetic VLBI sessions, but as the 5 minute smoothing/sampling interval is schedule independent and the magnitude of the movements is small, it has not triggered any elevation dependence studies. The amplitude of the daily L_1 variation is of order 1 mm.

4 Laser tracker

The most precise measurements are performed with a laser tracker, which is a laser interferometer on a dual axis rotating head where encoders detect angular movements. In addition to the invar measurements that monitor the monument height's thermal dependence, we examined whether we could detect an elevation dependent variation of L_1 as well. First measurements were made on the back of the reflector to the supposedly stable platform which co-rotates with the antenna azimuth atop the telescope concrete tower. The initial laser interferometer results from the tracker indicated systematic movements, but at closer examination the results did not supersede the measurement uncertainty. In order to lever the movement, we therefore mounted the tracker's retroreflector on a carbon fiber spinnaker boom which we protruded backwards from the platform. The effect, which is measurable at an order of 0.1 mm and corresponds to a telescope pointing error of 3 arcsec, is minor but at an order of 10 % of the specification not negligible. Some attempts were also directed towards quantifying the variations of L_2, but the inaccessibility of axis supports combined with a set of complex mechanical relations prohibited any qualified measures of this component. At Effelsberg where the reflector rests on a beam, this bending effect was more easily measured and turned out to be a significant contributor. It is plausible that L_2 variations could be captured with a tracker, but that would require intermittent decommissioning of essential electronic equipment and was therefore disregarded for this project.

5 Laser scanner

Where tracker measurements are extremely accurate in discrete points, they are not optimized to characterize surfaces. To measure the elevation dependent deformation L_3 of the reflector, we employed a metrology grade scanner which is a better tool for surface measurements although the accuracy of single points is not competitive to those of a tracker. The manufacturer recommended having the scanner's primary axis aligned with the vertical in order to preserve the instrument bearings and encoders. Adhering to the overall priority to make measurements as close to operating conditions as possible, the first attempts to scan the surface was made from a position close to the antenna vertex. However, the reflected signal from the smooth surface at flat angles proved insufficient to extract relevant data, and the scanner needed to be elevated from the vertex to increase the measuring attitude. We therefore had to relax the initial priority on an unloaded structure, and constructed a lightweight pneumatic controlled gimbal and a clamp which we attached to the subreflector quadrupod for an inverted scanner setup. This construction has also been reused by other instruments for related investigations of the telescope (Holst et al., 2017). Keeping the paraboloid vertex as reference, the telescope rim advances around 6 mm at low elevations compared to the zenith.

6 Electronic distance meter

For monitoring of observation axis movement which in terms of distance components essentially is L_4 and L_5, we attached lightweight, industrial grade laser EDMs as close to the center of the antenna as possible and pointed towards the subreflector. The EDMs were utilized to monitor both elevation and thermal dependence of the subreflector distance, which at an order of 3 mm is of comparable magnitude to the elevation compensation made during astronomical observations. In instances where an invar rod solution is not practical for L_1 measurements, an EDM solution may offer comparable results.

