ANTENNA VIBRATION MEASUREMENTS WITH ACCELEROMETERS

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ABSTRACT

We have made experiments on a 10-m antenna with accelerometers and angle encoders under a windy condition to diagnose motions of antenna structure. Power spectrum densities of acceleration obtained with the two instruments were consistent in a frequency range from 1 Hz to 10 Hz, but have a large discrepancy below 1 Hz due to noise in the accelerometers. A comparison of displacements estimated from data in the same frequency band (> 1 Hz) shows a good correlation between them, suggesting that the major source of pointing errors is the drive controller rather than the antenna structure.

INTRODUCTION

The specifications imposed for recent submillimeter antennas of a 10/12-m size in the open air are demanding and challenging. For example, 12-m antennas for Atacama Large Millimeter/submillimeter Array (ALMA) have a surface accuracy of better than 25 μm and pointing/tracking accuracy of better than 0.6" under a wind velocity of 9 m s^{-1} [1] . They must also be able to slew to new position 1.5 degrees away and settle to within 3 arcsec in less than 1.5 sec to cope with phase errors caused by fluctuations in the atmosphere.

Reference [2] discussed frequency content of telescope pointing errors. Loads on antenna structure due to wind cause elastic deformations, which deteriorate antenna's pointing and surfaces accuracies. The structural behavior of the telescope is typically measured at the encoders of azimuth and elevation axes, while the critical performance is the actual pointing on the sky. We need to make direct measurements of vibration motion of the main-dish and subreflector with a resolution of typically 3 - 5 μm. Seismic accelerometers serve this purpose for a frequency range from 0.1 to 100 Hz. A laser metrology system can also serve for a frequency range < 1 Hz. The low frequency component (< 1 Hz) is presumably due to wind load, and the high frequency (> 1 Hz) due to modal oscillation induced by a servo controller.

We have made experiments on a 10-m antenna of NRO[*] [3] with accelerometers and angle encoders under a windy condition to demonstrate how we can diagnose motions of antenna structure. The angle encoders have a 25-bit resolution (LSB = 0.039") and were measured to have an accuracy of 0.03" rms [4]. The drive system of the antenna under no wind disturbance has been measured to have servo errors of typically 0.04" and 0.10" rms for rotational velocities < 0.001 deg s^{-1} and 0.1 – 0.001 deg s^{-1}, respectively. The telescope was located at a highland of 1350 m elevation.

MEASUREMENT SYSTEM

Fig. 1 shows our system that is composed of 12 sensors, signal conditioners, and a data acquisition system. There are three piezoelectric seismic sensors (PCB Model 393B12) at a subreflector mount chassis, four beneath a panel support board of the backup structure (BUS), normal to the surface, one at a reference point near the center of the BUS, and four capacitive accelerometers (PCB Model 3701G3) at yoke arm ends (horizontal directions, perpendicular and parallel to the elevation axis). These data sampled simultaneously are combined to figure out the oscillations of antenna global structure. For example, differences between pairs of sensors in the BUS tell us a tilt motion of the dish in the reflector axis. The system had a noise floor of 3 - 8 x 10^{-4} [m s^{-2} /root Hz] in the 0.1 to 1 Hz band and 2 x 10^{-4} [m s^{-2} /root Hz] in the frequency range from 1 to 20 Hz under a condition of no wind. Our 16-bit ADC has 16 single-ended input

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channels with a bipolar input range of ±5 Volt, and makes negligible contribution to the noise floor. Comparisons between Fourier spectra of the sensor outputs under windy and no-wind conditions suggest that the components below 0.7 Hz seem to be due to noise (poor stability) of the sensors and/or measurement system.

