DESIGN AND PERFORMANCE OF A COMPUTER-BASED SYSTEM TO REGULATE THE POSITION OF A BEAM OF PROTONS

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ABSTRACT

A computer-based system has been developed to maintain the lateral position of a beam of protons to within a fraction of a millimeter. Scintillation counters, located close to the beam's horizontal waist, sample about 0.1% of each side of the beam. Their counts are recorded in scalers which are interrogated frequently by a PDP-9 computer. If the asymmetry in scaler counts indicates the beam is outside the software-specified limits, the computer operates a stepping motor to vary the current in a steering magnet situated 3 meters upstream of the scintillation counters. If the total correction becomes too large, a teletype warning is given.

This system is used in the wire chamber spectrometer at the Manitoba cyclotron to control the horizontal position of a 42 Mev ribbon beam 2 mm wide and 50 mm high having an intensity up to 5 nA. Tests have shown that this control system can maintain the lateral position of a symmetric ribbon beam at the scintillation counters to within ± 0.015 mm, provided that the shape of the beam does not change with time. The present measurements are not extensive enough to permit conclusive statements on either the amount of inherent beam wandering or the effects of the control system for spectrometer runs lasting longer than a few hours. However, during two shorter runs the beam was found to drift 0.75 mm laterally during a 2 hour run taken without control, and to be maintained within ± 0.085 mm of its mean lateral position during a 3 hour run taken with control.

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CHAPTER I

INTRODUCTION - THE NEED FOR REGULATION

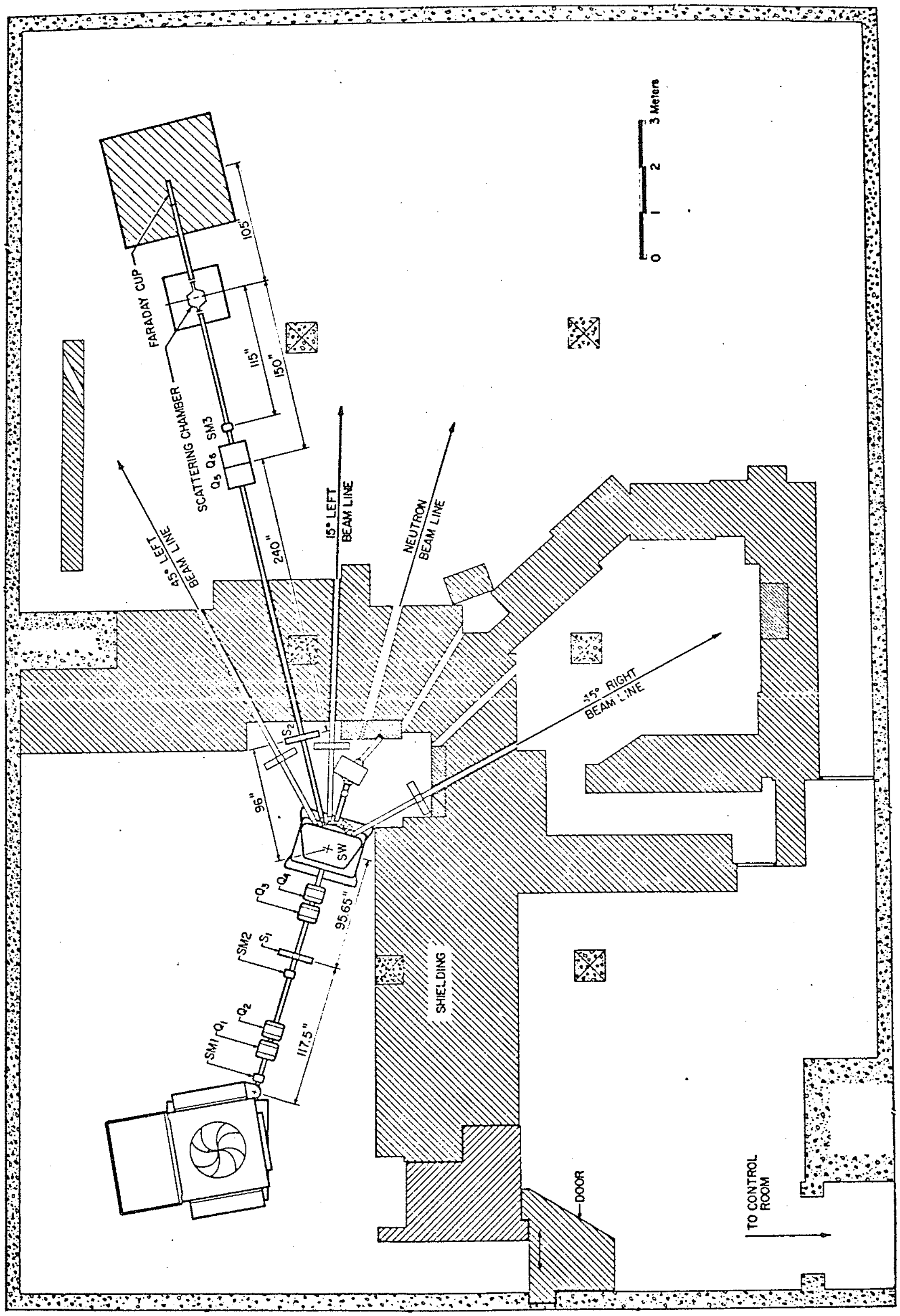
The subject of this thesis is the control of the lateral position of a ribbon beam of protons as it passes through a wire chamber spectrometer[1,2] used to study (p,2p) reactions. The energy of the proton beams used was usually about 45 Mev with intensities up to 5 nA.

The need for such control is threefold: on a gross scale there is a need to prevent the beam from striking components of the beam transport system or of the scattering chamber; on a fine scale there is a need to minimize systematic errors in the analysis of the wire chamber data; and there is a need to ensure reproducibility of experiment conditions from one run to the next. These are discussed in more detail below.

Figure 1.1 shows the beam line layout at the Manitoba cyclotron. The scattering chamber which contains the target gas is shown in Figure 1.2. The beam at the centre of the chamber typically has a width of 2 mm and a height of 50 mm. The length of the beam visible to the wire chambers is about 25 cm. This shape of the beam results from the focusing action of the quadrupole doublet Q5, Q6 about 4 m upstream of the scattering chamber center. The object for these quadrupoles is a slit located 10 m upstream of the scattering chamber center and typically $2\frac{1}{2}$ mm wide and 13 mm high. There are no other slits downstream of this object slit. This minimizes the neutron and gamma ray background

Figure 1.1

Cyclotron and beam transport layout for the 30° Left line. Protons produced by the cyclotron are focused to a horizontal waist at the slits S1 by the quadrupole doublet Q1, Q2. The beam that passes through these slits (typically 2.5 mm wide and 13 mm high) is focused by Q4 and SW onto slits S2 of similar dimensions. The energy of the beam is determined by NMR techniques from the magnetic flux across the poles of SW. Quadrupoles Q5 and Q6 are used to produce the ribbon-shaped beam in the scattering chamber. SM3 is the steering magnet that is used to regulate the lateral position of the beam inside the scattering chamber. The Faraday Cup is used to measure beam current passing through the scattering chamber.


FARADAY CUP
SCATTERING CHAMBER
Q5 Q6 SM3
105
115"
150"
240"
45° LEFT BEAM LINE
15° LEFT BEAM LINE
NEUTRON BEAM LINE
45° RIGHT BEAM LINE
S2
96"
SW
Q4
Q3
95.65"
S1
SM2
Q2
Q1
SM1
117.5"
SHIELDING
DOOR
TO CONTROL ROOM
0 1 2 3 Meters

radiation in the spectrometer scintillation counters and eliminates the neutron and proton flux through the wire chambers that would arise from slits inside the scattering chamber. However, the entrance port of the scattering chamber is only 18 mm wide and the exit port is only 33 mm wide. These cannot be made wider without increasing the thickness of the Havar windows on the vacuum pipes. Hence some method is needed to keep the beam from accidently striking the sides of the ports while obtaining data.