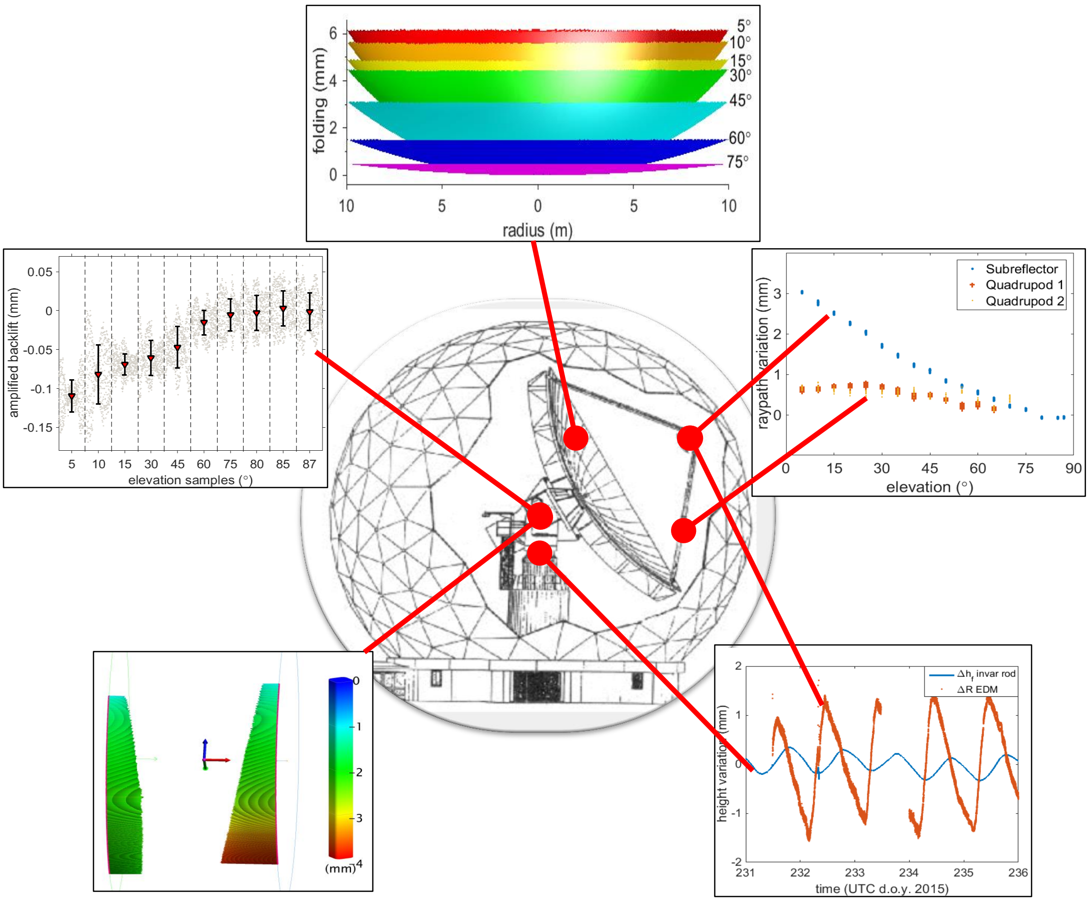

Fig. 1: Structural deformation of the Onsala 20 m telescope. Clockwise from top: elevation dependent main reflector deformation compared to 85° (L_3); elevation dependent subreflector distance and lower quadrupod supports' length (L_4, L_5); thermally induced subreflector distance (L_4) and monument height (L_1); elevation dependent collapse/bending of counter-weights (L_2 indicator); elevation dependent height variation of secondary axis (L_1).

7 Discussion

The telescope was primarily constructed for astronomical purposes, and the technical documentation for focal length, etc. appears to be set for 45° elevation. As the geodetic benchmark is zenith observations, the difference to low elevations become even more accentuated. To continue the dissemination of the deformation components, L_6 is short and its variations minor compared to that of the subreflector distance. A complete quantification of the path length variations therefore includes some more components than presented here. The overall effect of the deformations is not considered, but will be analyzed in a future publication (in progress). Nevertheless, given the VGOS sub mm accuracy objective, the magnitude of the deformations indicates that the effects need to be quantified at the recently deployed 13.2 m telescopes as well. As rms-evaluations are suited for goodness of fit but has limited implications for accuracy, metrologically traceable equipment are recommended for these quantifications.

8 Conclusions

These are direct measurements of the telescope deformations and path length variations. In order to achieve the GGOS objective of 1 mm accuracy for space geodetic observations, corresponding deformations need to be quantified at more sites. As a number of high productive legacy telescopes, e.g. Kokee Park and Ny-Ålesund are about to be decommissioned, it is imperative to measure the structural deformations of these stations before they are demounted and their properties are lost for future TRF and CRF generations.

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