25-METER MILLIMETER TELESCOPE MEMO NO. 68

Telescope Measuring by Stepping

Notes by J. W. Findlay -- January 26, 1977

1. Introduction

We have just reported* that the tests of the Findlay/Payne cart method for measuring telescopes show that the method can, in fact, provide the necessary measurement accuracy for the 25-meter surface. We have suggested that the next steps in this area should wait until the time is right to build the final system to be used on the telescope. This point in time is perhaps two years from now.

We have outlined* the ways in which the 25-meter surface will be made and set. In particular, we expect individual panels to be measured at the fabricator's shop to a measurement accuracy of about 15 microns. Thus we may ask why do we need the cart method to set the panels on the telescope when all we need is to know the positions of points near the setting screws for each panel?

This question has led Payne and myself to think of an adaptation of the cart method which might be simpler and easier to use. Also, we suggest that it might be used to measure enough points on the 140-foot telescope to settle the questions which still remain unanswered about the individual 140 foot panel shapes.

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* At the 25 meter Working Group meeting on January 24, 1977 at Tucson. A written report is in preparation.

2. The Method in Outline

We propose to use a rigid bar of length L between two well-defined points where the bar touches the surface. (See Figure 1). We shall measure the angle θ that the normal to the bar makes with the gravity vertical. In Figure 1 the y-axis is parallel to the gravity vertical. When the bar ends rest on points (x_1,y_1), (x_2,y_2) then:-

$$x_2 - x_1 = L\cos\theta, \quad y_2 - y_1 = L\sin\theta \qquad \ldots\ldots (1)$$

The bar is stepped along a radius in the surface till the edge of the dish is reached. Since we may assume we have started at $x_1 = 0$ and $y_1 = 0$ the series of measurements of θ allows us to derive all the (x,y) values. The method is the familiar one of levelling in surveying.

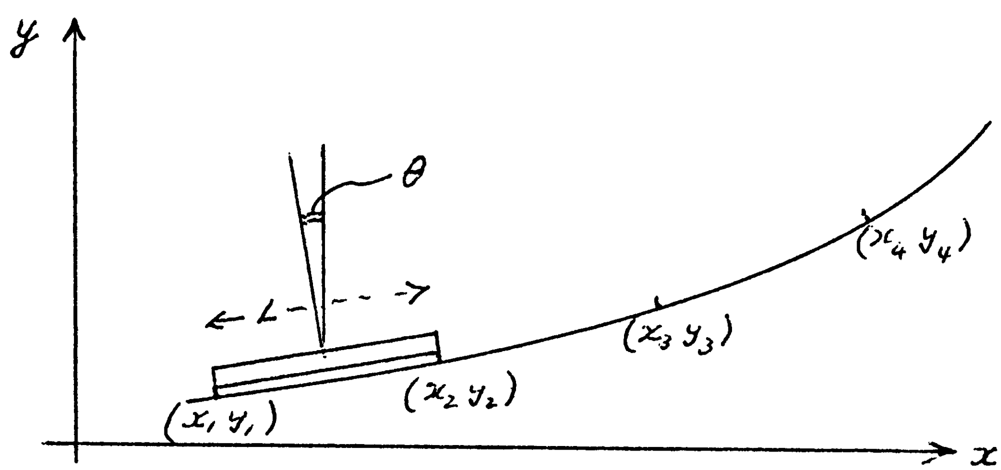


Figure 1

3. Accuracy

Let the errors in the values of L and θ be ΔL and $\Delta\theta$ respectively. The the errors in any increment of x (δx) and of y (δy) will be:-

$$\delta x = \Delta L \cos\theta - L \sin\theta . \Delta\theta$$
$$\delta y = \Delta L \sin\theta + L \cos\theta . \Delta\theta$$

These errors will be uncorrelated (in the absence of systematic errors, which we consider later), so that after N steps have been made we shall have accumulated errors of Δx and Δy given by:-

$$\left.\begin{array}{l} \Delta x \sim \sqrt{N} \times \delta x \\ \Delta y \sim \sqrt{N} \times \delta y \end{array}\right\} \qquad \ldots\ldots\ldots (2)$$