To understand the need to control the beam position on a fine scale, it is necessary to consider the means by which the (p,2p) reaction data are gathered and analyzed.[1-4]

A pair of wire chambers form a hodoscope on either side of the beam (Figure 1.2). They are triggered by coincident counts (an event) in their respective scintillation counters and the wire chamber data sent to a PDP-9 computer. If the event data are sufficient to define particle paths through each hodoscope, the computer tries to discriminate "real" events from random coincidences by determining whether or not the paths meet at a common origin or vertex. This is done by computing the horizontal and vertical coordinates of the intersection of each path with the assumed "beam plane", i.e. a vertical plane containing the longitudinal axis of the spectrometer. If the horizontal or vertical separation of the points of intersection exceeds the maximum spread anticipated due to the finite angular resolution of the spectrometer, the event is considered a random coincidence and is discarded.

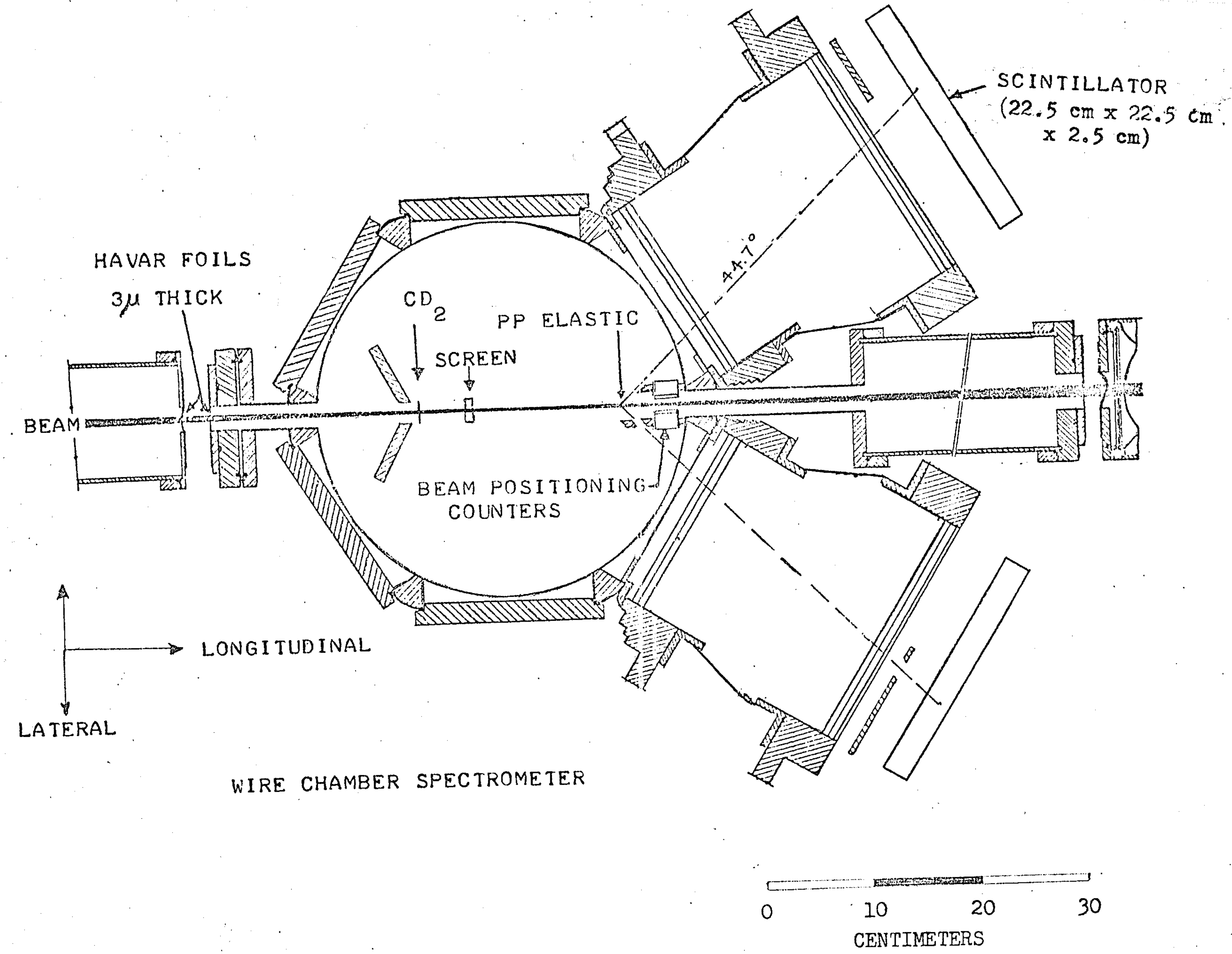
If the beam wanders during an experimental run a systematic error is introduced into the analysis which causes the loss of some valid data. This occurs because the event origin or vertex no longer lies on the assumed beam plane. This has no effect on the vertical separation between the points of intersection of each path, but strongly influences the difference in the horizontal co-ordinates of the intersections - see Figure 1.3. The resultant error depends on the angle which the particle path makes with the beam plane, but is always at least twice the beam displacement from the assumed beam position. In the case of 12.5°-12.5° scattering the error is 9 times as large as the displacement. For this reason some means of maintaining the position of the beam in the scattering chamber is required to prevent the loss of valid data while rejecting most random events.

This system to control the lateral position of the beam was built for a wire chamber spectrometer experiment to measure the very small cross section of proton-proton bremsstrahlung. To obtain results with small statistical errors requires many cyclotron runs over an extended period of time. Reproducibility of the beam position is necessary to ensure compatibility of the data from different runs.

Figure 1.2

Scale drawing of the scattering chamber and wire chambers. Entering from the left, the beam passes through two Havar foils of 6 μ total thickness plus a 2.6 cm air gap at the entrance to the scattering chamber which is filled with hydrogen gas. The longitudinal extent of the beam seen by the four wire chambers is defined by two pairs of vertical baffles. Scattering angles accepted are in the range 12.5° to 44.7°.

