



MULTIPLE MIRROR TELESCOPE OBSERVATORY

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Design Summary of the 6.5 Meter telescope Instrument Rotator Control System Using a Tape Feedback Encoder

Subject: Conversion Technical Memorandum 92-1

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Abstract:

The 6.5 meter telescope will be mounted on the existing MMT altitude-elevation (Alt-Az) mount. Tracking with an Alt-Az mount causes the cassegrain field to rotate during observing. This rotation is corrected by precisely counter rotating the entire cassegrain instrument.

A graduated encoding tape to be mounted around the circumference of the rotator bearing is proposed. The encoding tape will provide rotator position feedback to a VMEbus computer. The resolution requirement of 2^{18} bits is derived from the desired pointing and tracking performance. The sources of position error and their effects on accuracy are presented. An accuracy of 0.05 arcseconds RMS at the edge of a 1.0° field appears feasible with the proposed encoding tape, using achievable mounting tolerances and software error correction.

¹With appreciated technical support and criticism from
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Introduction:

A VMEbus computer with a dedicated motion controller will generate the position commands and monitor the instrument rotator position. The rotator position will be encoded by a Farrand Inductosyn².

The Inductosyn can be thought of as a rotary transformer with two secondaries. The rotating primary is mounted on a spring steel tape. The tape is wrapped around the circumference of the axis to be measured. The stationary secondaries are mounted on a slider³ that spans 4 inches of the tape. Four to eight sliders are distributed around the circumference to average the effects of runout, concentricity and scale accuracy.

The tape Inductosyn scales with multiple curved sliders has the resolution of friction driven encoders with a potentially simpler mechanical installation and alignment. This advantage is offset by complex interface electronics.

The tape mounting surface must have a runout of less than ± 0.001 inches. The required air gap between the tape and the slider is 0.007 inches and must be uniform across the slider. The variation in air gap due to runout, eccentricity, concentricity and vibration can not exceed ± 0.001 inches.

The ultimate accuracy of the tape system depends on the ability to compensate for mounting tolerances. The non-cyclic variation of surface runout and tape accuracy are minimized by averaging readings from all the sliders.

The cyclic errors can be minimized in software and with multiple sliders. To correct for the twice per revolution error of eccentricity, two sliders 90 degrees apart are required. To correct for the once per revolution error of concentricity, two sliders 180 degrees apart are required. To allow the use of shift registers to perform the high speed division required for averaging, the number of sliders should be a power of two (2,4,8...). This sets the minimum number of sliders to four.

²Farrand Controls; 99 Wall Street; Valhalla, NY 10595-1447

³slider; a read head, made up of sine and cosine windings

Required Performance Calculation

Positioning Resolution with the f/5.27 telescope :

A circular field on the sky with a diameter spanning 1 degree has a circumference, C

$$\begin{aligned} C &= 1 \text{ degree} * 3.1416 \\ &= 3600 \text{ arcseconds} * 3.1416 \end{aligned}$$

This circle, on the sky, must be resolvable into cords spanning 0.05 arcseconds⁴.

$$\begin{aligned} \text{resolution} &= C / (0.05 \text{ arcseconds/part}) \\ &= (3600 * 3.1416 \text{ arcseconds/rev.}) / (0.05 \text{ arcseconds/part}) \\ &= 226,194.7 \text{ parts/rev.} \end{aligned}$$

Any circle can be divided by the resolution to determine the angular resolution.

$$\begin{aligned} \text{angular resolution} &= (360 * 60 * 60) \text{ arcsec./rev.} / 226,194.7 \text{ parts/rev.} \\ &= 5.73 \text{ arcseconds / part} \end{aligned}$$

In other words, an angular rotation of 5.73 arcseconds will move a star 0.05 arcseconds of span at the edge of a 1° field.

