DYNAMIC WIND EFFECTS ON LARGE TELESCOPES

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ABSTRACT

In an attempt to understand and correct wind-induced errors in the pointing and surface figure of large, high-precision telescopes, observatories have begun to measure the effects of dynamic wind loading. For example, there have been two pointing studies on the Nobeyama 45m radio telescope and a study on the Gemini South 8m Optical Telescope. Additional tests are planned on other telescopes. This paper provides a summary of some tests and results to date, and the implications for the design and operation of large radio telescopes. Additionally, some recommendations will be presented for future test programs.

INTRODUCTION

With new advances in active surfaces and thermal management, the primary remaining challenge in designing the next generation of large radio telescopes is the wind. Wind loading is a large enough effect to degrade both surface and pointing accuracy, at least at shorter wavelengths, and it is dynamic in nature. In the past, the effects of wind on radio telescopes have generally been calculated using assumed static pressure distributions. While the assumed distributions are approximate at best, this approach has allowed designers to show that a given telescope design should be able to operate up to the desired wind load. As existing telescopes are operated at shorter wavelengths, their accuracy requirements become more precise, lowering their operational wind speeds.

New, larger telescopes present additional problems. Not only are they intended for operation at shorter wavelengths, but they also have lower structural frequencies, resulting in potential dynamic response to the wind. The latter problem is compounded because the larger diameter reflector also presents a greater cross-section to the incident wind, resulting in higher loading. Thus, large telescopes are subjected to larger loads and have greater risk of dynamic excitation due to their lower resonant frequencies, yet they must still maintain high precision. The introduction of dynamic effects into the design problem increases uncertainty in the analysis. Higher-order effects become potentially significant, so the accuracy of the model is more important. However, even with a perfect finite element representation of the structure, the output predictions are only as good as the input loading assumptions. Since wind loading distributions and the interaction of the wind flow with the structure are complicated, the performance of the design becomes more difficult to predict accurately.

In an attempt to understand the wind loading, some observatories have begun to measure the effects of dynamic wind loading on their telescopes. In particular, there have been pointing studies on the Nobeyama 45m radio telescope [1,2], and a study on the Gemini South 8m Optical Telescope [3,4,5]. Other observatories plan to conduct similar tests.

The Nobeyama 45m test data provide insight into the on-sky pointing behavior of a large radio telescope. The unique feature of this data set is that it includes simultaneous information on structural motion and on-sky pointing. This combination allows determination of the structural modes that are affected most by the actual wind loading conditions. However, the light winds during the test and the lack of a controlled-input case (such as an impact test) make comparison of the data with finite element analysis (FEA) difficult.

Learning from the results obtained at the 45m, the tests at the 8m were designed to include an impact test and to vary more parameters. Additionally, the tests at the 8m benefitted from strong winds and the presence of a configurable dome, which allowed more control over the wind loading on the telescope. As a result, the data from the 8m is much more complete and could be used to produce a benchmark to compare FEA predictions with the actual performance of the telescope measured in the field. However, use of these data in design of a large radio telescope is more difficult because of the differences in size and basic structural design.

In the sections below, we review these two sets of tests and the results generated to date. Additionally, we discuss some future plans for data analysis and recommend new tests that would be useful.

TESTS AND RESULTS

Nobeyama Radio Observatory (NRO) 45m telescope

The NRO tests were funded by the Large Millimeter-wave Telescope (LMT) project in order to determine if the dynamic pointing variations were likely to be a problem. At the time, a laser-based structural measurement system tied to an optical telescope had been proposed for measuring the actual pointing of the LMT. Since such a device would only correct for slowly-varying errors, the project sought to understand the amplitude of the dynamic effects.

The NRO 45m was an ideal instrument for this test, because it has comparable collecting area and operates at high enough frequency to have a small beam. Two tests were conducted. In the first test, astronomical measurements were made on the limb of the moon. Pointing errors were estimated by comparing the results with a model of the response. Uncertainties in the model made it difficult to obtain reliable estimates of the amplitudes of the pointing errors, but a frequency domain analysis of the data revealed some features (e.g., 0.5–3 Hz) that could be due to structural vibration (Fig. 1). The primary limitations of this test were the difficulty of determining the actual pointing amplitudes and the inability of this testing approach to isolate the structural source of the pointing errors.