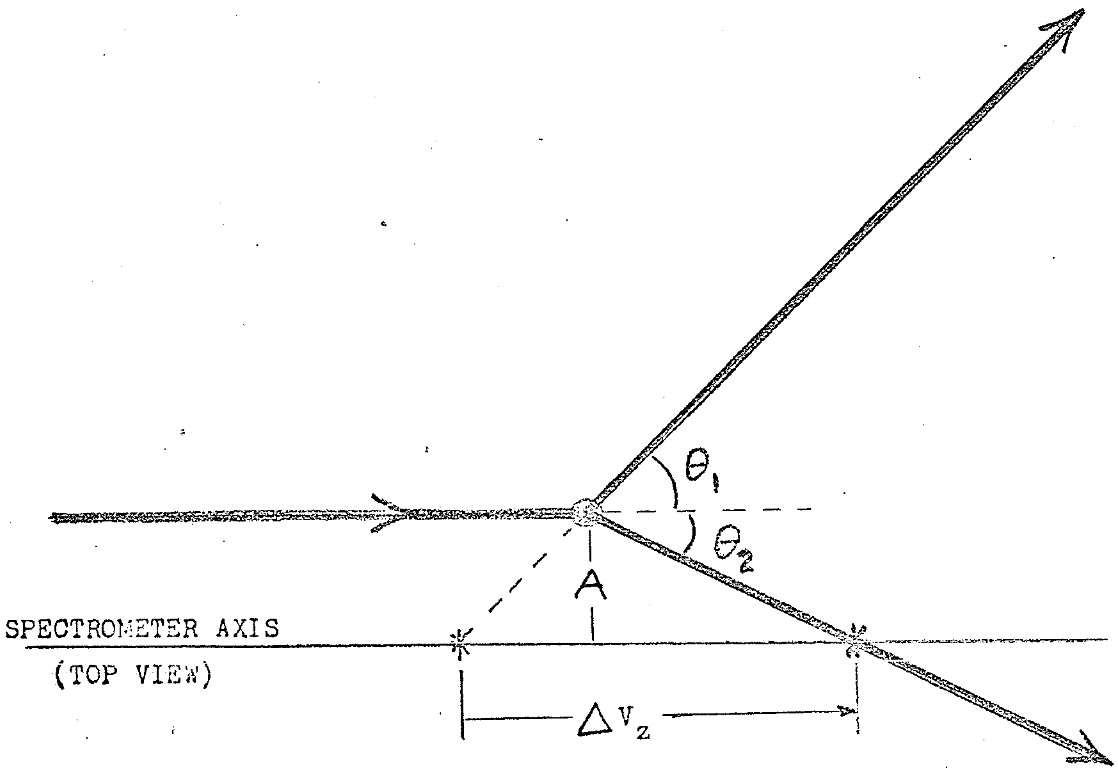
Beam positioning counters located near the chamber exit are used to sense the lateral position of the beam. Protons scattered from a 0.15 mm thick CD_2 target at the upstream end of the reaction volume and 45°-45° elastic scattering from hydrogen gas at the downstream end were used to test the beam control system. A screen (lines of zinc sulfide on an aluminium plate) can be moved into the path of the beam to examine the cross-section of the beam inside the scattering chamber.



WIRE CHAMBER SPECTROMETER

Figure 1.3

Systematic vertex errors caused by beam wandering. A scattering event (at angles Θ_1 and Θ_2) is shown whose origin is displaced a lateral distance A from the spectrometer axis. This introduces a bias of $A(\cot\Theta_1 + \cot\Theta_2)$ into the longitudinal separation between the points of intersection of the projected tracks with the spectrometer vertical/longitudinal plane of symmetry (assuming infinite angular resolution) and may cause the event to be rejected by the vertex analysis routines of the wire chamber software.



$$\Delta V_z = A(\cot \theta_1 + \cot \theta_2)$$

CHAPTER II

THE CONTROL SYSTEM

Any beam control system may have to contend with three main types of unwanted beam motion: (a) sideways displacements, (b) "steering" or turning aside, and (c) pivoting* about a beam waist - see Figure 2.1. In general, four separate position sensor/control magnet systems are required to regulate the beam's position and direction of flight both horizontally and vertically. This thesis considers one such sensor/magnet system for the regulation of the lateral position of a ribbon beam in a reaction volume 20 cm long.

Near-parallel sideways displacements are usually a mild form of or a combination of the other two cases. If, upon looking "downstream" (in the direction of flight of the charged particles), one sees the control steering magnet followed by a thin solid target followed by the beam position sensor, then aligning the beam at the position sensor will improve the beam's position at the target but will change the beam direction somewhat.

Similarly this magnet-target-sensor arrangement will reduce beam wandering caused by "steering" provided there are no beam focusing elements between the source of the steering and the sensor. When such a focusing element (quadrupole) is present (as it is for this wire chamber spectrometer - see Figure 1.1) the steering causes the beam to pivot about the beam waist and makes

*Pivoting about a beam waist location implies that the beam pitches in a vertical plane or yaws in a horizontal plane.

correction much more difficult. If the waist and sensor locations coincide, the motion is not even detected. If the waist and target coincide, the motion is detected by a sensor downstream but the correction makes matters worse at the target position. In our experiment the target is a 20 cm long volume of hydrogen gas. As long as the beam waist lies upstream of the reaction volume or downstream of the sensor the lateral position control presented here does reduce the steering-pivot effects. This will be explained more fully in the discussion of the test results in Chapter 6.4.

Several methods of monitoring or controlling the position of charged particle beams are discussed in the literature. The principal methods used to detect undesirable beam motion are sensing coils,[5,6] split Faraday Cups,[7,8] and ion chambers.[9,10] For the most part these are used in closed-loop analog systems that are independent of the main experiment. The beam sensors are usually designed for use with spot beams and are often some distance from the target at which control is desired.

The method of lateral position control presented here uses scintillation counters to sample a fraction of each side of the ribbon beam inside the scattering chamber just in front of the exit pipe. This is as close as any sensor can be placed to the reaction volume and yet, because of the small fraction ($\lesssim 0.1\%$) of the beam intercepted, it does not produce background radiation in the large scintillation counters of the spectrometer. A digital system was chosen partly because of the availability of some of the hardware and partly because of the ease of incorporating the beam position

