Pressure measurements on the 76-meter Jodrell Bank radio telescope and a scaled down model in the wind tunnel

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ABSTRACT

ESO will measure pressure fluctuations on the surface of the 76 m radio telescope at Jodrell bank and on a scaled down model of this telescope in a wind tunnel. The data will be used to calculate the effect of pressure variations on the overall deformation of the mirror and in particular the effect on segment to segment misalignments taking into account the correction capabilities of the segment supports.
Keywords: ELT / Segmented mirror / Wind pressure

1. INTRODUCTION

The construction of co-rotating buildings for extremely large telescopes which could guarantee a sufficient protection from the wind would account for a large fraction of the budget. It would be much cheaper to use only a sliding cover and operate the telescope in open air. In that case extremely large optical telescopes will be affected by wind disturbances in several ways.

- Pointing and tracking by the large scale wind torques on the whole structure.
- Deformations of the structure generating misalignments of the optical components by large scale wind pressures. Here the optical components are regarded as undeformed rigid bodies.
- Deformations of the large segmented mirrors by large scale pressure variations over the area of the whole mirror causing deformations of the supporting cell structure.
- Differential rigid body movements of neighbouring segments caused by pressure variations with scales of the order of a segment.
- Deformations of individual segments due to small scale pressure variations.

Various components of the control system will attempt to correct these errors.

- *Tracking errors* : corrected by a fast steering mirror towards the end of the optical train at frequencies of several Hz.
- *Misalignments of the optical components* : corrected by repositioning the optical components at low frequencies of 0.1 Hz or less.
- *Differential rigid body movements of the segments* : corrected by fast rigid body movements generated by the segment actuators based on signals from position sensors at the intersegment edges collected at frequencies of up to approximately 3 Hz.
- *Deformations of the segments* : detected at high frequencies partially by position sensors at the intersegment edges but corrections of the segments at frequencies larger than 3 Hz are not foreseen.

Since the bandpasses and ranges of the corrections are limited one needs to know the amplitudes of the errors generated by the wind. The most important parameters to be retrieved from the data of the pressure variations are the power spectra and the correlation functions where the filtering effects

due to the correction loops have to be taken into account.
In an undisturbed boundary layer the pressure variations are well known. They can be described on the basis of the standard von Karman spectrum and the Taylor hypothesis. But in the vicinity of a large telescope structure and on the optical surfaces little is known about the spatial and temporal spectra of the pressures. The pressure field will depend strongly on the orientation of the telescope with respect to the wind direction, the zenith distance of the pointing, and the location on the mirror. One may have the following areas :

- When the telescope is pointing into the wind the characteristics of the incoming wind are not significantly modified on the telescope surface. The power spectra and correlations of the pressure fields should therefore be similar to the ones in the boundary layer.
- When the telescope is pointing away from the wind or towards the zenith there will be recirculation zones at the edges of the mirror with different power spectra and correlation functions.
- Parts of the mirror will be obstructed by the structure supporting the secondary mirror. In some telescopes this structure is a truss sructure and the turbulence behind it may have the characteristics of grid turbulence with an integral length of the order of the grid size.

Computer simulations can give information about time averaged pressure fields but are not capable to reach the interesting regime of small scale and high frequency fluctuations. Wind tunnel tests have to cope with the large reduction factors of up to 100 coming from the maximum proposed size of 100 m for the telescope and a possible size of the order of 1 m in the wind tunnel. The ideal solution is therefore a full scale measurement at existing large radio telescopes like the 76 meter telescope at Jodrell Bank shown in figure 1 on the left hand side. Measurements with a scaled down model of this telescope in the wind tunnel can give valuable information about the scalability of such pressure measurements. ESO will therefore conduct such a measuring campaign within the next year.

2. SPECIFICATIONS FOR THE MEASUREMENTS AT THE RADIO TELESCOPE

The major requirements for the pressure measurements on the radio telescope are :

- Possibility to measure the pressure distribution over the whole mirror and also on smaller spatial scales.
- Sampling rate significantly higher than the envisaged correction rate of the segment alignment of 3 Hz.

To measure the overall pressure distribution 160 pressure sensors are distributed over the mirror as shown in figure 1 on the right hand side. They are located in the gaps between the panels of the reflector. To avoid any disturbing influence of the gaps, which are on average a few millimeters wide, on the measurements, they will be bridged around the pressure sensors. In addition, 40 sensors will be distributed over the smaller shaded areas in figure 1 to measure pressure variations over a smaller scale. The sampling rate will be at least 50 Hz.
The 76 m radio telescope at Jodrell Bank is an ideal candidate for such measurements.

- It is located on a plane which guarantees that for most of the time the incoming wind in the turbulent boundary layer has reasonably well known characteristics. To measure the wind speed and its orientation and to check the power spectrum an ultrasonic anenometer will be installed on a mast at a height of 20 m ?? above the ground at a location where the wind flow is not affected by the telescope or other buildings.

