LATVIAN JOURNAL OF PHYSICS AND TECHNICAL SCIENCES
2012, N 6 (II)
DOI: 10.2478/v10047-012-0037-x

EVALUATION OF DAMAGE AND DEFORMATION OF RT-32 RADIO TELESCOPE

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The main objective of the work was to analyze the operation of the large radio telescope RT-32 at the Ventspils International Radio Astronomy Centre (VIRAC). The analysis has been performed in order to evaluate dimensional changes in the RT-32 structural base due to reorientation of the antenna mirror. Three different orientations of the dish were considered, and the dimensional changes in the load carrying substructure were measured. The measurements were made to estimate possible effect of the geometrical changes of the antenna due to gravitational loads on the overall performance of the radio telescope with respect to the obtained astronomical results, their accuracy and validity. Comprehensive mapping and classification of the corrosive damage of steel elements in the antenna have been done. A preliminary numerical analysis by the finite element method was carried out to demonstrate the overall effect of the damaged steel beams on the geometrical distortion of the antenna surface.

Key words: *large radio telescope, dimensional changes, corrosive damage.*

1. INTRODUCTION

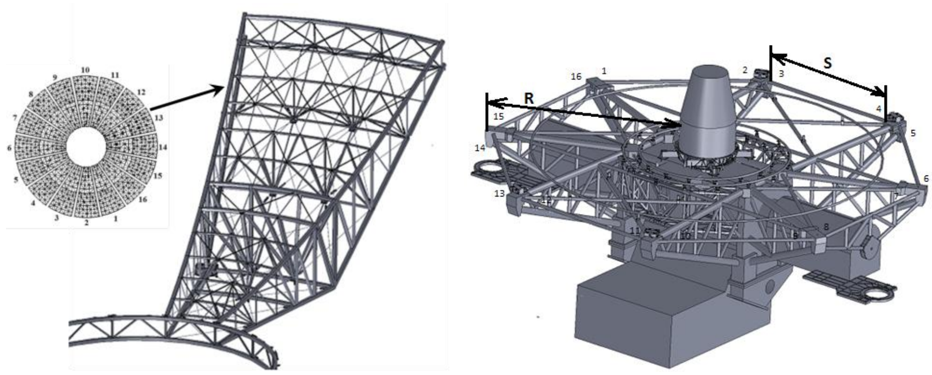
Almost a decade ago two large radio telescopes RT-16 and RT-32 located at Irbene (near Ventspils, LATVIA) were transferred to the management of the Ventspils International Radio Astronomy Centre (VIRAC). The radio telescopes were built by Soviet Army in 1969–1973 for military purposes. As a whole, at Irbene not only fully-steerable parabolic antennas, 32m and 16m in diameter (RT-32 and RT-16, respectively) are located but also a campus with well-developed infrastructure [1, 2].

Currently, the RT-32 radio telescope is fully operational and is used for astronomical measurements within diversified international projects. In order to fully utilize the potential capabilities of antenna for the work in international observational networks it is planned to perform complete renovation of the structure. The renovation will include changes in the control, communication, steering, and power systems. However, the most thorough work should be done on the repair of structural elements of antenna, since the structural integrity and stability are crucial for the safe and accurate operation of the telescope. It is planned to replace the damaged structural elements (beams), renovate the beam joints and perform anti-corrosion/anti-thermal surface treatment (painting) of all steel elements. In order for the restoration work to be efficient (in terms of the overall results and resources) comprehensive information about the existing damage of the structure is required. Unfortunately, the assessment of the RT-32 technical state is hindered by the absence of any kind of proper documentation. Therefore, it was necessary to perform extensive experimental investigation of all structural elements of the antenna, and – based on the results – to compile its detailed description. This would include the information on each element of the structure (beams, trusses, bolts, etc.), as well as on assemblies and joints. One of the most important parts of this work was to map and classify different damage types for steel elements. Based on the results obtained, 3D digital models were created for further numerical analysis. The analysis allows prediction of the whole structure behaviour under different loading, such as gravitational loads (at different orientation of the antenna) and/or wind loads.