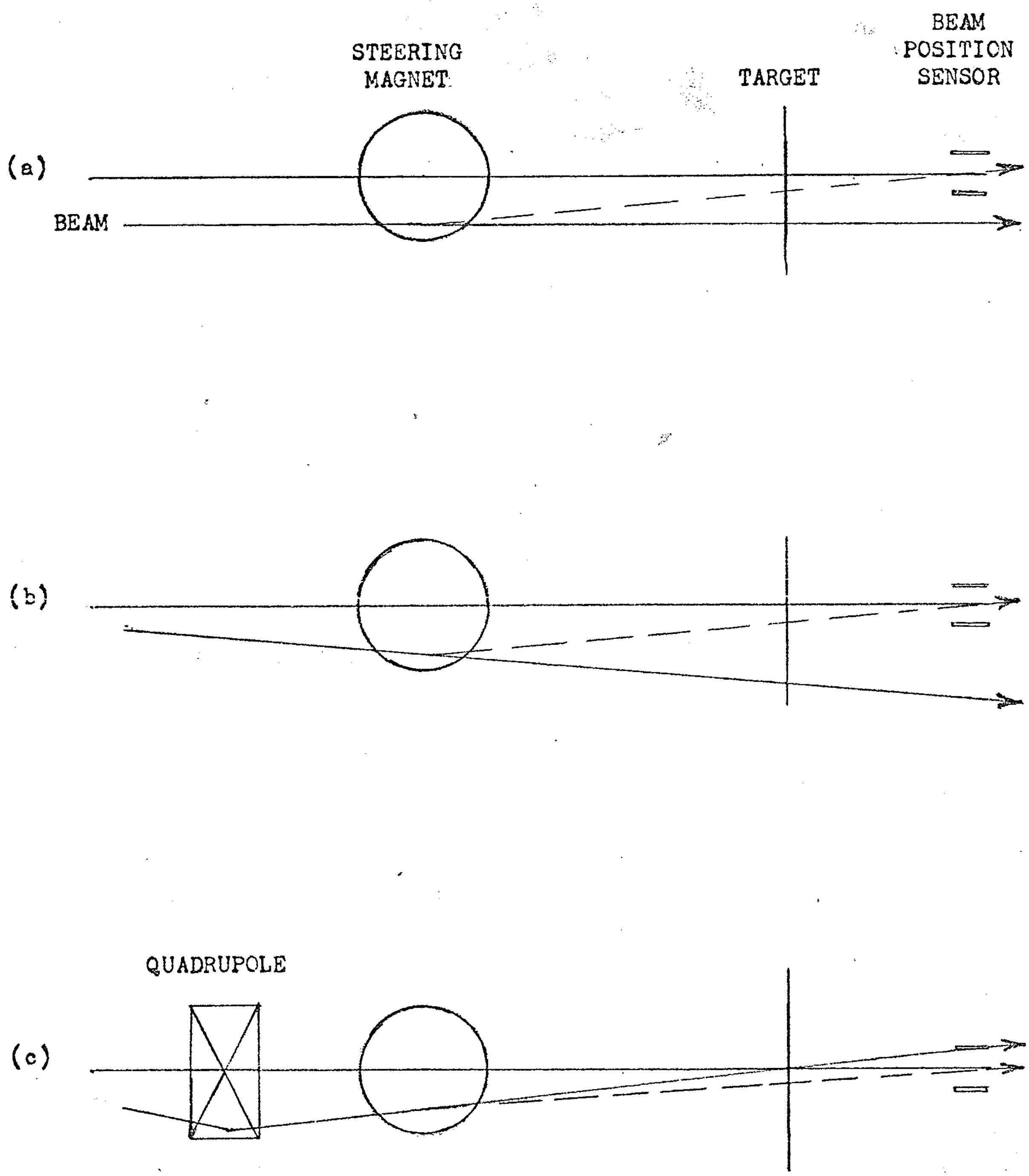
Figure 2.1

Three types of undesirable beam motion are shown by the solid arrows. The dashed arrows show the effect of the control system.

(a) The beam passes the control magnet, target and position sensor parallel to the required axis but displaced from it. The control system improves the position but alters the direction.

(b) Somewhere upstream of the control magnet the beam has been turned away from the desired direction. Again the control system improves the position of the beam at the target.

(c) A steered beam as in (b) has been turned back toward the axis by a focusing quadrupole doublet. As the steering changes the beam will pivot about the beam waist. If the waist is at the sensor, this motion will not be detected. If the waist is at the thin target as shown, the position control will move the beam further off axis at the target. If the waist is upstream of the target or downstream of the sensor, some improvement can be achieved in the beam position at the target.


STEERING
MAGNET
TARGET
BEAM
POSITION
SENSOR
(a)
BEAM
(b)
QUADRUPOLE
(c)

control into the real-time operation of the spectrometer. The response of the computer-oriented system is easier to modify (by software) than the response of analog systems (by hardware). In normal operation the digital system is quite sensitive yet stable.

A block diagram of the system used here to control the position of the proton beam is shown in Figure 2.2. The average beam current was less than 5 nA in 5 nsec bursts spaced 35.1 nsec apart. The scintillation counters were positioned so that their pulse rates were in the range 1 - 3 x 10^6 per nA. Thus it was expected that, on average, each scintillator would detect one proton from at most every second beam burst. The fast electronics were arranged so that protons detected on successive beam bursts would be counted separately. However, if more than one proton arrived from one burst their signals "piled-up" and they were counted as one proton. As this should happen equally often on each side no problems were anticipated.

After each event in the spectrometer was detected (approximately 50/sec), the totals of the pulses collected from each scintillation counter between events were interpreted by the PDP-9 program to determine the lateral position of the beam. If the beam at the scintillation counters was on the vertical/longitudinal plane of symmetry of the spectrometer, no further action was taken. If the beam was off-axis, as indicated by an asymmetry in the counts from the left and right scintillation counters, the program drove a stepping motor to change the steering magnet current to bring the beam back on-axis. A small deviation (usually $\pm$ $1\frac{1}{2}$%) in the left/right ratio of scintillation counts was permitted in the on-axis case to allow for statistical fluctuations of the data.

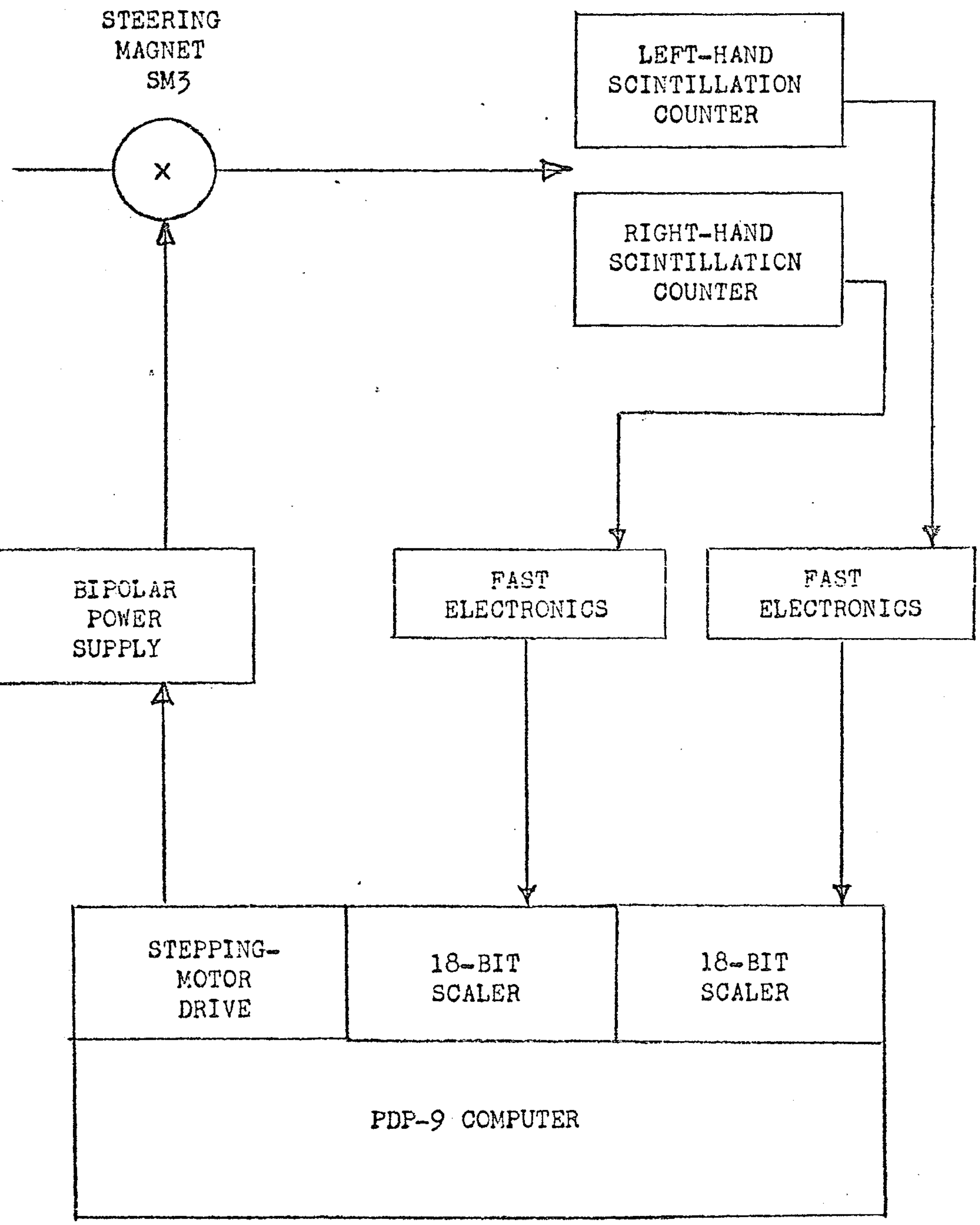
Two techniques were used to prevent the system from oscillating about the specified ratio. The allowed deviation, within which the ratio of left/right scintillation counts indicated an on-axis beam, was chosen to be greater than the expected statistical spread in the ratio of the counts. In addition, the change in the steering magnet current caused by one motor step was chosen to change the left/right ratio of the count rates by less than the deviation allowed by the program. Even if some particular data rates or beam conditions did lead to oscillation, the experimeter would see this from the indicator lamps on the motor drive or from the computer output at the end of a run. He could then overcome this by instructing the computer to average data from successive events, to change the allowed deviation of the ratio, or to look for trends in the beam motion before taking action.

