p̄ Note 375

TARGET AND LENS MOTOR CONTROL DESIGN AND TESTS

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Target and Lens Motor Control Design and Tests.

Introduction

This note describes two systems which have been considered to control the positions of the target and lithium lens devices in the antiproton source. D.C. gearmotors drive the devices. The authors designed a closed loop motor control system, which is described, but which will not be used because of the software and hardware support required. The front end program does not allow the full range of standard CAMAC communications; it is designed to be compatible with a small number of module types used in specific applications. Consequently, we have decided to use an open loop system, which is also described.

Results of tests performed with one gearmotor driving the lithium lens module are presented. The impact of these results on the accuracy of an open loop control system is considered.

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Target and Lens Motor Control Design and Tests

The antiproton production target and the lithium lens will be movable under computer control. Positions of these devices will be measured with LVDT's, RVDT's, or 10 bit rotary encoders. D.C. gearmotors have been chosen to drive the devices, because they will produce less peak loading and vibration damage to the system than stepping motors.

Two models of gearmotors with output speeds of either 1 RPM or 22 RPM will be used. The speed of these motors decreases by 30% at maximum rated load, so the speed will depend on such factors as condition of bearing surfaces, stresses of attached cabling, and upward versus downward motion. The worst anticipated case results from the difference in torque between upward and downward motion of the lens, which is 200 inch-ounces with clean bearing surfaces. For the most powerful motor in the package size for which the system has been designed, the motor specification charts indicate that there will be a speed differential of 5%. Nominal speeds of all motions are listed in Table 1.

In order to reach a destination in one step, the authors proposed the closed loop control system shown in Figure 1. A microprocessor based module C-057

would accept direction of motion and destination information from the front end computer. The C-057 would then turn on the appropriate motors and read back the current position of the device at a rate of 100 Hz until the destination was reached, at which time the C-057 would turn off the motors. Analog position transducers would be read into the C-057 through a 16 channel sample and hold module with a multiplexed ADC. An interface module to be designed and built would handle all communications between the C-057 and (1) sample and hold module, (2) rotary encoders, (3) motor drive cards, (4) motor power supply, and (5) limit switches. Limit switches would be wired directly to motor drive cards to override the control system in inhibiting motion in a particular direction when a limit was reached. A current trip circuit on the driver cards would protect a motor if its limit switch failed. Positions and limit switch and motor driver card status bits would periodically be sent from the C-057 to the main computer for display on the parameter page.

The lens will be moved in the X-Z plane by a pair of motor driven eccentrics, one inside of the other. The angular positions of the eccentrics will be measured with respect to a fixed external reference using 10 bit rotary encoders. On the production module, each

encoder will turn one revolution per eccentric revolution. The relationship between (x, z) and angles (θ_1, θ_2) is derived in Appendix 1. In that configuration one encoder count will equal 0.352 degree of eccentric rotation, or a resolution in (x, z) of 0.00159 inch at the points of poorest linear resolution. When an operator wishes to move the lens in x or z, the desired (x, z) or increment will be entered at a console. An applications program will convert the (x, z) to (θ_1, θ_2), which will be sent to the C-057 module to locally execute the motion.

The results of measurements made on the drive system for the outer eccentric of the lens module are presented in this note. A one RPM TRW gearmotor, model 409A149, was coupled to the eccentric through a 3:1 speed reduction. The angular position of the eccentric was measured with a 10 bit rotary encoder, which was geared to turn three revolutions per revolution of the eccentric. For these measurements one encoder count corresponds to 0.117 degree of eccentric rotation.

Figure 2 shows angular displacement as a function of the time the motor was powered. The eccentric was driven in a clockwise direction as viewed from above. A load of 425 lb of lead was stacked on the lens mounting plate to simulate the load of a lens. Five trials were averaged for each point. For moves of 10 - 60 sec,

the standard deviation of readings was typically less than 8 counts. For moves of one second or less the standard deviation was constant at about 0.5 count and was dominated by encoder resolution. Measurements were linear and reproducible to about 1%. Measurements were also made in the counterclockwise direction with the load, and in both directions without a load. Five trial averages were within ±1% of the clockwise loaded data. There was dynamic braking on the motor for all of these measurements, but previous measurements indicated that the braking did not have a significant effect on stopping time.