To give some numerical values, it seems quite reasonable that ΔL could be only a few microns. One maker of inclinometers, Schaevitz, makes instruments with the specifications given in Appendix 1. For the moment we suggest that $\Delta\theta$ might be 10^{-5} radians (2 arc seconds) and noting that N is roughly equal to the dish radius R divided by L we see that the error in y grows as L is made larger. The choice of L (or of N) will be made for practical reasons, and a value of N of about 25 is probably good enough for any dish on which this technique will be used. These rough estimates suggest that the edge errors in x will be about the same as those in y and both (for N = 25) will be 25 to 50 microns for a 25-meter diameter dish.

We believe we have overcome the much more serious problems of systematic errors in the method using the cart, and thus see no trouble in keeping such effects small in this technique, insofar as the errors in L are concerned. Both systematic and random errors in θ need further discussion.

The main systematic error in θ is likely to arise from movements of the dish with respect to gravity while a set of measurements are being made. However, if we define the axes of the measurement system to lie (for example) with two axes in a well defined flat surface at the dish vertex and the third normal to that surface, then the movement of the axes with respect to gravity can be continually monitored by two orthogonal inclinometers. We also note, as von Hoerner has shown, that under good conditions our 140-foot is well behaved in this respect, and that we are only concerned with the angular tilts which take place during a set of measurements along a single radius. We will not describe the data taking method in detail, but a single set of 25 readings would be taken and read into the computer in about 3 minutes, so that tilt stability should be achieved.

The random errors in θ can be assessed from Appendix 1. For the moment we assume that the full angular range of the inclinometer would be 30^{o} - a value correct for measuring the 140-foot. The hysteresis and resolution specification of 0.0001% of full scale suggests a repeatibility of 0.5×10^{-6} radian (0.1 arc second). The linearity is only 0.02% of full scale, or about 10^{-4} radians (22 arc seconds) , but in view of the repeatibility we assume that the instrument can be calibrated to at least one arc second. In a final version some temperature control may be needed. The $\pm$ 5 volt output would be digitised with a 16-bit A/D converter so that one bit would be 1.6 arc seconds. This could be improved, but is the basis for the suggested 2 arc second random error used earlier.
The 5 millivolts of random noise from the inclinometer seems large - means will have to be found to avoid errors due to this.

4. The Method in Practice

We will briefly describe the method as it would bc used on a well-designed millimeter-wave telescope. We assume that the telescope surface plates have been made and measured in a shop to a high individual accuracy. In this process we would have set into each plate the correctly designed locators where the ends of the bar would subsequently rest. These locating points would be referenced to the individual plate measurements. When the plates are mounted on the telescope they would be set quite accurately by straightforward means. The locator points would be arranged to lie on radial lines, but it might be that a bar of fixed L might not exactly bridge all pairs of points. The bar would thus be designed to have a small, measurable variability of L. A given reading would consist of placing the bar in position, levelling it transversly, then signalling to the computer to read θ and the actual L value. This latter would be read by a depth transducer of the kind used on the cart (but with longer travel)

One of the small desk-calculator computers of the H-P 9000 series with the ability to store data on a cassette tape would hold all the data and would be able to compute the (x,y,z) values for all points measured.

5. Conclusions and Things to Do

If the method survives criticism we should go ahead and test it in a simple form, first on the 140-foot test panels and then use it on the 140-foot itself. It would be much easier to overcome the telescope bending problem with this method than with the cart.

JWF Jan. 26th 1977

SPECIFICATIONS

GENERAL

Schaevitz inclinometers are DC-operated, closed-loop, force-balance transducers which inherently possess accuracy and stability several orders of magnitude greater than open-loop systems. Packaged in lightweight, hermetically sealed housings, these miniature pendulous devices have integral solid-state circuitry. Available in a wide variety of configurations, these gravity-referenced sensors provide an analog DC signal directly proportional to angular deviations.