In this design two assumptions are made about the horizontal intensity "profile" (cross-section) of the beam: (a) that it remains constant as time passes, and (b) that it decreases monotonically away from the centroid. In practice these conditions were usually satisfied. Occasionally the profile was a bit skewed but this was compensated for in the calibration of the ratio of the count rates as a function of lateral beam position.

One useful model for discussion ascribes to the beam a uniform vertical intensity profile and a Gaussian lateral intensity profile. As shown in Appendix A this leads to the prediction that the log (left count rate/right count rate) will be an approximately linear function of the lateral beam displacement.

Figure 2.2

Block diagram of the beam position control system. Having passed through the quadrupole doublet Q5, Q6 and the steering magnet SM3 (Figure 1.1), the beam enters the scattering chamber. Scintillation counters located near the chamber exit (Figure 1.2) sample about 0.1% of each side of the beam. Fast electronics modules amplify, shape and pre-scale the phototube pulses for input to 18-bit scalers on the PDP-9 computer. Software criteria are applied after each spectrometer event to decide if the beam position needs to be corrected. If it does, the computer changes the steering magnet current appropriately by stepping the helipot current control on the bipolar power supply.


STEERING
MAGNET
SM3
LEFT-HAND
SCINTILLATION
COUNTER
RIGHT-HAND
SCINTILLATION
COUNTER
BIPOLAR
POWER
SUPPLY
FAST
ELECTRONICS
FAST
ELECTRONICS
STEPPING-
MOTOR
DRIVE
18-BIT
SCALER
18-BIT
SCALER
PDP-9 COMPUTER

CHAPTER III

DESIGN OF THE SYSTEM COMPONENTS

This chapter presents the design of the scintillation counters, the fast electronics, the PDP-9 scalers, the steering magnet drive, and the software used with these components.

3.1 Scintillation Counters

The sensors used to sample each side of the ribbon beam were scintillation counters made from pieces of NE 102 plastic scintillator[11)] glued to perspex lightpipes by NE 580 optical cement.[11)] The lightpipes were mounted by means of General Electric RTV-615A potting compound upon end-window phototubes of two-inch diameter.

The appearance of the scintillators and lightpipes to an observer looking downstream is shown in Figure 3.1. Three separate scintillators are used in each counter to sample the beam over a height of 38 mm to keep the pulse rate tolerably low. Each scintillator is 3.2 mm wide, 1.6 mm high and long enough (23 mm) to stop 50 Mev protons. The shape of the lightpipe is complex because the 2-inch diameter phototubes must sit on the chamber floor below the beam while the scintillators must lie close to the beam yet not obstruct protons on their way to the wire chambers. Both scintillator/lightpipe assemblies were painted to keep ambient room light out of the phototube. NE 560 diffusely reflecting paint[11)] was used for the first several coats and then several coats of interior flat white latex paint were applied. The right-hand counter also had one coat of blackboard paint applied between the NE 560 and latex paint layers.

RCA-6655A phototubes were used because they were available from a previous experiment and had suitable characteristics:

gain = 1.6×10^6 at 1,000 volts

anode pulse rise time = 3.1 nsec at 1,250 volts

average anode current = 0.75 mA (maximum)

The high gain was important since the light pulses would be attenuated by the small, intricate lightpipes. Some of these light pulses would already be degraded because some protons would enter a scintillator obliquely and not lose their full energy in it. To be sure of counting all intercepted protons the gain must be high enough to saturate the amplifiers in the fast electronics. Fast pulse response was necessary because the pulses can come as close together as 35 nsec. Since the counting rate can be as high as 15×10^6 pulses per second, the high anode current rating was also necessary.

The phototube base circuit is shown in Figure 3.2. Since both counters are connected to the same power supply a distribution box is used to provide isolation between the counters and to allow small voltage adjustments so that pulse heights from the two counters can be approximately matched. The current in the resistor chain was made large to provide maximum voltage stability on the phototube dynodes. This and the requirement that the base circuit occupy only a small volume were attained by the use of 8,200 ohm, 0.5 watt, 1% precision, deposited-carbon resistors. In addition, 2,000 pf temperature-independent ceramic capacitors were used in

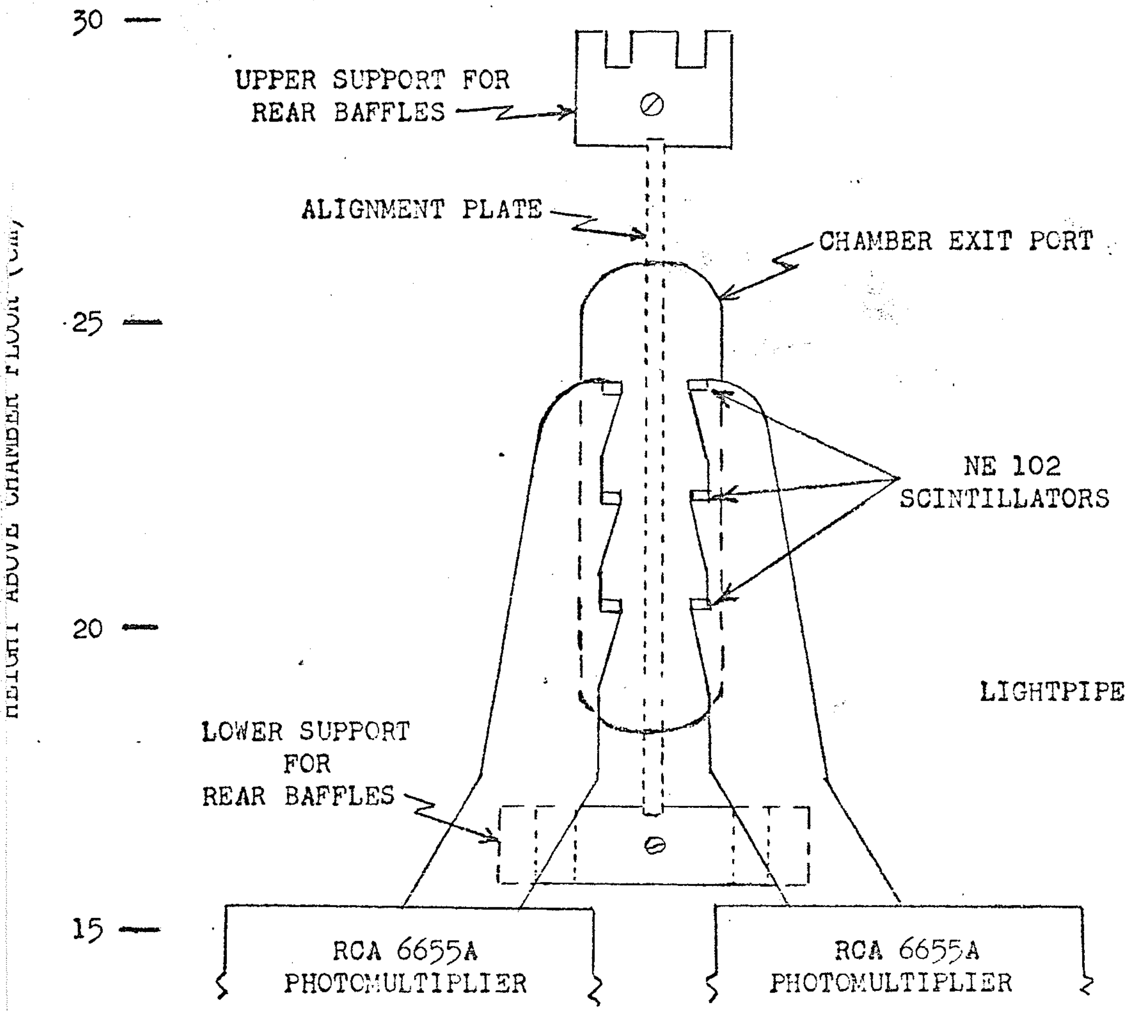


Figure 3.1a

Plane view looking downstream with the downstream baffles (see Figure 1.1) removed. The removable alignment plate (dotted line) is shown coplaner with the vertical plane of symmetry of the spectrometer. The lightpipe is shaped to collect as much light from the scintillators as is possible without intercepting too much of the beam.