Figure 3 shows the data for clockwise motion with a load for motor pulse lengths of less than 1 sec. The initial steep rise represents the time during which the motor is accelerating. At 50 msec the motor has reached full speed. The average speed during a 60 sec pulse is 20.7 encoder counts/sec. Assuming linear acceleration from 0-20.7 counts/sec in 50 msec, the displacement at 50 msec would be 0.52 count. Since a total displacement of 2.1 counts was measured for a 50 msec pulse, the system must have drifted 2.1 - 0.5 = 1.6 counts after power was turned off. The encoder on the production module will have a factor of three less resolution; in that case, average speed will be 6.9 counts/sec (145 msec/count) and drift will be 0.5 counts after power is turned off.

Backlash data were measured by pulsing the motor in one direction, then pulsing in the reverse direction, and observing how much smaller the encoder displacement was for the first reversed pulse. Backlash in both directions was measured to be 14 encoder counts or 1.64 degrees of eccentric rotation. This corresponds to 4.92 degrees at the gearmotor output. Factory specifications quote an average backlash of 3 degrees, dependent on gear ratios. In the production module backlash will be 4.7 encoder counts, giving a worst case error in (x, y) of the lens of 0.0074 inch.

Because of the amount of hardware and Software support required to implement the closed loop control system described above, the open loop system shown in Figure 4 is being considered. An application program would convert the destination entered at a keyboard to a number of steps and direction of motion. This information would be sent to a C-057 module configured as a stepping motor controller. The C-057 would communicate through an interface module with motor driver cards, which would use the number of steps to pulse length modulate a single pulse to the appropriate motor. Two trials might be needed for long moves or to take up eccentric backlash. Analog position information would be sent to MADC channels, and encoder outputs, limit switches and overcurrent status would be sent to

a multiplexed C-180 for read out to the parameter page. A DC motor control system, including a C-057, an interface module, and motor driver cards mounted in a crate has been designed by Jeff Elseth.

The simplest solution to the motor control system will be pursued. That now appears to be:

1. Use an open loop system with a C-057 configured as a stepping motor controller.
2. Buy the most powerful motors in the package size we have designed for, to minimize speed dependence on load. The result should be better than ± 5%.
3. Accept backlash error in the eccentric system.
4. Incorporate anti-backlash in the target horizontal movement. (All other movements have no backlash since they are always preloaded in the same direction by gravity.)
5. Follow up on the Fermilab interface and DC motor drive modules in existence. Adapt them to this application.
6. Note that the C-057 pulse train is programmable. The stepping rate can be varied between 1 Hz and 10 KHz, and the range is 1 to 32767 steps. A full scale count would generate a 9 hour interval at 1 Hz and a 3.28 second interval at 10 KHz. At 100 Hz, the pulse width resolution would be at least 10 times finer

than the time required to move one least count of the position readout system, and a full scale count would take 5.46 minutes, which is longer than all full scale movements (except target vertical movement of 6 inches which would require 6.52 minutes).

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Table 1

Target and Lens Speeds and Position Resolutions

Motion	Nominal speed	Position resolution*
Target: rotation	1 RPM continuous	0.351 degree
vertical (±3.0")	0.0092 inch/second	±0.016 inch (worst case) (±0.022" with linearity)
horizontal (±1.0")	0.0092 inch/second	±0.0037 inch (±0.0062" with linearity)
Lens: rotation (±1°)	0.0080 degree/second 0.139 mr/second	±0.019 degree = .33 mr
vertical (±1.0")	0.0092 inch/second	±0.0037 inch (±0.0062" with linearity)
X, Z (eccentric encoders)	0.011 inch/second (max.)	±0.0016 inch (worst)
θ_1, θ_2 (eccentric encoders)	2.00 degrees/second	0.351 degree
X, Z (LVDT's) (±.25")		±0.0014 inch (±0.0020" with linearity)

* Resolution includes effects of ±5°F temperature change on MADC's (65 ppm/C°), LVDT's (400 ppm/F°), and LVDT stability (0.125% = 1250 ppm)

Resolution does not include linearity of LVDT's and RVDT's (±0.25%, ±0.125% of range), which could in principle be compensated by calibration. If not compensated, its effect is to make overall resolution at maximum travel equal to the numbers in parentheses.

