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THE THERMAL BEHAVIOUR AND THERMAL CONTROL OF RADIO TELESCOPES

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ABSTRACT

In steerable, and especially in high precision radio telescopes it is necessary to keep the temperature induced deformations at a comparable, or even lower, level than gravity induced deformations to guarantee good observational performance. It is therefore necessary, and possible, to make during the design phase exploratory Dynamic Thermal Model calculations which predict with good accuracy the expected thermal behaviour of the telescope, and which define the thermal lay–out of the construction. On existing telescopes, the temperature distribution monitored at 100 – 200 thermally important points used in a Finite Element Analysis can produce realistic values for real–time correction of temperature induced focus, pointing, and beam shape errors.

INTRODUCTION

The performance and operation of radio telescopes, and in particular of high precision radio telescopes for observations at mm/submm–wavelengths (100 – 600 GHz), is affected by gravity, temperature, and wind induced structural deformations. While gravity induced deformations are fully predictable from Finite Element (FE) calculations [1,2], at present this is to a lesser extent the case for temperature induced deformations, and hardly the case for rapidly changing wind and gust induced deformations [3,4]. Temperature induced deformations can be of the same scale as gravity induced deformations, unless special precautions are being taken. The evaluation of temperature induced deformations comes up during the design of a radio telescope, and later during its operation and improvement. For studies during the design phase significant progress has been made in the prediction of the thermal behaviour of a radio telescope from Dynamic Thermal Model (DTM) calculations which evaluate the telescope in its pojected thermal environment. For existing telescopes similarly significant progress has been made in actual temperature monitoring of telescope structures and feed–back of this information for focus and pointing control, but also for radiometric corrections (beam shape, gain) of astronomical observations. We explain how thermal effects can be handled during the design phase and how they can be measured and controlled during operation of a radio telescope. We give references of DTM calculations and temperature monitoring of radio telescopes in operation.

THE DESIGN PHASE

During the design of a radio telescope the questions to be answered concerning temperature effects are, for instance: (1) does the telescope fulfill the focus, pointing, and beam shape specifications[1] under the influence of the thermal environment in which the telescope will reside, which may be at sea level (cm wavelength telescopes), at a high altitude site (mm/submm wavelength telescopes), or in space (submm/far–IR wavelength telescopes); (2) can the telescope be built in conventional way from steel and aluminum or are low thermal expansion materials (CFRP) required; (3) is elaborate passive thermal control (paint, insulation, radiation shields) and/or active thermal control (ventilation, climatization) necessary ?, etc. The answers to these questions impose specifications on the construction, like white or shiny paint at the outside, thickness of insulation, volume of ventilated air, heating and cooling facilities of the telescope structure or of the radome/astrodome, etc.

During the design of a telescope – either an open–air telescope or a radome/astrodome enclosed telescope – the expected thermal behaviour can be studied from DTM calculations [5,6,7] in which the telescope structure is subjected to a realistic simulation of the influence from the time–variable thermal environment into which the telescope is to be placed. Basic knowledge of the thermal environment (air temperature, wind speed, solar irradiation, sky transparency etc.) is obtained from meteorological services or actual site tests. The DTM

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[1] With D the diameter of the telescope and λ the wavelength of observation, the focus F should be stable within $\Delta F \leq (1/10)\,\lambda$, the beam width θ stable within $\Delta\theta \leq (1/10)\,\theta \approx (1/10)\,\lambda/D$, the reflector surface precision σ within $\sigma \leq (1/15)\,\lambda$.

calculations consider heat exchange between the telescope structure and the environment through convection by ambient air and wind, through variable solar illumination, and through radiative coupling towards the cool sky and the warm ground. The heat exchange is governed by well–known physical relations to be found in textbooks on Heat Transfer [8,9]. These relations include natural convection and forced ventilation. In the DTM calculations the telescope structure is divided into a large number (say, $N \approx 300$) significant thermal components which are connected to each other by conduction, convection, and radiation. The resulting $\sim (3-6)\,N$ coupled differential equations are solved by a network analysis program [10] which gives the temperatures $T_i(t)$ of the components $[i = 1,...,N]$ as function of time (t) and thermal state of the environment. The temperatures $T_i(t)$ can then be used in a FE calculation to derive the temperature induced deformations. DTM calculations of the air and the telescope inside a ventilated radome (Onsala & Haystack telescope) and a model astrodome are found in [11]; calculations of this type were for instance used to model a radome–enclosed 50–m LMT. DTM calculations of the thermal behaviour of the actively controlled IRAM 30–m telescope are found in [6,7]; calculations of this type were for instance used to model a ventilated 64–m SRT .