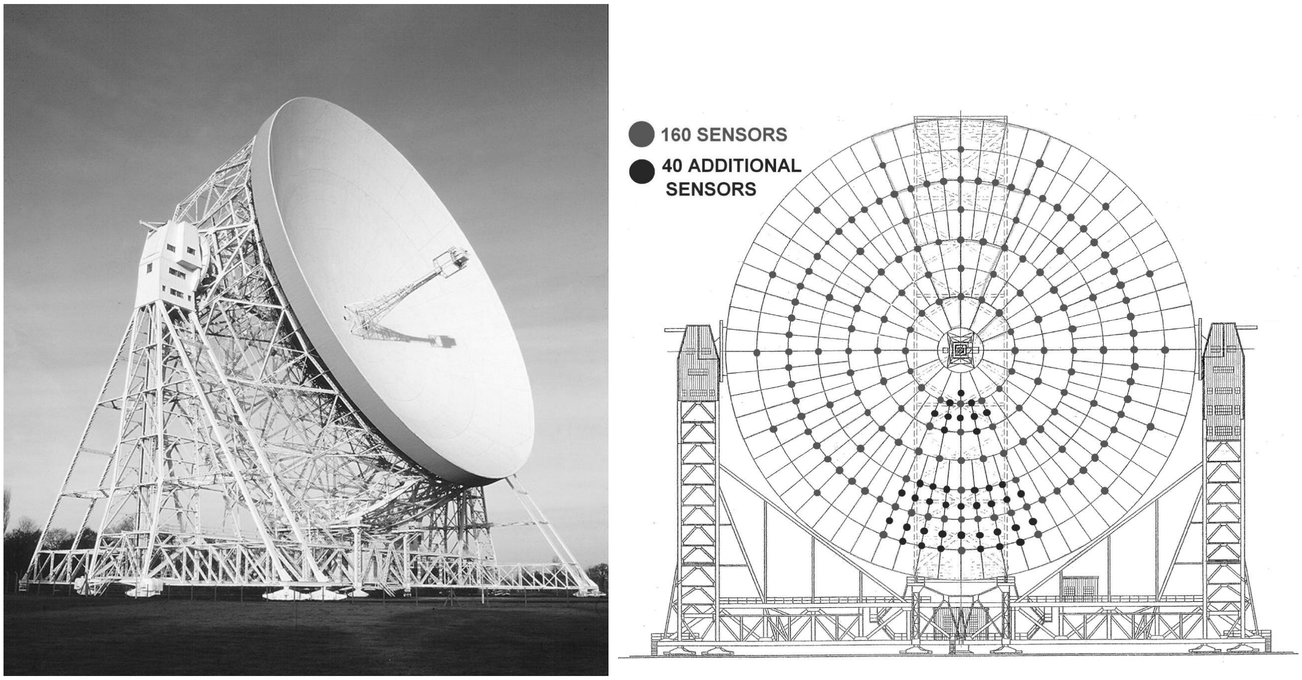

Figure 1: 76 meter Lovell Radio Telescope at Jodrell Bank and the distribution of the sensors on the front surface of the reflector.

- The front surface is not, at least when the telescope is pointing into the wind, obstructed by parts of the telescope structure or other infrastructure in front of it.
- Above the original reflecting surface a new one has been installed. The two surfaces form a cavity with an average height of two meters. This greatly simplifies the installation of the cabling and the sensors.

To have sufficient energy at high frequencies the measurements may have to be done at high wind speed conditions.
At a height of approximately 50 m above the ground and a wind speed of 10 m/s the corner frequency of von Karman power spectrum is approximately 0.02 Hz. With a sampling rate of at least 50 Hz and therefore detected frequencies of up to 10 Hz one gets well into the inertial regime.
We are very grateful to the staff at Jodrell Bank who permitted us to perform these measurements at their telescope and have been given us a lot of assistance. The sensors are designed and will be installed by the firm PSP Technologien im Bauwesen in Aachen.

3. SPECIFICATIONS FOR THE MEASUREMENTS IN THE WIND TUNNEL

The wind speed will be approximately the same as in the full scale measurements. The integral length will be of the order of 1 m and therefore about 100 times smaller than in the full scale measurements. Therefore also the Reynolds number will be 100 times smaller. To keep at least the other important dimensionless parameter, the Strouhal number, at the same value as in the full scale measurements the highest detectable frequencies should be 100 times higher than the highest detectable frequencies in the full scale measurements. They should therefore be of the order of 1000 Hz. With standard equipment one can reach sampling rates of a few kiloHertz. Preliminary measurements in wind tunnels have shown that one can measure the power spectra of the velocities and of the pressures in a free boundary flow in a wind tunnel, which follow the expected laws in the inertial regime, up to frequencies of approximately 1500 Hz. Fluctuations of pressures with frequencies up to 1500 Hz should therefore be detectable with sufficient accuracy.

The major problem are acoustic waves which are created by the wind generator in the tunnel. Fortunately they seem to have well defined peaks and can therefore be eliminated numerically during the processing of the data.

The major specifications for the wind tunnel tests are therefore :

- 1:70 scaled model of the radio telescope with the same distribution of pressure sensors.
- Accurate detection of fluctuations with frequencies up to 1500 Hz.

4. ANALYSIS OF THE DATA

The time series will have lengths of a few minutes. They will be measured for various angles between the axis of the mirror and the incoming wind. The following parameters will be calculated :

- Power spectral densities at all locations.
- Correlation functions between the pressures at all locations.
- Correlation functions based on filtered time series, where the high-bandpass filter describes the capability to correct aberrations at frequencies up to approximately 3 Hz.

Finally the results should give an answer to the question whether ELTs with segmented mirrors can be operated in open air. The results should furthermore be useful also for radio telescopes for the prediction of the deformation of the reflector under wind pressure.