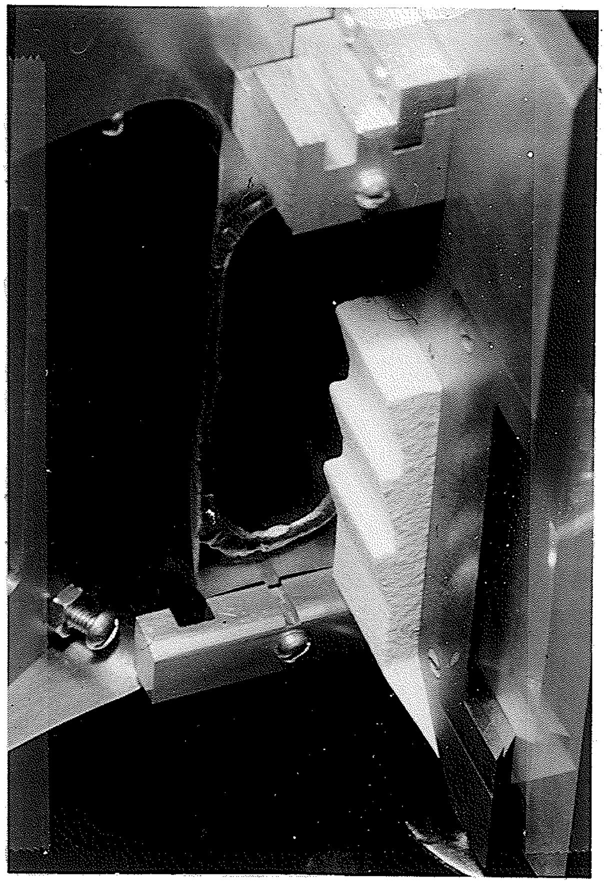
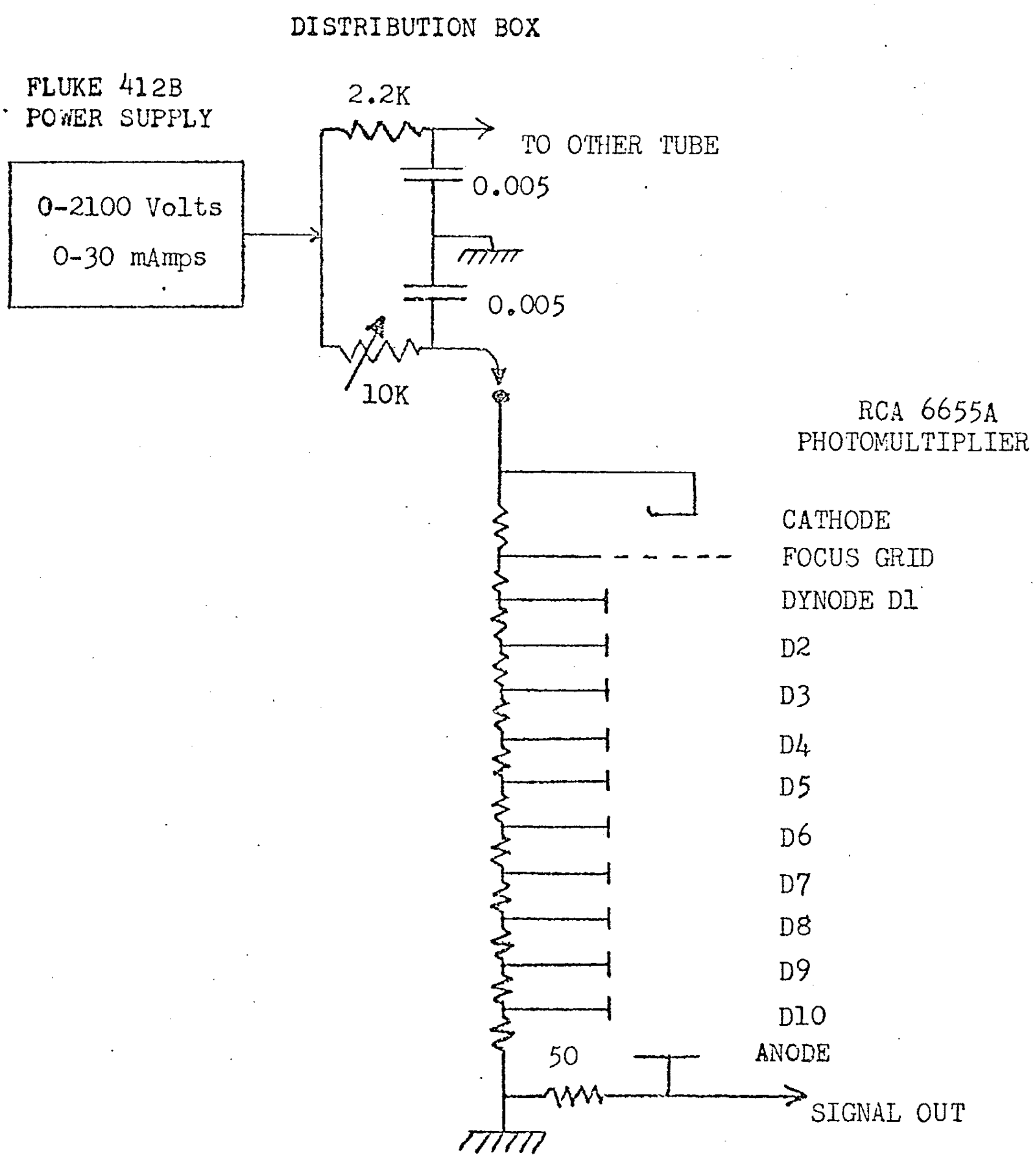


Figure 3.1b

Photograph of the right scintillation counter in position, taken with the top of the scattering chamber removed. The right-hand downstream ("rear") baffle is in place.

Figure 3.2

Photomultiplier base circuit and high voltage supply. The distribution box allows a single high current, high voltage supply to be used for both tubes. The need for a high voltage decoupling capacitor at the output is avoided by the use of a negative supply voltage on the cathode. This necessitates wrapping the mu-metal tube shield with insulating tape but keeps the anode signal line at a safe voltage.



DYNODE CHAIN COMPONENTS	VALUE	PART NAME	MANUFACTURER
RESISTORS	8.2 Kohm	N12 1%	WELWYN
CAPACITORS	2000 pf	MUCON 500WVDC	REPUBLIC ELECTRONICS

parallel with the resistors of dynodes D9 and D10 to further smooth the high voltage on these dynodes.

The counter positions are calibrated by holding an aluminium plate parallel to the vertical plane of symmetry of the scattering chamber. Each movable base plate on which a phototube is mounted is then set to the position at which the scintillators should touch this plate and the counters moved by hand until they do. The calibrated scale and vernier thumbwheel on the base plate are then used to move the counters to the desired separation between them.