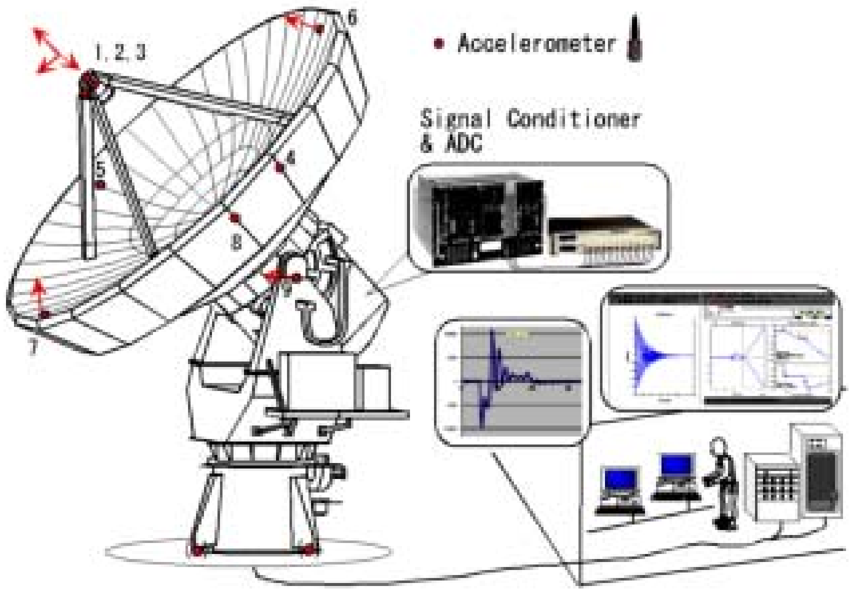

Figure 1. Antennas vibration measurement system with accelerometers

RESULTS AND DISCUSSION

Sensor outputs and angle encoder readouts were simultaneously recorded at a rate of 100 Hz, while the antenna was driven at a rotational speed of 10^{-5} deg s^{-1} and was pointed at various wind attack angles under a windy condition of typically 10 m s^{-2}. Fig. 2-a shows a sample of angle encoder readout data for which the pointing error sensed at the elevation axis was 0.21" rms. This large error is induced by wind load (0.04" rms under no wind). The Fourier spectrum of the position errors of the elevation angle has large amplitudes in frequency range from 0.2 to 2 Hz (Fig. 2-b). The spectrum shape is the combination of wind spectrum and drive control frequency response. The acceleration at the distance of the accelerometers from the elevation axis can be estimated from the second order differential of the angle error readouts if the antenna structure is rigid (Fig. 2-c).

Fig. 3-a displays the acceleration of tilt motion of the dish measured with two sensors (#6 and #7 in Fig. 1). A Fourier operation gives the frequency content of the acceleration (Fig. 3-b). We compare the two plots of power spectrum density obtained with the two instruments, the angle encoder (Fig. 2-c) and the accelerometer (Fig. 3-b). The two spectra seem to be consistent in a frequency range from 1 Hz to 10 Hz, but have a large discrepancy below 1 Hz. The components below 1 Hz seem to be noise (poor stability) of the sensors and/or measurement system. We can notice that there is a dip around 8 Hz in both figures, which is due to a filter effect of the antenna drive controller to reduce the oscillation of the 10-m antenna at the Eigenfrequency of about 8 Hz. We also see a peak near 5 Hz, which was unexpected, and for which we re-tuned the controller parameters later.

A Fourier spectrum of displacement can be obtained by division of individual acceleration components by its frequencies squared (ω^2) (Fig. 3-c). An inverse Fourier operation gives a time profile of antenna tilt (Fig. 3-d). Because the components below 0.7 Hz seem to be due to noise, we omitted the frequency components below 1 Hz of the accelerometer data. The pointing error in elevation of the main dish sensed with the accelerometers was 0.25" rms.

In order to compare the accelerometer and encoder data in the same frequency band, Fig. 2-d is obtained to estimate position errors, neglecting the lower frequency components <1 Hz of the encoder data in Fig. 2-c. A comparison of displacements thus obtained (Fig. 4) shows a good correlation between them for which residual errors from a diagonal line is 0.16" rms. This might suggest that the major source of pointing errors of the 10-m antenna under a windy condition is the drive controller rather than the antenna structure.