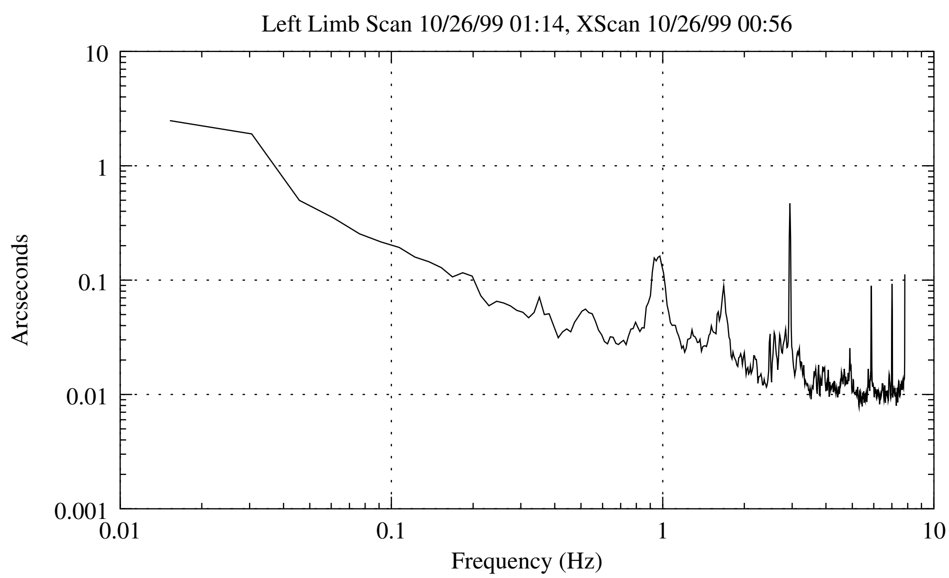

Fig. 1: Typical On-sky Pointing Error Spectrum

To address these limitations, we conducted a second series of tests at the NRO 45m. In this second test, we improved the observation method to measure the pointing error vs signal strength curve on the Moon directly, using constant rate cross scans. Additionally, we added more than 40 high-sensitivity accelerometers at various locations around the structure. These changes enabled simultaneous measurement of structural response and on-sky pointing errors. The results from this test indicated that the dominant errors have the structural shape of a rigid body motion of the structure. However, there some modes are excited that have forms not well modeled by a rigid body tilt. A typical result for the vibration of the primary reflector under windy conditions is shown in Fig. 2.

The most important limitation in this test was that there was never a windy condition during on-sky observation. That is, there is structural data for windy conditions and simultaneous structural and pointing data for calm conditions, but never a direct measurement of significant wind response of the telescope during observation.

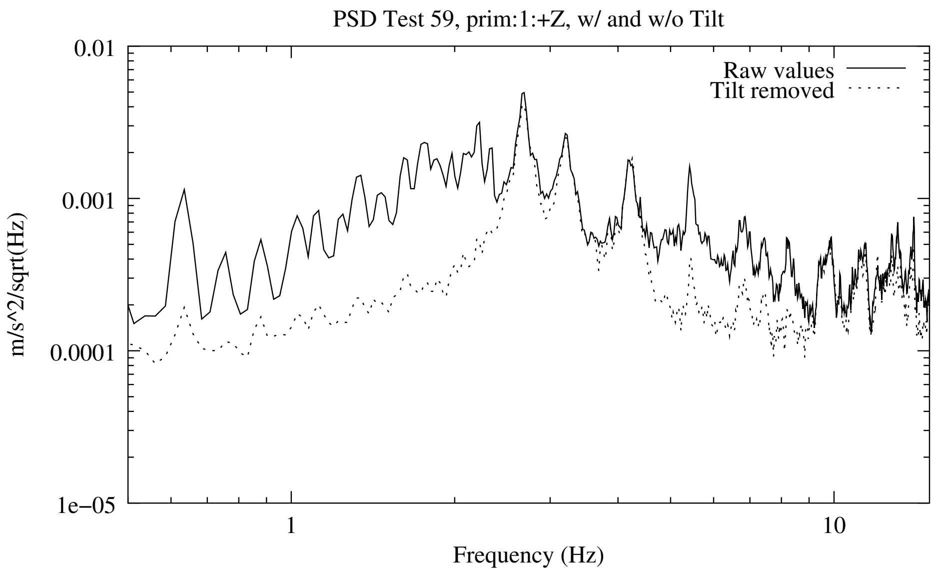

Fig. 2: Response of a Typical Accelerometer on the Primary in Windy Conditions

Gemini South 8m optical telescope testing

The original goal of the Gemini tests was to obtain a direct measurement of the pressure distribution on the 8m primary mirror cell under a variety of enclosure configurations. Additionally, the local wind conditions were monitored by five ultrasonic anemometers. The test was augmented by adding more than 70 high sensitivity accelerometers to the structure. The sensors were monitored simultaneously, allowing a more complete characterization of the system loading and response.