The current work describes the methodology and results of measuring the deformations of load carrying substructure of the antenna at different orientation (with respect to the ground) of its mirror. The complete mapping and classification of corrosive damage of the relevant RT-32 elements (steel beams, joints, etc.) are presented below, along with the preliminary results of the numerical analysis performed to estimate the antenna distortion resulting from its reorientation.

2. MAPPING OF DAMAGED ELEMENTS

The load currying substructure of the antenna contains a large number of individual beams. For the mapping of beam damage the whole substructure is divided into segments (total 16). A segment of the supporting substructure for the antenna mirror is shown schematically in Fig. 1*a*, while the base substructure – in Fig. 1*b*.



(a) (b)

Fig.1. Segment of the mirror supporting structure (a) and base substructure (*b*).

The damage detected in the structure can be classified in the following way:

1. Corrosion of small/medium beams near the holes for water evacuation (Fig. 2).
2. Splitting of large/medium beams, most likely caused by internal ice pressure (Fig. 3). This type of damage is most often observed at the ends of beams.
3. Corrosion in the areas adjacent to the joints of multiple beams (Fig. 4).

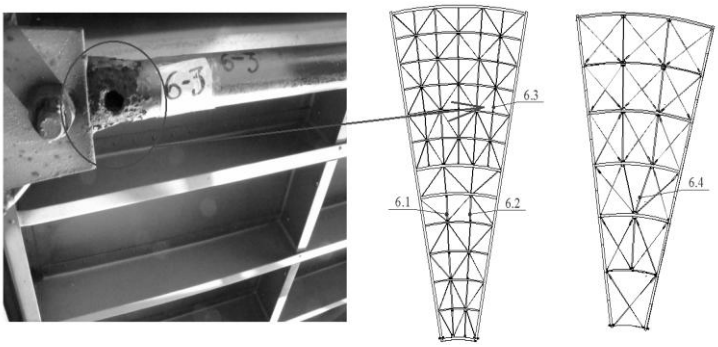


Fig. 2. Corrosion of small/medium beams near the holes for water evacuation.

Fig. 3. Splitting of a large/medium beam.

Fig.4. Corrosion in the areas adjacent to the joints of multiple beams.

The results of the complete mapping of damage show that most of the corrosion in the structural elements has formed around the holes that were drilled in order to evacuate the water accumulated in the hollow pipes (beams). The water in pipes most likely accumulated due to condensation but also due to precipitation (rain, snow etc.) which penetrated pipes through microcracks and other defects. The hole drilling in the original structure was performed by the former owners of telescope (Soviet Army). When analyzing the location of holes we revealed that – in general – the drilling had not been done in the optimal places of beams, and many holes are located above the bottom of pipes thus forming cavities from which water could not escape. Moreover, in some dish segments the holes in the beams were drilled in the upper rather than bottom part of the structure, which means that water was rather accumulated than evacuated. This undoubtedly caused much more rapid damage initiation and spread of corrosion over a considerably larger area. It should also be noted that – perhaps – after the drilling the freshly exposed metal was not treated (coated) in any way, thus creating the points for corrosion initiation.

The supporting substructure for the mirror consists of 6886 elements (beams). Analysis of this substructure has shown that 183 elements are severely damaged and have to be replaced in the nearest future. The majority of damaged beams (~75%) are located in the upper part of the structure, with the highest level of damage in segments 13, 14, which are located in the upper right quarter (see Table 1 and Fig. 1). The cause of such uneven distribution of damage can be attributed to the poor choice of location for the holes to evacuate water, as mentioned above.