The required resolution on the 76.37 inch diameter instrument rotator encoded surface will be;

$$\begin{aligned} \text{encoder resolution} &= (76.37 * \text{PI}) \text{ inches/rev.} / 226,194.7 \text{ parts/rev.} \\ &= 0.00106 \text{ inches / part} \end{aligned}$$

At the edge of a 1.0° field from a f/5.27 telescope the encoder tape scale can be defined as;

$$\begin{aligned} \text{tape scale} &= 0.00106 \text{ inches on the tape} / 0.05 \text{ arcseconds on the sky} \\ &= 0.0212 \text{ inches / arcsecond on the sky} \end{aligned}$$

The f/5.27 telescope will produce a focal plane 24 inches in diameter. At the edge of a 1.0° field the plate scale can be defined as;

$$\begin{aligned} \text{plate scale} &= (24 \text{ inches} * \text{PI} / 226194.7) / 0.05 \text{ arcseconds on the sky} \\ &= 0.0072 \text{ inches / arcsecond on the sky} \end{aligned}$$

Minimum Instrument Rotator Encoder Requirements :

To meet the above requirements a resolution of 2¹⁸ bits (262,144) plus one bit for servo error, or 2¹⁹ bits (524,288) will be needed.

⁴An object will span a linear distance on the sky. The length of this span subtends an angle expressed in arcseconds.

Rotator Position Angle Accuracy and Repeatability:

The repeatability of the position angle is the error between any two attempts to perform the same commanded move. The accuracy of the position angle is the error between where the instrument rotator is and where it should be. The repeatability of this system will be better than the accuracy.

The repeatability will be limited only by resolution of 2^{19} bits minus 1 bit of servo jitter and quantizing error. This puts the repeatability at better than 5 arcseconds of rotator angle (0.0431 arcseconds span on the sky). Without software error correction the worst case accuracy of a 90 degree move will be about 12 arcseconds (0.105 arcseconds span on the sky). Although cyclic system error can be mapped by error correction software, the final accuracy will always be worse than the repeatability.

Detailed instrument rotator positioning accuracy calculations are shown on page 6.

Velocity :

The maximum speed (full slew rate) will be 2 degrees/second (7,200 arcseconds/sec). The minimum tracking speed is defined at 0.1 sidereal rate or 1.5 arcseconds/sec. This will require a 4,800:1 speed range. At speeds below 1.5 arcseconds/sec and above zero, the peak to peak track error will increase. At zero speed the position accuracy is a function of gain and feedback resolution.

Instantaneous speed regulation depends on a high pulse rate, an accurate graduated scale and compensation for tape mounting tolerances.

The encoder pulse rate required to provide an effective velocity loop bandwidth is given by Canon⁵

$$P = 45 * BW / RPM$$

The inner velocity loop should have a bandwidth 8 to 10 times the required position loop bandwidth of 8 Hz. To achieve a minimum of 64 Hz velocity loop bandwidth at 1.5 arcsec/sec, a resolution of $2^{25.3}$ (or 41.47+06) counts per revolution or greater is required.

A six speed resolver⁶ could be mounted on each drive motor to function as commutation and velocity feedback. Although the accuracy is only 2^9 bits per cycle, each cycle could be interpolated to a resolution of 2^{16} bits. This resolution multiplied through the 135.2:1 gear ratio gives a high resolution (low accuracy) velocity feedback of $2^{25.7}$ (53.16E+06) bits/rotator revolution.

Velocity loop Bandwidth, Hz	Instrument Rotator tracking Velocity RPM (arcsec/seconds)
8.2	6.94E-06 (0.15)
82.0	6.94E-05 (1.5)
200.0 ⁷	6.94E-04 (15.0)
200.0	6.94E-03 (150.0)
200.0	0.25 (5400.0)
200.0	0.33 (7200.0)

The maximum velocity feedback frequency of 0.30 MHz is generated at 0.33 RPM. At the PMAC-VME⁸ digital motion controller's lowest encoder sampling clock rate the encoder signal can be up to 1.47 MHz.