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Tev 1	Target hall		

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Figure 1

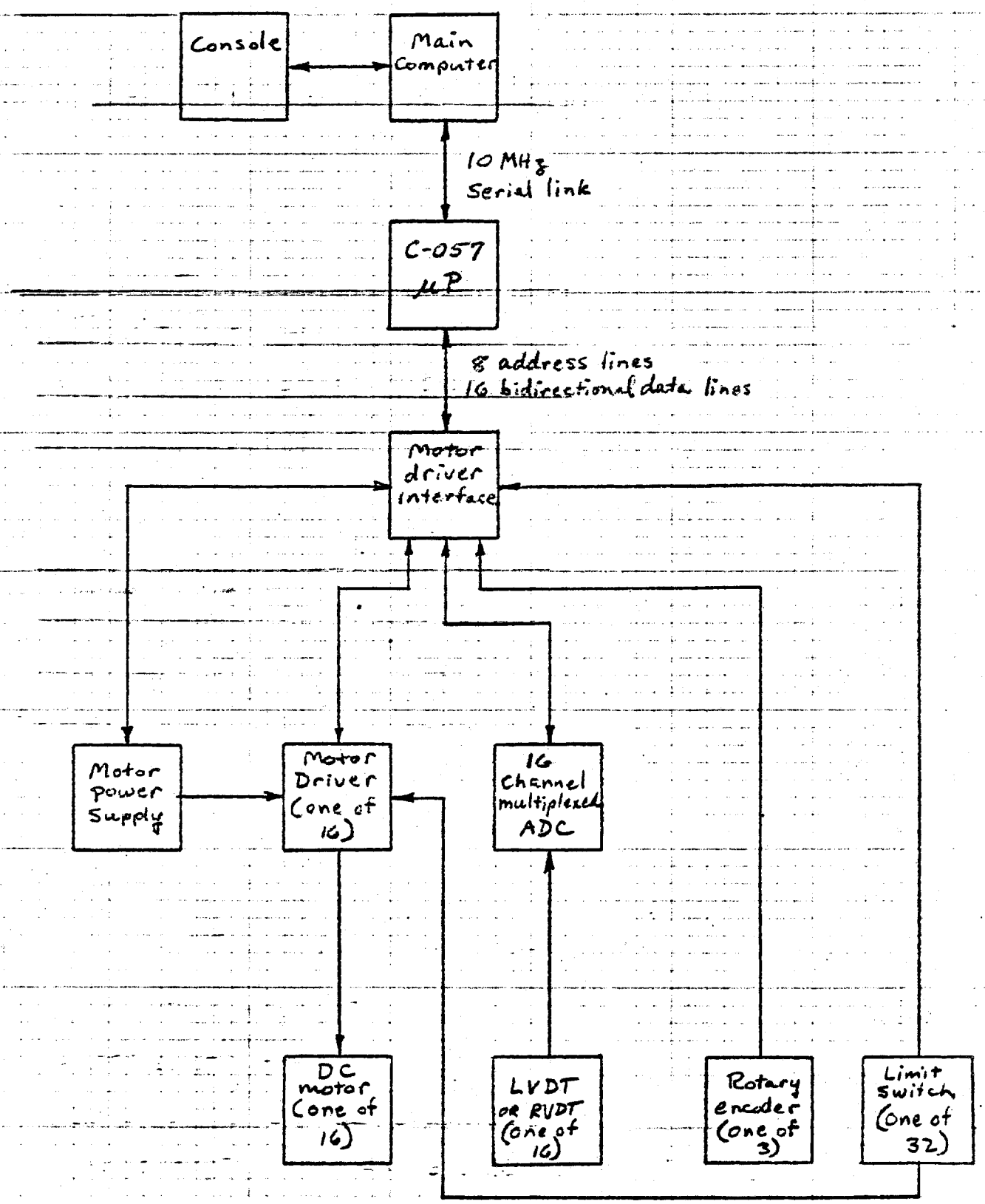