To summarize, we are able to say that today it is no longer necessary to base the thermal design of a cm or mm–wavelength radio telescope exclusively on the analysis of static thermal load cases (T–gradients, rms–T distributions, etc.), as usually done so far. The availability of powerful network analysis programs allows a sufficiently detailed structural sub–division (components) of the telescope structure and a sufficiently precise dynamic analysis of its thermal behaviour (see the examples mentioned above) for a realistic simulation of the time–variable thermal environment. Such DTM calculations are especially important in case an active thermal control system (ventilation, climatization) must be evaluated [6].

THE OPERATIONAL TELESCOPE

DTM calculations made during the design provide a good initial understanding of the expected thermal behaviour of a radio telescope under construction. Several DTM calculations of *existing* telescopes and radomes, and comparison with actually measured temperatures, have shown [6,7,11] that the prediction of the component temperatures $T_i(t)$ can be made with high precision, i.e., dependent of the detail of sub–division of the telescope structure (large N) and detail of the thermal environment, of the order of $2-3^{\circ}$ C. However, despite of this agreement, but probably because of lack of general experience, real–time prediction and correction of telecope performance (focus, pointing, reflector surface etc.) from DTM calculations using as input the actual thermal state of the environment have not yet been made. The feasibility of DTM calculations does therefore not eliminate, at present, the necessity of temperature measurements of a (high precision) telescope structure, either for pure verification of the earlier predictions or for evaluation of the actual thermal state.

While temperature monitoring at $5-20$ points of a telescope structure and subsequent use of the data for telescope control has been applied since some time [6,12], the relatively low expense allows today the installation of some 100 to 200 temperature sensors on a telescope structure and mointoring of the temperature distribution on a short time scale of ~ 5 minutes, as for instance applied on the IRAM 30–m telescope and the Nobeyama 10–m telescope. Significant progress has therefore been made in the actual measurement, monitoring, and also understanding of the time–variable thermal state of large and complex telescope structures (weight: 100 to 300 ton; telescope components: alidade or fork, reflector backup structure, panels, subreflector supports etc.) using $100-200$ sensors located at *thermally important FE nodes.* The search of thermally important FE nodes, as well as the study of the adequacy of $100-200$ sensors, can be made by subjecting each FE node (or groups of nodes) to a thermal test load (say 1° C temperature difference of the node under investigation with respect to an otherwise thermally homogeneous structure) and inspection of the corresponding influence on the focus and pointing characteristics and/or the reflector surface shape (beam shape). Applying this FE–supported search to the IRAM 30–m telescope, we have found that 50 sensors placed in the yoke ($\sim$ 180 ton), 100 sensors placed in the reflector backup structure ($\sim$ 100 ton), and 1 sensor per subreflector support, together with extrapolation of the measured temperatures to the FE nodes without sensor (ca. 6 % to 94 %), provide a realistic picture of the thermal state of the telescope [13] and realistic values of the temperature induced deformations. For this particular telescope we have verified the predictions based on the temperature measurements and FE calculations against measurements of focus and pointing corrections and the reflector surface shape (beam shape). The agreement is good; details of these exploratory studies are found in [14,15].

To summarize, we are able to say that temperature monitoring at 100 to 200 *thermally important* points allows the construction of a realistic picture of the time–variable thermal state of a radio telescope and of the asscociated temperature induced deformations. Such temperature measurements combined with FE calculations allow a real–time correction of focus and pointing errors and a real–time determination of radiometric corrections (beam shape, gain), which – as judged from experience – are required even on a telescope with sophisticated thermal control [6,7]. It is important to state that the search of points (nodes), where temperatures are to be measured, and the number of sensors, which give a reliable picture of the temperature distribution throughout the telescope (with extrapolation to FE nodes without sensor), can be made with good confidence from simulation studies using only a relatively simple FE model of the telescope.

PERSPECTIVE

To our knowledge, not many institutes/firms have yet applied DTM calculations for the design of a radio telescope and certainly not for real–time predictions using the actual state of the thermal environment, be it since for long wavelength (cm) telescopes the thermal question is of lower importance, be it that only a few large diameter high precision short wavelength telescopes have been built so far [the situation is more advanced for optical telescopes] . Nevertheless, having gained (and exchanged) more experience of the measured and calculated thermal behaviour of cm and mm–wavelength radio telescopes, we are confident that thermal questions can eventually be handled with comparable rigorosity as today gravity induced deformations can be handled. Using DTM calculations, it is possible to base the thermal concept of a radio telescope already during the design phase on a more realistic situation. It is, on the other hand, expected that temperature monitoring and subsequent finite element analysis will in the near future significantly contribute to the success of the new generation high precision telescopes, especially those for observation at mm–wavelengths.

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