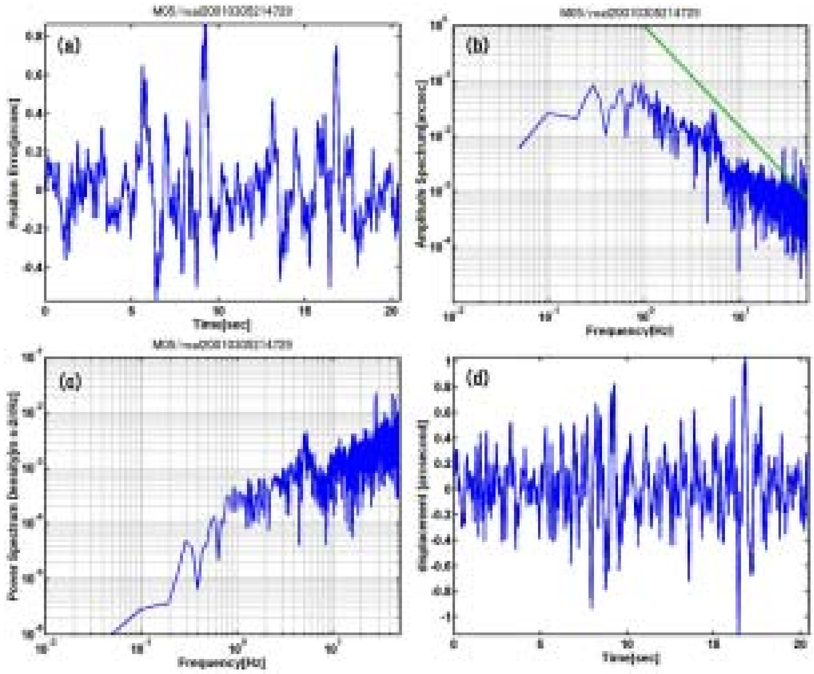

Figure 2. (Panel A): Position error readouts from the elevation encoder under a windy condition (about 10 m s^{-2}). (Panel B): A Fourier spectrum of the position error. The inclined line (green) shows the slope of the Davenport wind spectrum ($\alpha = -5/3$). (Panel C): A Fourier spectrum of the acceleration derived from the second order differential of the angle errors shown in Panel A. (Panel D): Estimated position errors derived from an inverse Fourier operation using components >1 Hz in Panel B, which can be compared with panel D in Fig. 3.

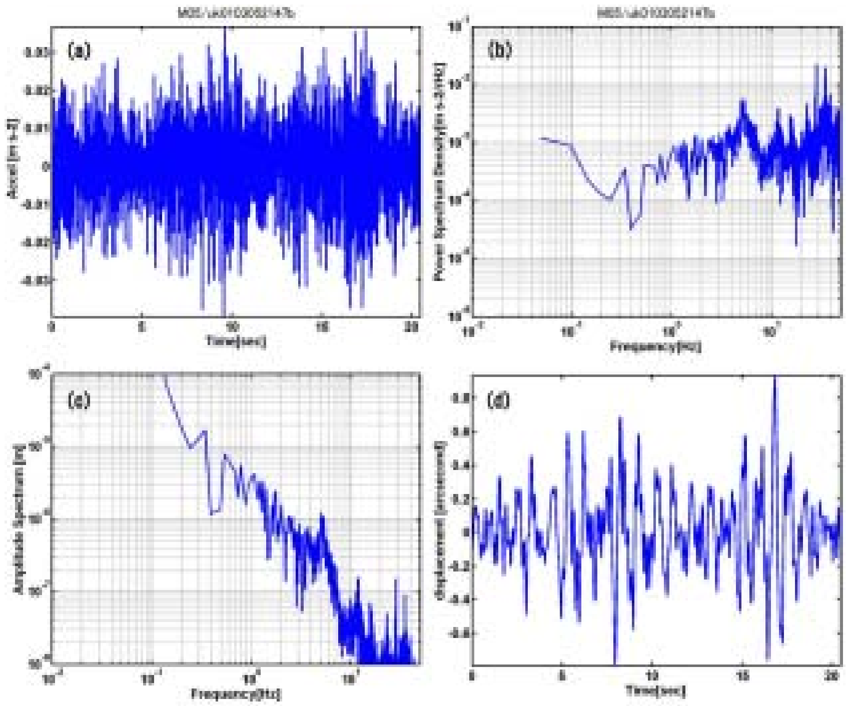

Figure 3. (Panel A): Difference of accelerations measured the two sensors mounted at the edge of the main dish (#6 and #7 in Fig. 1) which corresponds to tilt motion of the dish. (Panel B): A Fourier spectrum of the acceleration. (Panel C): A Fourier spectrum of the displacement, derived by dividing the acceleration by its frequencies squared (ω^2). (Panel D): Estimated position errors derived from an inverse Fourier operation using frequency components >1 Hz in panel C.

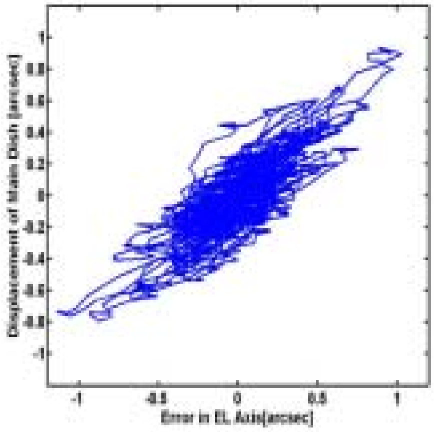

Figure 4. Correlation of displacements derived from the two methods

We have demonstrated the measurement technique of antenna motion with accelerometers. We were unable to make reliable measurements for the lower frequencies, 0.1 – 1 Hz with the 393B12 sensors. It is necessary to evaluate frequency content at this frequency band where the antenna oscillates at large amplitudes. We are able to make more sensitive and reliable measurements with sensors which have a lower noise floor, for example, PCB Model 393B31. Coordinated measurements both with accelerometers and laser metrology systems will help to make reliable comparisons.

ACKNOWLEDGMENTS

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