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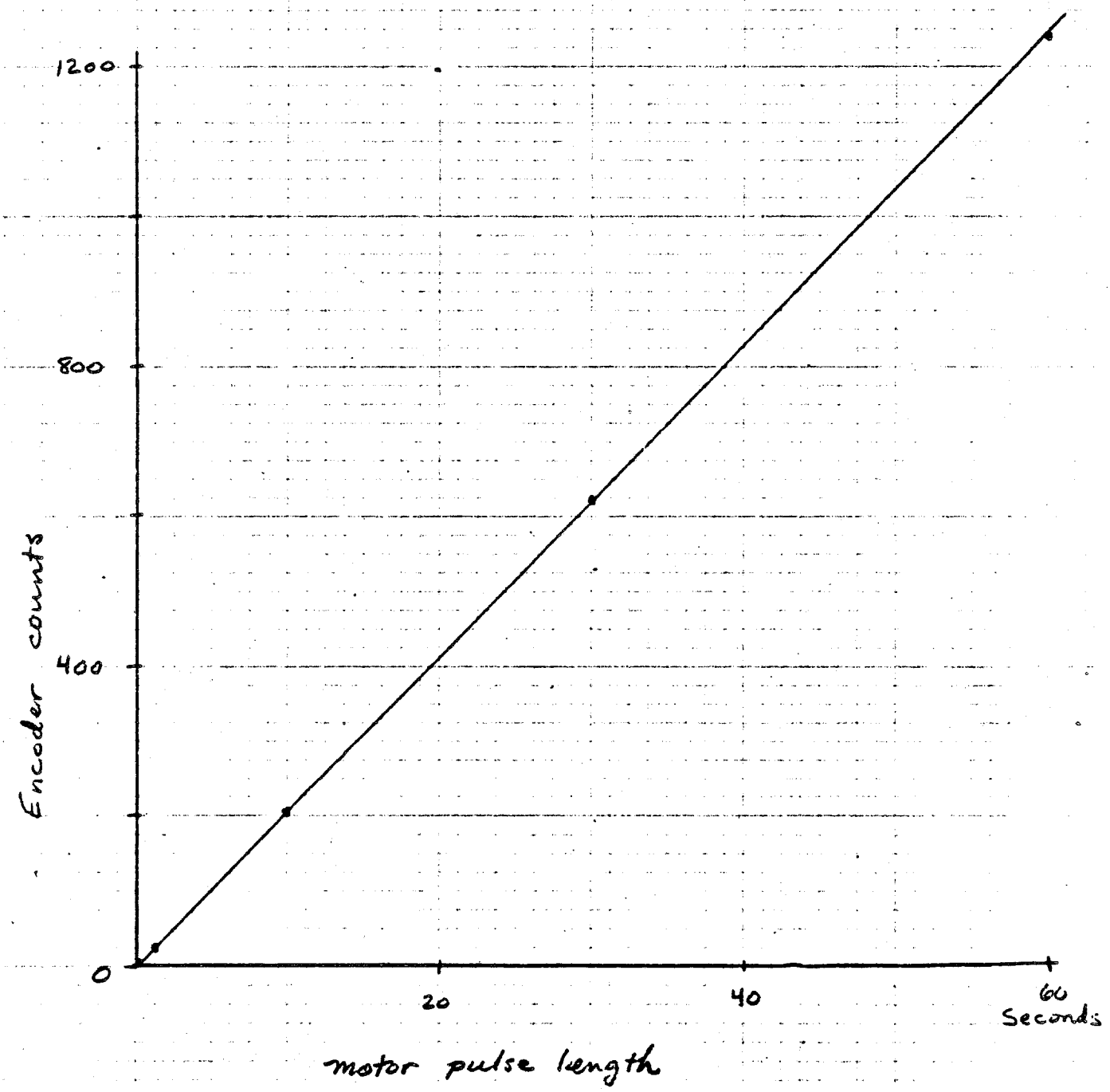
Figure 2
cw rotation
425 lb load



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SUBJECT: Lens eccentric motor calibration 0-1 sec