Table 1

Damage and its distribution in the antenna supporting structure

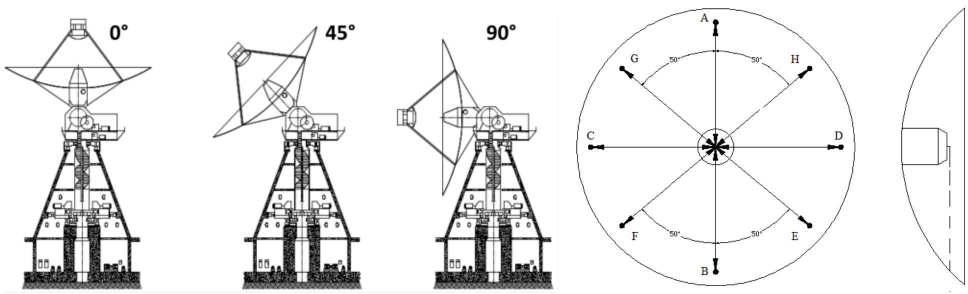
Segment Nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total damage	13	12	3	3	8	4	4	6
***U/B/M (%)**	69/31/0	84/8/8	100/0/0	100/0/0	62/13/25	75/25/0	75/0/25	83/17/0
Segment Nr.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Total damage	13	17	13	13	39	21	8	8
***U/B/M (%)**	84/8/8	88/0/12	70/15/15	69/23/8	95/5/0	95/5/0	50/0/50	75/13/12

*Damage (%) in upper/bottom/middle parts of the mirror supporting structure

3. DEFORMATION MEASUREMENTS: THE ANTENNA SURFACE

All measurements of dimensional changes were taken using a laser distance sensor Leica DISTOTM A5.

The relative changes in the dimensions of antenna surface were estimated based on the results of measurements at the chosen points on the middle cone of the dish to its edge on the circumference. These points are always the same for different orientations of the antenna. This so-called “apparent radius” was measured for three orientations (0°, 45° and 90°) of the antenna (Fig. 5*a*) and for eight different locations on the dish (Fig. 5*b*). For each of these points the antenna was balanced and levelled (see Fig. 5*b*) separately for every measurement in order to minimize error. For each point, multiple measurements (six to ten repetitions) were made. The average values along with standard deviations are presented in Table 2, where also the real values (in mm) of the apparent radius and relative changes (in %) at reorientation are given.



(a) (b)

Fig. 5. Different RT-32 antenna orientations (*a*); locations on the dish circumference where measurements of “apparent” radius were made (*b*).

Table 2

Averages of multiple measurements for each point on the dish edge

Antenna orientation	Distance from center at different locations (mm)							
	0° (B)	50° (F)	90° (C)	130° (G)	180° (A)	230° (H)	270° (D)	310° (E)
0°	15053	15047	15008	14948	14908	14913	14956	14998
St. Dev.	1	3	1	2	1	2	2	6
45°	15063	15054	15008	14937	14896	14902	14954	15003
St. Dev.	1	2	1	1	2	1	2	5
90°	15061	15053	15004	14931	14892	14893	14950	15003
St. Dev.	1	2	1	1	2	1	1	2
Wind speed	5.8 m/s	5.8 m/s	6.2 m/s	5.9 m/s	5.7 m/s	5.7 m/s	5.9 m/s	5.7 m/s

Antenna orientation	Changes of distance (in % with respect to 0° orientation)							
	0° (B)	50° (F)	90° (C)	130° (G)	180° (A)	230° (H)	270° (D)	310° (E)
45°	0.066	0.052	-0.002	-0.075	-0.080	-0.075	-0.014	0.029
90°	0.054	0.044	-0.023	-0.117	-0.106	-0.131	-0.040	0.028

Antenna orientation	Changes of distance (in % with respect to 45° orientation)							
	0° (B)	50° (F)	90° (C)	130° (G)	180° (A)	230° (H)	270° (D)	310° (E)
90°	-0.012	-0.008	-0.021	-0.042	-0.027	-0.056	-0.026	-0.001

The results tabulated above show that the results obtained at measuring the apparent radius are stable and reproducible, with the maximum standard deviation of only ~0.01% from the average measured value. The relative changes in the dimensions of the antenna circumference are very small (the maximum change less than ±0.1% except couple points), depending on the location on the dish perimeter. Even though the relative changes seem to be very small, in actual numbers this corresponds to the dimensional changes of 10…20 mm. Considering the operational wavelength spectrum of the antenna [3], it is yet to be evaluated if such variations in the dish geometry can compromise the accuracy of the astronomical measurements to be carried out in the future.