PRINCIPLES OF OPERATION

All models incorporate a pendulous mass and operate on a torque-balance principle. From the equation:

Torque=Moment of Inertia X Cosine Component of Gravity

it follows that the force due to gravity or a component of that force applied to a flexure-mounted pendulous mass will develop a torque about the axis of rotation. By arranging the mass so that any resultant motion develops an electrical signal (which is properly amplified and supplied to an electrical torque generator acting on the mass), an equilibrium is produced between the two torques. When the pendulous axis is vertical so that the mass swings horizontally, the force is proportional to the sine of the angle of deviation. For small angles the sine, tangent, and angle are all linearly proportional to each other.

The electrical torque-generator, a coil in a magnetic field, develops a torque proportional to the coil current. The net result is a current proportional to the gravitational force, accompanied by an infinitesimal displacement of the pendulous mass. By permitting the current to pass through a stable resistor, a voltage proportional to the force is developed.

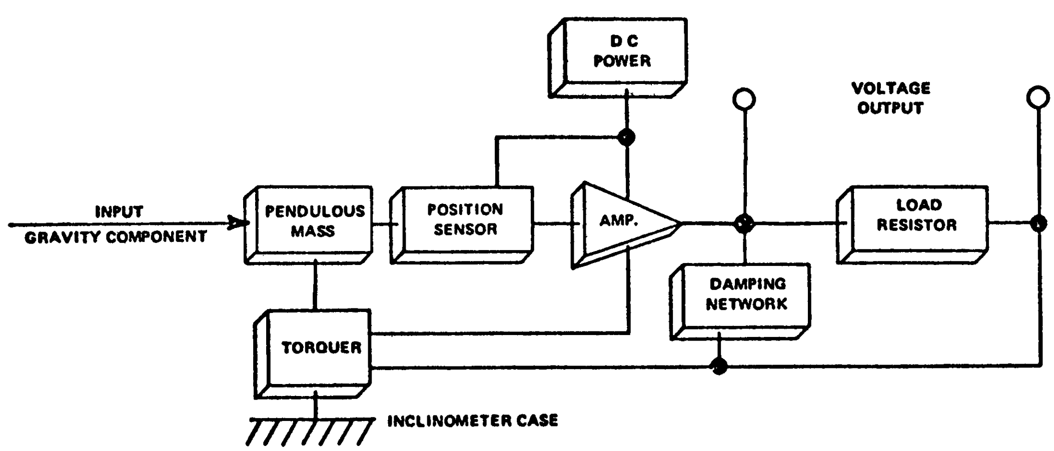
The advantage of such a system is that the two main sources of inaccuracy in an open-loop device, the mechanical spring and the displacement-to-voltage transducer, are eliminated. Thus, problems of non-linear springs, mechanical hysteresis, temperature coefficient of modulus of elasticity, spring deflection due to temperature and fatigue are non-existent with these torque-balance devices. Undesirable characteristics inherent to open-loop devices, such as sensitivity to supply voltage, non-linearity in the force-to-position pickoff, temperature coefficient of scale factor, and zero shift with temperature, are eliminated.

SPECIFICATIONS FOR LSO, LSL, AND LSA SERIES INCLINOMETERS

Input Voltage	Balanced-line ± 12 V dc[1] ±10%
Input Current	10 ma dc maximum (6 ma dc average)
Full Range Output Voltage	±5.0 V dc
Noise Output	5 mv rms maximum (random noise)
Zero Offset	Less than 0.1% of full scale
Damping Ratio	0.55 to 0.75 of critical (0.3 to 1.0 on request)
Operating Temperature	0°F to + 180°F
Alignment	±0.25°
Linearity	±0.02% full scale
Hysteresis & Resolution	0.0001% full scale
Cross-Axis Sensitivity	0.5%
Thermal Coefficient of Sensitivity	0.015%/°F (0.003%/°F optional in LSO and LSL)
Full Scale Ranges[2]	Sine 14.5°, sine 30°, sine 90°

[1] Two-terminal vehicle battery supply can readily be adapted for balanced-line voltage output.

[2] Sine 1° and other ranges available on special order.



BLOCK DIAGRAM - INCLINOMETER