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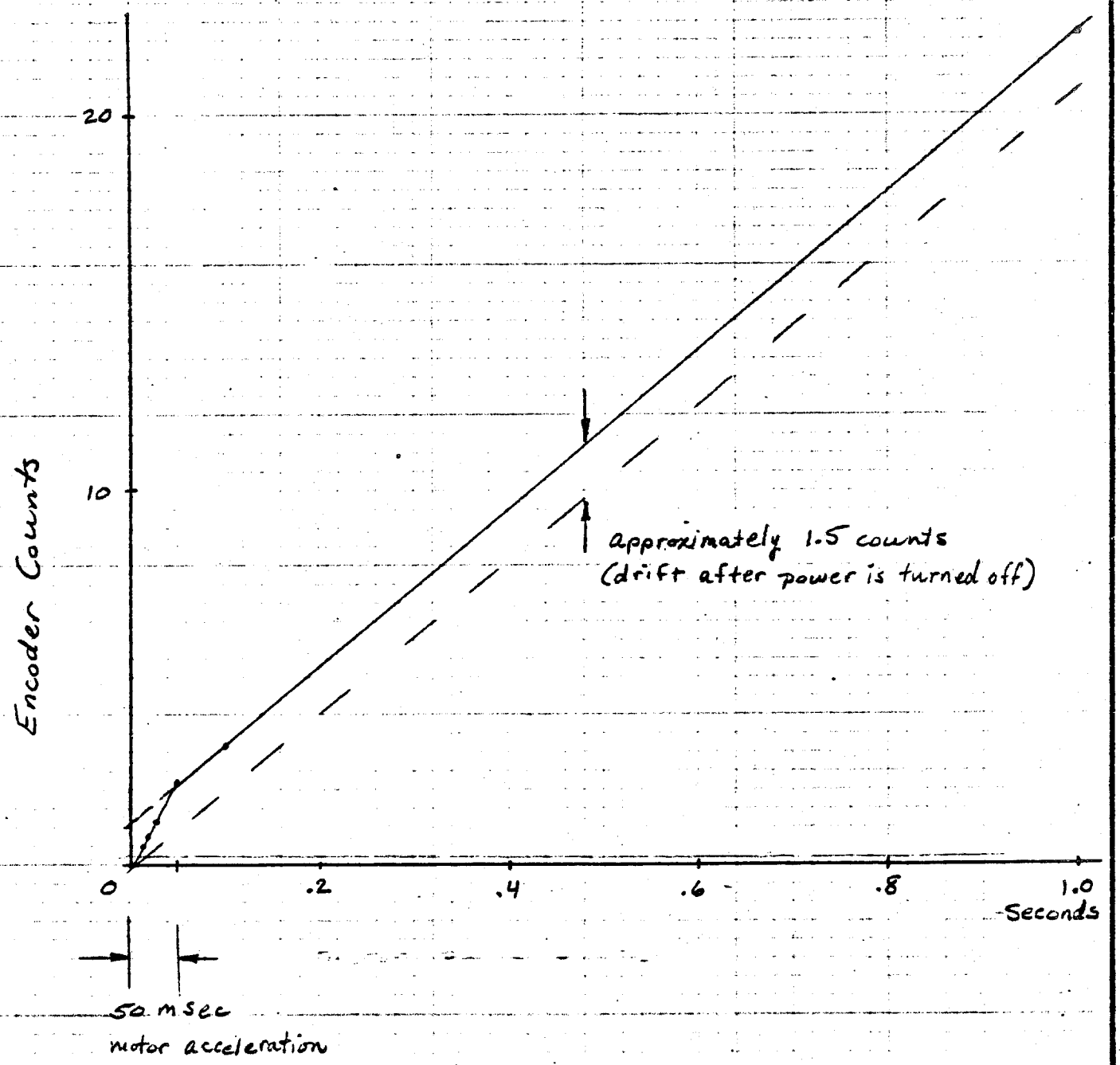
Figure 3
cw rotation
425 lb load