It also should be noted that larger dimensional variations of the telescope are observed when antenna is reoriented from 0° to 45° or 90° than when the orientation is in the range from 45° to 90°, which was somewhat expected. On the other hand, the relative changes of dimensions when the antenna is reoriented from 0° to 45° or from 0° to 90° do not differ much (there might be only a minor difference – probably within the accuracy of measuring device in the experiments).

4. DEFORMATION MEASUREMENTS: THE BASE STRUCTURE

The geometrical changes of the substructure (schematically shown in Fig. 1*b*) were also measured at different antenna orientations – in the same manner as for the mirror supporting structure, see Fig. 5*a*. Two parameters were measured: 1) length, *S*, of the side of the octagon around the base substructure (see Fig. 1*b*); 2) “apparent” diagonal of the octagon, *R* (i.e. distance from a side of the central cone to the corresponding corner of the octagon, as shown in Fig. 1*b*). Also in this case, the measurements at different orientations of the antenna were made between the same points chosen on the base substructure. Multiple (three to five) measurements for each point were performed in order to minimize error.

For comparison purposes, one average value is calculated by pooling together all measurements. This is done separately for the side length and the diagonal length. The deviation (in %) from the average value was computed for each measurement. The results are presented in Table 3 and Table 4 for the side length and the diagonal length, respectively. Once again, it can be inferred that the relative changes of dimensions due to reorientation of the antenna from 0° to 45° or 90° are fairly small (not to be confused with the deviation from the average values): a) approx. ±0.005% for the side length; b) approx. ±0.02% for the diagonal length. In the absolute values it is about 0.4 mm and 2 mm for the side and the diagonal length, respectively.

It should be noted that these values are much lower than those obtained for the dimensional changes of the mirror supporting substructure. This might indicate that even though the base substructure of antenna is rather rigid, structure under the dish is deforming itself, probably due to the presence of damaged structural elements described in Sect. 2.

Table 3

Deviations of side length, *S*, from the average values (in %)

	Deviation from the average value in (%)								Average in (m)
Orientation	*1→2*	*3→4*	*5→6*	*7→8*	*9→10*	*11→12*	*13→14*	*15→16*	
0	0.002	0.015	-0.024	-0.037	0.015	0.054	0.002	-0.024	**7.704 ± 0.002**
45	0.008	0.008	-0.005	-0.044	0.008	0.060	-0.005	-0.031	**7.704 ± 0.002**
90	0.000	0.013	-0.013	-0.065	0.013	0.065	0.000	-0.013	**7.704 ± 0.003**

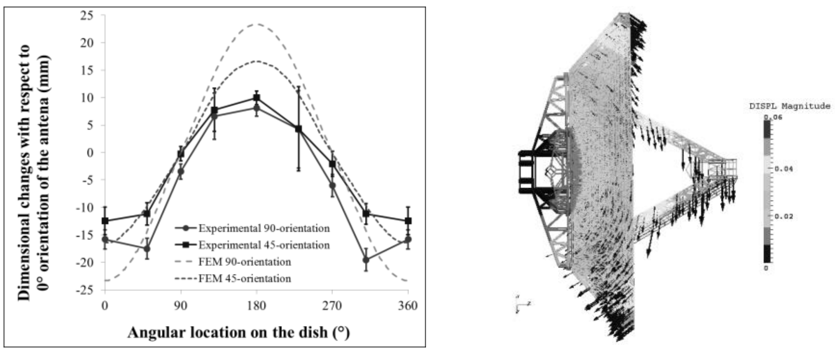
Table 4

Deviations of octagon "diagonal" length, *R*, from the average values (in %).