The Gemini South telescope was ideal for this test because it is a large, modern optical telescope with a detailed FE model. The telescope is located in an enclosure with large vent gates that can be opened independently, so it was possible to control the wind loading conditions on the structure. Finally, the telescope had reached the stage of its commissioning where it could be moved, but had not yet had the primary mirror installed. This was essential, because not only was more time available for performing the tests, but it was also straightforward to conduct a modal impact test on the structure. An impact test permits dynamic characterization of the real telescope instead of relying on the predicted values from the FE model.

During the wind testing, four major parameters were varied: the azimuth angle of attack to the wind, the telescope elevation angle, the position of the upwind vent gate, and the position of the downwind vent gate. Additionally, the test was designed using Design of Experiments (DOE) methods, which helped to minimize systematic errors in the results while expanding the coverage of the parameter space. For some of the tests, we were also able to use DOE to obtain an estimate of the total experimental error.

A typical result is shown in Fig. 3. This figure shows the pressure power spectral density at a particular location on the mirror (averaged over 16 tests), the error bars for the experiment, and the average values with the upwind vent gate open and closed. From the results, it is clear that the upwind vent gate, not surprisingly, has a substantial effect on the pressure loading of the primary mirror cell. A less intuitive result, which is not pictured here, is that the same analysis reveals no statistically significant effect on the pressure on the primary with change in elevation angle. It is also worth noting that an examination of the cross spectra indicate that only very close sensors have any statistically significant cross-correlation. This suggests that telescope modeling should use pressure distributions for the quasi-static loads, but that the dynamic loads may be better modeled by applying uncorrelated loads.

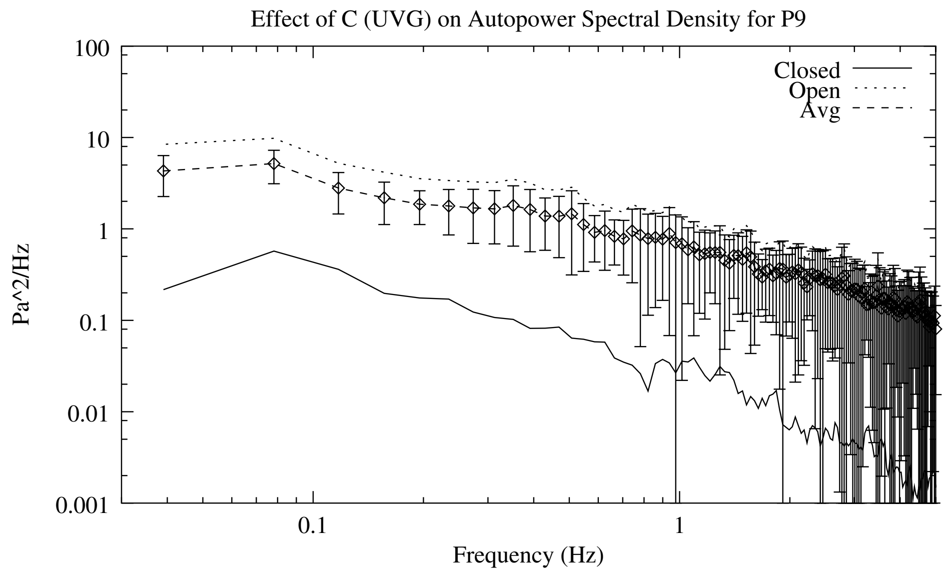

Fig. 2: Effects of the Upwind Vent Gate on a Typical Pressure Sensor

FUTURE ANALYSIS AND TESTING

In addition to future tests, there is still much that could be accomplished with the currently available data sets. Current work includes comparison of structural pointing predictions and on-sky results from the NRO 45m data, detailed structural analysis of the Gemini South data, and updating of the Gemini South FE model using the structural response and modal data.

From the standpoint of understanding wind response on telescopes, there are some telescopes that would be particularly interesting and useful to test. One of these is the LMT. Its large size and high precision make it a good candidate, and there has been much analysis on its wind response. Similarly, the GBT would be interesting to test, though its unusual design makes comparison with other antennas more difficult. A final example would be testing the prototype antennas for the Atacama Large Millimeter Array (ALMA). Since these high-frequency antennas will be tested in a variety of ways before being shipped to their high altitude site, they would be an excellent testbed for quantifying and perhaps even correcting for wind effects on antenna structures.

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