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	TEV 1	Target Hall		

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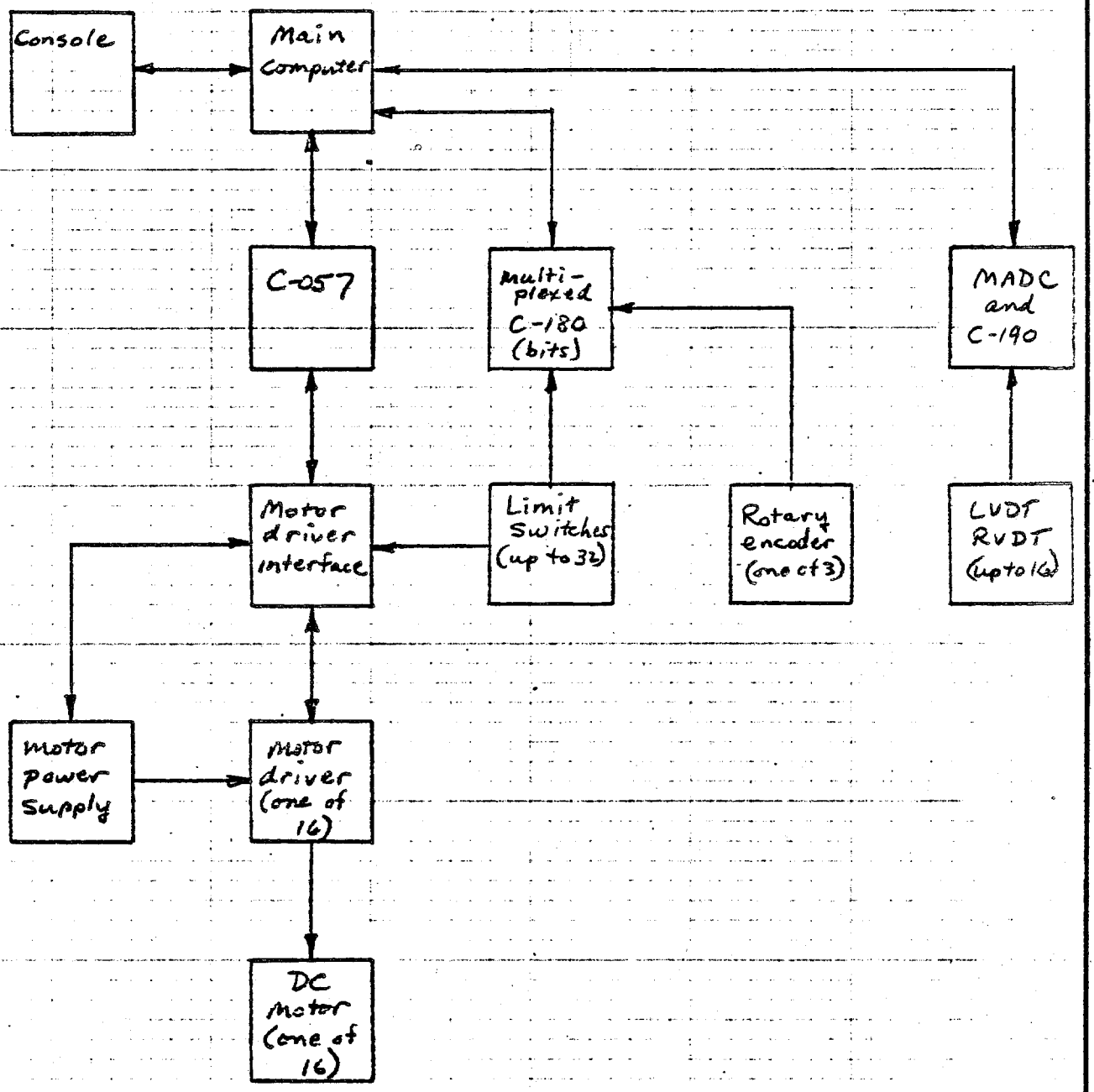
Figure 4



Appendix 1

$(X, Z) \rightarrow (\theta_1, \theta_2)$ coordinate transformation for lens eccentrics