3.2 Fast Electronics

The electronic components which amplify and shape the pulses must be capable of high frequency operation (hence "fast" electronics). Under typical conditions the probability of detecting a pulse from any particular beam burst is about 10% while the probability of detecting a pulse from each of two successive beam bursts (35.1 nsec apart) is about 1%.

A block diagram of the fast electronics is shown in Figure 3.3. Some of the modules were constructed in the Physics Department Electronics Shop and some were purchased from EG&G Incorporated.[12)] The pulses from the phototube were usually shortened by a clipping-stub (66 cm of RG58U shorted at its free end) at the input to the first amplifier. This ensured that the TR104S/N integral discriminator would produce only one output pulse for each input pulse, even when used at a threshold sensitivity of 100 mV. On some occasions, satisfactory operation was achieved without using the clipping-stub. The first amplifier then raised the scintillation counter pulses well above the noise caused by pickup of the cyclotron radio-frequency on the 75 m coaxial cable from the Experimental Room to the Control Room. The second amplifier compensated for attenuation in this cable and raised the signals above the threshold of the integral discriminator. Every signal that remained above the 100 mV threshold for at least 4 nsec but no more than 28 nsec caused the discriminator to produce one logic pulse output. These pulses were prescaled by the EG&G divide-by-eight unit, S100/N. The output of this unit alternates between -700 mV and ground, changing state after every fourth pulse. A pulse converter circuit, designed and constructed in the Physics Department Electronics Shop, produced a -2.5 volt, 60 nsec pulse for input to a PDP-9 scaler every time the output of the S100/N changed from -700 mV to ground. The schematics of the pulse converters are given in Appendix B.

3.3 PDP-9 Scalers

To count the number of scintillation pulses detected between events in the spectrometer, two 18-bit scalers were constructed and interfaced to the PDP-9 computer - see Appendix C. A third scaler, built as a spare, was sometimes used to measure charge collected in the Faraday Cup by counting the output pulses from a charge integrator.

A block diagram of one scaler is shown in Figure 3.4. Pulses presented to the scaler input gate are passed to the flip-flop register if the scaler is "enabled" but are blocked if the scaler is "disabled" or is being read into the PDP-9. Those pulses that pass through the gate are counted by incrementing the 18-bit flip-flop register. The three low-order flip-flops are of a high-speed series

Figure 3.3

Block diagram of the fast electronics. Typical pulses observed in the control room are also shown. Phototube pulses observed without the clipping-stub are shown in Figure 4.1.

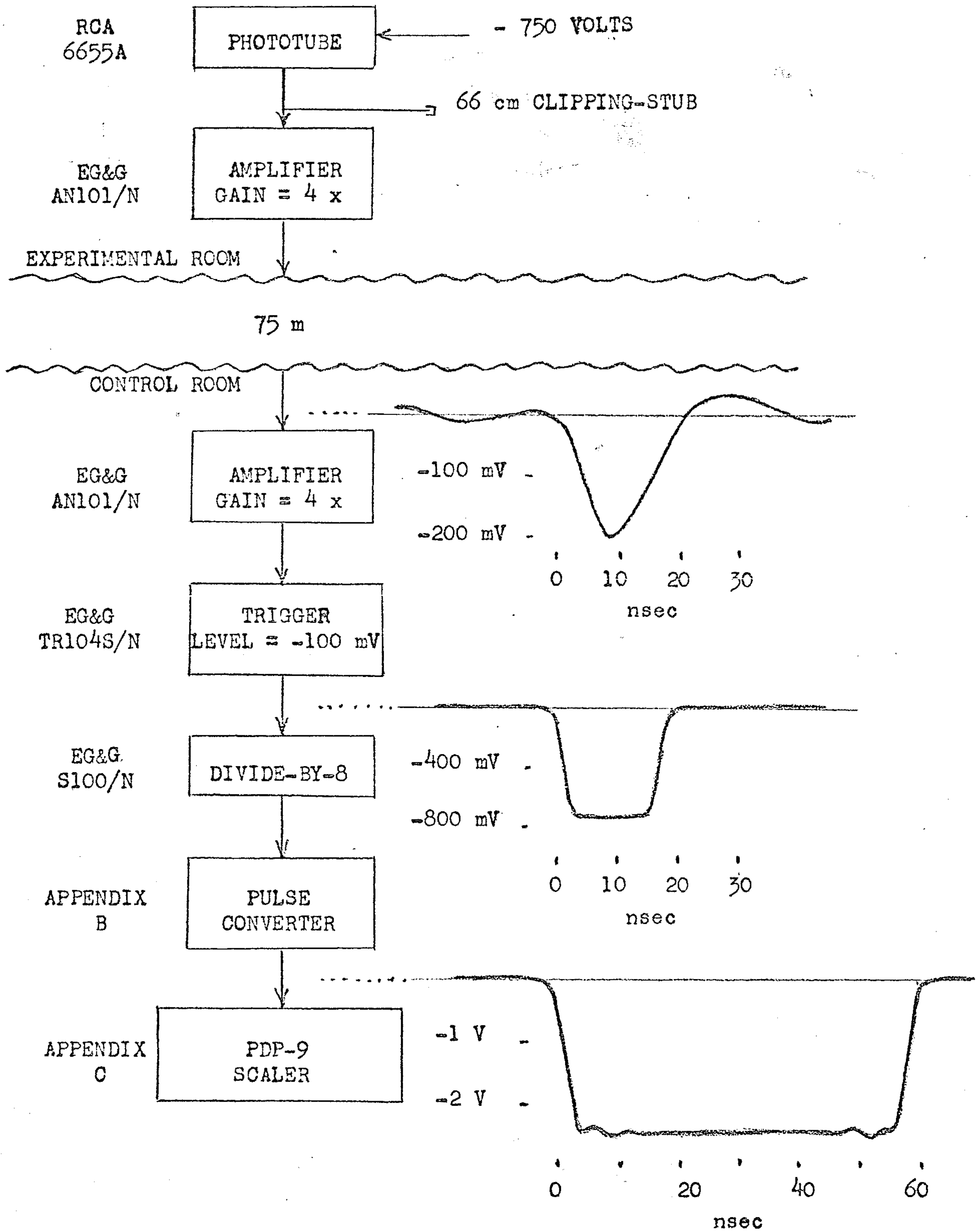
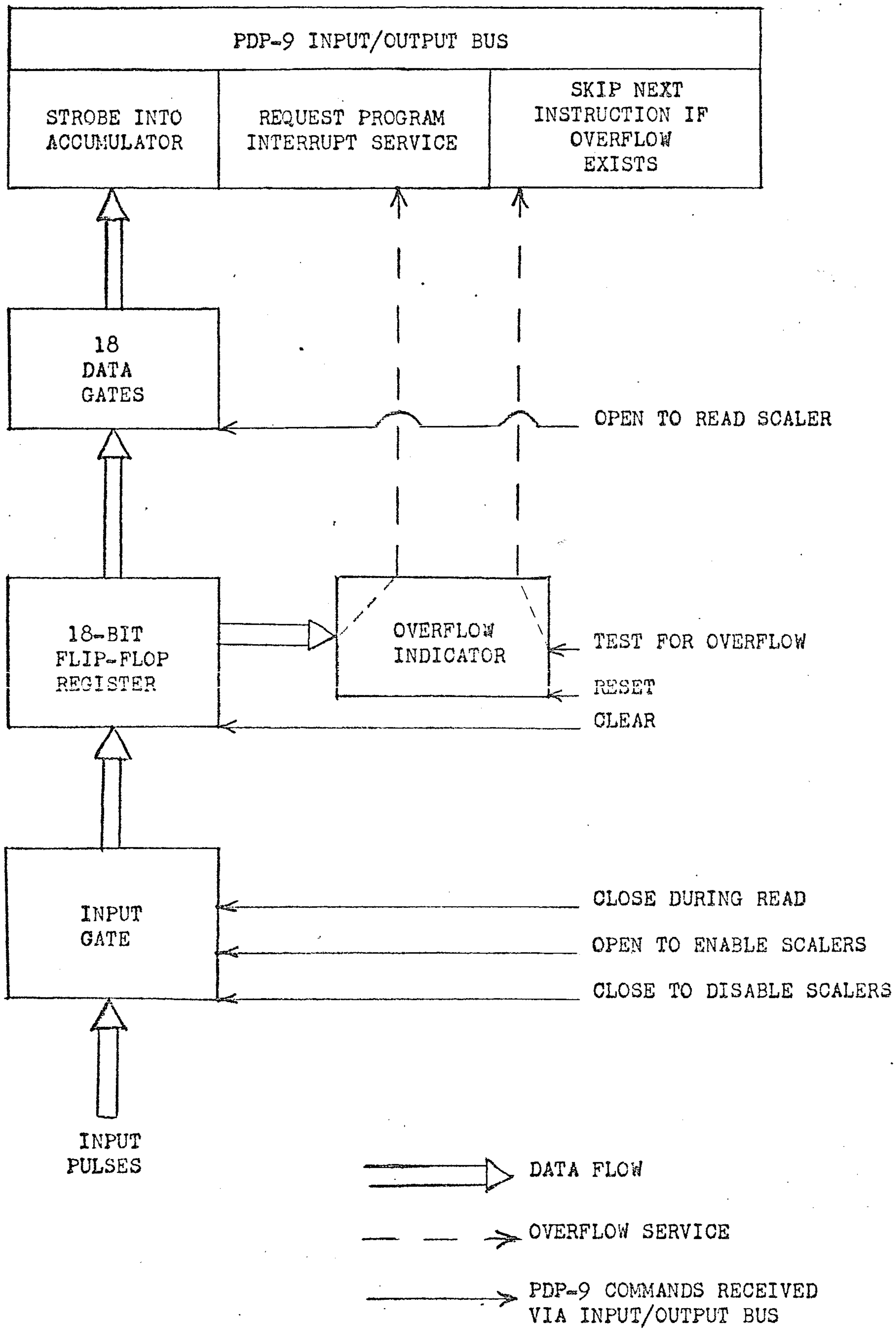