	Deviation from the average value in (%)								Average in (m)
Orientation	*R1*	*R3*	*R5*	*R7*	*R9*	*R11*	*R13*	*R15*	
0	0.095	-0.088	-0.200	-0.088	-0.098	0.095	0.177	0.106	**9.827 ± 0.013**
45	0.100	-0.093	-0.215	-0.093	-0.103	0.100	0.182	0.121	**9.827 ± 0.014**
90	0.095	-0.098	-0.200	-0.098	-0.108	0.095	0.187	0.126	**9.826 ± 0.014**

5. FEM SIMULATION

The numerical simulation using the finite element method (FEM) was performed in order to estimate the maximum theoretical values for the deflection of structural elements due to reorientation of antenna and for qualitative verification of the experimental measurements. These data are given here for the indicative purposes only; thus, neither the calculation methodology nor the results are discussed in great detail.



(a) (b)

Fig. 6. Results of FEM calculation: the displacement on the circumference of the dish (*a*); overall distribution of the whole antenna's displacements (*b*).

The numerical simulation results for undamaged antenna are presented in Fig. 6 as the displacement on the dish circumference (Fig. 6*a*), and the overall distribution of displacements for the whole antenna structure (Fig. 6*b*). These results fit fairly well the experimental measurements – the total maximum displacement is in the order of 15…25 mm.

Comparison of the FEM results for displacements along the circumference of the dish at the antenna 0°-orientation with and without damage is shown in Fig. 7.

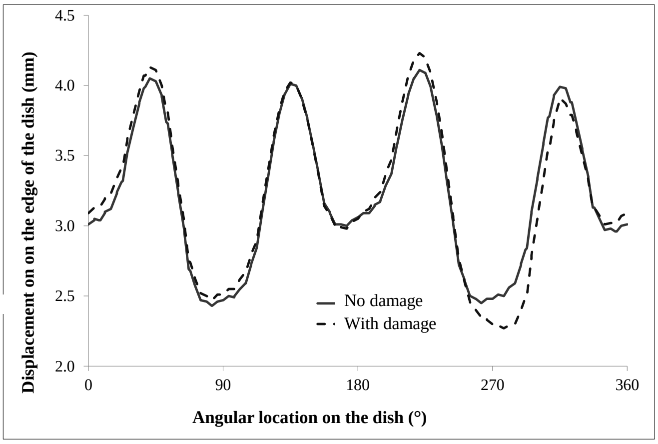


Fig. 7. Results of FEM calculation: the displacement on dish circumference for the antenna with and without damage.

6. RESULTS AND DISCUSSION

The results obtained from the numerical analysis are in line (the same order of magnitude) with the data obtained in the FEM analysis of a similar antenna (RT-70, see [4]). These data show that the maximum displacement of the RT-70 main reflector is 12 mm at the zero angle of antenna orientation and 38.6 mm at its horizontal orientation.

The results presented in Fig. 7 show the total displacement within 2.5… 4 mm; there is no significant difference between the displacements of antenna edges in the cases with and without damage. The largest differences are observed around point D (270°) on the dish (Fig. 5*b*), which corresponds to sectors 13 and 14 of the antenna (see Fig. 1). As the results presented above (Table 1) show, these sectors had the largest number of damaged elements.

The extensive experimental study of the damage in structural elements of the RT-32 radio telescope has revealed that out of the total 6886 elements in the mirror supporting substructure 183 are significantly damaged by corrosion.

Three typical types of damage were identified:

1) corrosion of small/medium beams near the holes for water evacuation;
2) splitting of large/medium beams, most likely caused by internal ice pressure (this type of damage is most often observed at the ends of beams);
3) corrosion in the areas adjacent to the joints of multiple beams.