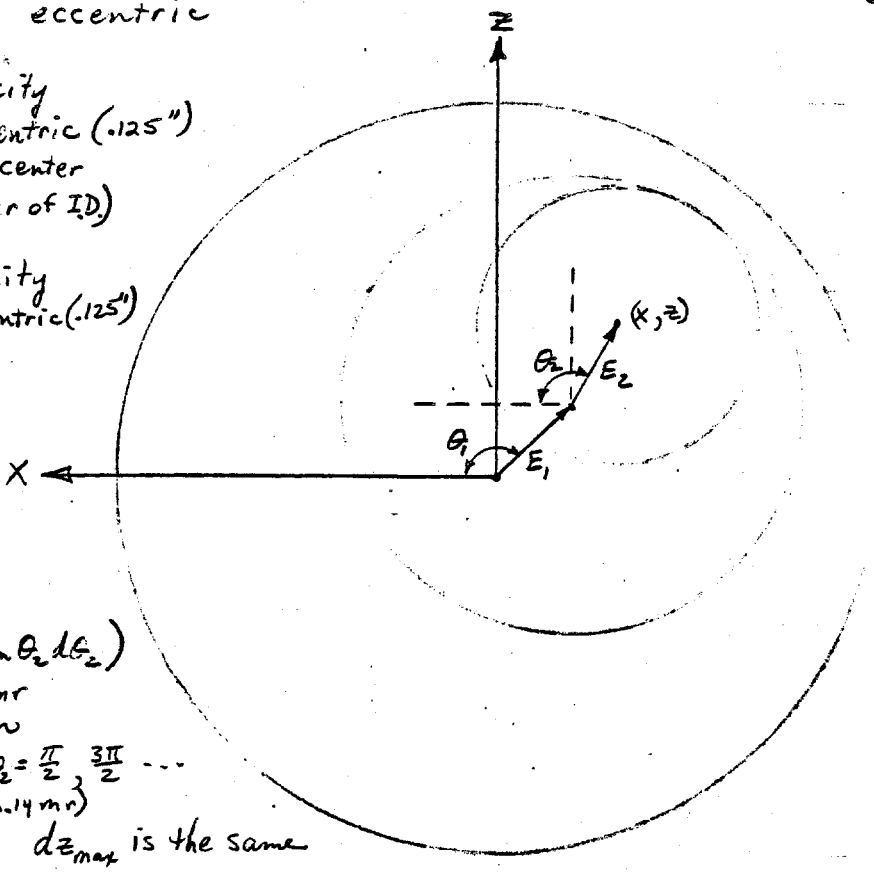
1. (x, z) are the Cartesian coordinates of the center of the bore in the inner eccentric

   θ_1 is the angle between the x-axis and the radius of eccentricity of the outer eccentric

   θ_2 is the angle between the x-axis and the radius of eccentricity of the inner eccentric

   E_1 is the eccentricity of the outer eccentric (.125") (distance between center of O.D. and center of I.D.)

   E_2 is the eccentricity of the inner eccentric (.125")



The equations relating (θ_1, θ_2) to (x, z) are

$$\boxed{\begin{aligned} x &= 0.125\,(\cos\theta_1 + \cos\theta_2) \\ z &= 0.125\,(\sin\theta_1 + \sin\theta_2) \end{aligned}}$$

2. Resolution in x is:

$$dx = -0.125\,(\sin\theta_1\, d\theta_1 + \sin\theta_2\, d\theta_2)$$

$d\theta_1 = d\theta_2 = \frac{1}{1024}\,\text{rev} = 6.14\,\text{mr}$

= angular resolution

dx is maximum at $\theta_1 = \theta_2 = \frac{\pi}{2}, \frac{3\pi}{2} \ldots$

$dx_{max} = -0.125\,(6.14\,\text{mr} + 6.14\,\text{mr})$

$\boxed{dx_{max} = 0.00154 \text{ inch}}$ $\quad dz_{max}$ is the same

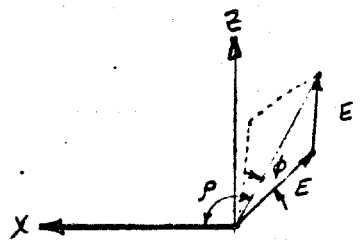
3. To solve for the inverse equations:

   - There are two (θ_1, θ_2) solutions for each (x, z) except (1) the origin which has an infinite number of solutions, and (2) any point on the circle of radius $E_1 + E_2$ which has one solution $\theta_1 = \theta_2$

   - Define the variables $\rho = \tan^{-1}\frac{z}{x}$, $\phi = \cos^{-1}\left(\frac{\sqrt{x^2+z^2}}{2E}\right)$, where

     ρ = the angle between the x axis and the line segment from the origin to (x, z)

     ϕ = the angle between E_1 and the line segment from the origin to (x, z)

$$\begin{Bmatrix} \theta_1 = \rho - \phi \\ \theta_2 = \rho + \phi \end{Bmatrix} \text{ or } \begin{Bmatrix} \theta_1 = \rho + \phi \\ \theta_2 = \rho - \phi \end{Bmatrix}$$

$$\boxed{\begin{aligned} \theta_1 &= \tan^{-1}\frac{z}{x} \mp \cos^{-1}\left(\frac{\sqrt{x^2+z^2}}{2E}\right) \\ \theta_2 &= \tan^{-1}\frac{z}{x} \pm \cos^{-1}\left(\frac{\sqrt{x^2+z^2}}{2E}\right) \end{aligned}}$$