⁵Arnold, Frank, "Laser Encoders Provides Super Resolution For High Precision Applications", PCIM, February 1990, PP 26-32

⁶Harowe Servo Controls, inc; model 21BRCX-330-P20D

⁷Limited to 200 Hz or less by the velocity loop time constant

⁸Delta Tau Data Systems, Inc; Programmable multi-axis motion controller

Hardware to Meet the Required Performance

Inductosyn Tape :

The Inductosyn tape will be directly coupled to the rotator about the optical axis. The Inductosyn mounting surface will have an O.D. of 76.370 inches.

radius = 38.185 inch
circumference = 239.9 inch
surface = 0.002 inch TIR

The Farrand transducer is a linear flexible spring steel tape. A pitch of 0.2 inch/cycle and a 10 bit Inductosyn to digital (I/D) converter was chosen.

number of cycles = 239.9 inch/rev. / 0.2 inch/cycle
= 1199 cycles/rev.

scale resistance = (239.9 inch/12) * 0.75 ohms/ft
= 15.0 ohms +/-20%

resolution
counts per rev. = 2^{10} counts/cycle X 1199 cycles
= 1,227,776.0 counts
or $2^{20.2}$ bits per revolution
or 0.95 bits/arcsecond of rotator angle

Inductosyn to Digital Converter (I/D) :

Using Farrand Controls I/D Quad Converter, 219100-I:

Inductosyn resolution = 0.2 inch/cycle
= (76.37 * 3.1416 inch/rev) / 0.2 inch/cycle
= 1199 cycles/rev.
= 1199.0 cycle/rev. * 1,000 divisions/cycle
= 1,199,000 divisions/rev.
or $2^{20.2}$

Inductosyn Preamplifier :

The preamplifier is located near the Inductosyn. It amplifies the sine and cosine signals before they are sent to the I/D converter.

The voltage transfer ratio (VTR) of the 0.2 inch/cycle Inductosyn is 433/1 at 6 KHz. The required converter input signal voltage is 2.0 V RMS. This will require using a standard preamplifier gain of 1250 and an excitation voltage of 0.7 V RMS.

Excitation Power Oscillator :

The excitation voltage is 0.7 V RMS into a 15.0 +/-3 ohm primary winding. The excitation frequency will be 6 KHz.

A reference signal is also derived from this oscillator. The reference signal voltage will be 90 degrees advanced with respect to the excitation and have a magnitude of 2.5 V RMS

Instrument Rotator Positioning Accuracy

Accuracy of the Tape (arcseconds) :

The Inductosyn tape scale accumulates error with displacement. This error is repeatable and non-cyclic.

Inductosyn accuracy = +/- 100E-6 inch/ft (scale only)

Angular accuracy = (100E-06 inch/12 inch/ft) * (3600 arcsec/deg.)
= +/-0.030 arcseconds / degree

error = degrees * (0.030 arcsecond / degree)

Surface Runout (arcseconds) :

The runout and eccentricity of the tape mounting surface contribute the dominant error. This error is repeatable and cyclic within one revolution.

THETA = degree X pi/180; radian

delta radius = 0.001 X degree/90; radius varies 0.001 inches over 90 degrees

error,radian = ((radius + delta radius) X THETA - radius X THETA)/radius

= ((38.2 + (.001 X degree/90)) X THETA - 38.2 X THETA) / 38.2

error,arcseconds = (3600 X 180/pi) X error,radian

Inductosyn to Digital Converter (arcseconds) :

The I/D converter electronics error does not accumulate with displacement. The published accuracy of AD2S82LP is 2.0 arcminutes/cycle plus a non-linearity of 1 LSB in 2¹⁶ bits (0.3 arcminutes/cycle).

error,arcseconds = 2.3 X 60 / 1199 cycles/rev

Other sources of error such as signal/reference phase shift, signal differential phase shift and cross talk between leads can be planned for and corrected. The tape pitch variation over the operating temperature will not affect angular measurements. Temperature will not significantly effect the voltage transfer ratio (VTR).

Summary of Worst Case Error vs. Displacement (No software error correction) ** arcseconds **

PA displacement (degree)	tape	surface	converter
1	= 0.03	0.001	0.115
9	= 0.27	0.085	0.115
18	= 0.54	0.34	0.115
36	= 1.08	1.36	0.115
54	= 1.62	3.05	0.115
90	= 2.70	8.48	0.115