The most probable cause for the initiation and spread of corrosion is poor choice of places for drilling the holes in pipes to evacuate water from the structural elements. Due to incorrect placement of the holes the water was entrapped in the hollow beams thus causing premature corrosion of metal. Most likely, this is also the reason why the damage is not distributed evenly across the mirror supporting substructure – in some segments of the dish upper part the damage is much more spread than in bottom segments. Even if most of the damaged elements do not pose immediate threat for the structural integrity of the antenna, the severely damaged beams and joints have to be replaced as soon as possible to ensure safe and precise operation of the telescope.

The dimensional changes of the antenna were measured at its different orientations with respect to the ground. Three orientations were considered: 0°, 45° and 90°. The measurements were done for the mirror supporting structure and also for the base substructure of the whole telescope. In all cases, the relative changes turned out to be fairly small – in the order of 0.1% for the structure under the mirror and 0.005–0.02% for the base substructure. However, the real dimensional changes are ~10…20 mm in the former case and only few millimetres in the latter. This indicates that the telescope base substructure is rather rigid and deforms very little, whereas the dimensional changes of the substructure under the dish are much more significant. This is most likely due to the presence of damaged structural elements in the mirror supporting substructure.

The results of numerical simulation fit fairly well those obtained in experimental measurements, according to which the maximum displacement of antenna dish is in the order of 15…25 mm. It should be noted that these changes were predicted for undamaged parts of the antenna, which might imply that this level of dimensional changes were built into the original design and accounted for the accuracy of antenna operation (some kind of self-compensating mechanism). However, considering the operational wavelength of the antenna it should be estimated whether such variations of the dish geometry might compromise the precision of astronomical measurements for the RT-32 radio telescope.

7. CONCLUSIONS

Since the FEM model is developed using only direct measurements for the antenna (without any technical documentation), the results of simulation could be considered quite reasonable. The accuracy of modelling can still be improved if more detailed information is available (e.g. on the wall thicknesses of pipes or/and the internal design of some isolated structures).

The analysis of displacements on the dish edge calculated by FEM for the antenna oriented vertically up (0°-orientation) has shown that the influence of damaged elements on the total displacement is only minor (practically negligible), except for the highly damaged areas (sectors 13 and 14).

ACKNOWLEDGEMENT

This research was supported by the European Social Fund (project No. 2009/0231/1DP/1.1.1.2.0/09/APIA/VIAA/151).

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RADIOTELEESKOPA RT-32 DEFORMĀCIJAS UN BOJĀJUMU NOVĒRTĒJUMS

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K o p s a v i l k u m s

Aprakstītais darbs ir saistīts ar lielākā Inženierzinātņu institūta ”Ventspils Starptautiskais Radioastronomijas Centrs” rīcībā esošā radioteleskopa RT-32 antenas metāla konstrukcijas izpēti. Uzskaitīti 183 bojājumi, kuri lielākoties atrodami antenas režģojuma virsējā daļā. Bojājumu galvenais rašanās cēlonis ir korozija, kā arī kļūdaini izurbtās vietas kondensāta izvadīšanai.

Papildus tika veikti antenas nesošā režģa un pamatkonstrukcijas deformācijas pētījumi pie trim dažādiem savērsuma stāvokļiem. Iegūtie rezultāti parādīja, ka virsējās konstrukcijas deformācijas izmaiņas ir ~0.1%, savukārt balsta konstrukcijas izmaiņas sasniedza 0.01%.

Virsējā režģojuma palielinātās novirzes iespējamais cēlonis ir režģa bojātie elementi, kur lielākās novirzes tika konstatētas tieši visvairāk bojāto segmentu robežās.

Deformāciju modelēšanai tika izveidots RT-32 galīgo elementu modelis un veikti vairāki aprēķini. Iegūtie aprēķinu rezultāti tika salīdzināti ar mērījumu datiem un līdzīga teleskopa RT-70 galīgo elementu modeļa aprēķiniem.