RCA
6655A
PHOTOTUBE
- 750 VOLTS
66 cm CLIPPING-STUB
EG&G
AN101/N
AMPLIFIER
GAIN = 4 x
EXPERIMENTAL ROOM
75 m
CONTROL ROOM
EG&G
AN101/N
AMPLIFIER
GAIN = 4 x
-100 mV
-200 mV
0 10 20 30
nsec
EG&G
TR104S/N
TRIGGER
LEVEL = -100 mV
EG&G
S100/N
DIVIDE-BY-8
-400 mV
-800 mV
0 10 20 30
nsec
APPENDIX
B
PULSE
CONVERTER
APPENDIX
C
PDP-9
SCALER
-1 V
-2 V
0 20 40 60
nsec

Figure 3.4

Block diagram of the PDP-9 scalers. The "pulse counter" of each scaler is the 18-bit register of flip-flops. Data gates allow input pulses to be counted or the scaler contents to be read by the computer. An overflow indicator can signal the computer when the count capacity of the scaler is exceeded. Command signals from the computer can turn on, read, clear, turn off, etc. each scaler separately. Complete schematics are shown in Appendix C.


PDP-9 INPUT/OUTPUT BUS
STROBE INTO ACCUMULATOR
REQUEST PROGRAM INTERRUPT SERVICE
SKIP NEXT INSTRUCTION IF OVERFLOW EXISTS
18 DATA GATES
OPEN TO READ SCALER
18-BIT FLIP-FLOP REGISTER
OVERFLOW INDICATOR
TEST FOR OVERFLOW
RESET
CLEAR
INPUT GATE
CLOSE DURING READ
OPEN TO ENABLE SCALERS
CLOSE TO DISABLE SCALERS
INPUT PULSES
DATA FLOW
OVERFLOW SERVICE
PDP-9 COMMANDS RECEIVED VIA INPUT/OUTPUT BUS

to allow the scaler to accept input pulses at a rate up to 10 MHz. At any time the program can execute a "read" command which opens a set of 18 data gates to strobe the contents of the scaler into the accumulator of the computer. The scaler can also be cleared to zero at any time by computer command. (One precaution must be taken; any command to clear or to disable a scaler must be followed by a command to reset the overflow indicator since this could be set by the clearing of the high-order flip-flop.) If the number of pulses counted after one clear command but before the next exceeds 262,143, an overflow indicator is set and the scaler requests a Program Interrupt for service. Separate computer commands can test the condition of this overflow indicator and can reset it.

Several commands to a scaler are often issued together by using the "micro-coding" feature of the PDP-9 machine language. Thus we have the following IOT (Input/Output Transfer) commands for the various operations: (In all of these examples the functions shown in parentheses are carried out contemporaneously but are incidental to the main purpose of the command. This is because for each scaler three commands perform seven functions - a saving on the cost of hardware necessitates increased software complexity.):

- to clear and enable scaler #1*

  IOT 5104 /clear (disable)

  IOT 5102 /enable; clear overflow (read)

- to read scaler #1

  IOT 5113 /clear accumulator

*The appropriate commands for the other scalers are obtained by replacing "51" by "52" for scaler #2, or by replacing "51" by "53" for scaler #3.

/block input during read (test overflow)

/read (enable; clear overflow)

- to read and clear scaler #1

IOT 5117 /clear accumulator

/block input during read (test overflow)

/read (enable; clear overflow)

/clear scaler (disable)

IOT 5102 /enable (read; clear overflow)

- to read, clear and disable scaler #1

IOT 5117 /description as for IOT 5117 above

IOT 5106 /clear overflow (read; enable)

/disable scaler (clear scaler)

- to test for overflow of scaler #1

IOT 5101 /skip next instruction if the scaler has overflowed (block input for 2 microseconds)

- to clear the overflow indicator of scaler #1

IOT 5102 /clear overflow (read; enable)

The scaler will remain enabled unless this command is immediately followed by IOT 5104 to disable it.

These three scalers occupy three bins in the cabinet of the PDP-9. A connector panel is provided (see Appendix C) for the input BNC's and for several indicator lamps. Each scaler input is wired to two parallel BNC's; the input cable is connected to one BNC, the other is to be terminated by a resistor equal to the characteristic impedance of the cable (here 50 ohms). Standard input pulses are -2.5 volts of width 60 nsec at repetition rates up to 10 MHz. A lamp is provided which is ON when the scaler is enabled and

OFF when it is disabled. Another lamp indicates when the scaler has overflowed. A switch is provided to disconnect the overflow indicator from the Program Interrupt facility. Nine other lamps have been wired via a patch plug to indicate the status of certain scaler flip-flops so that the operation of the scalers may be monitored visually. The output of a B-series oscillator (2 Mhz) is available from another BNC for general use or scaler testing.

3.4 Steering Magnet and Power Supply

The steering magnet used (see Figure 3.5) could provide both horizontal and vertical steering but only the horizontal steering was utilized here. Five amperes is the maximum current which its coils can withstand but this was found to be sufficient to steer the beam of 42 Mev protons by $\pm$ 25 mm inside the scattering chamber - more than enough for our needs.

Direct current to the steering magnet is provided by a bipolar power supply designed and built in the Physics Department Electronics Shop. The current range is $\pm$ 1.5 amperes, adjustable by means of a 10-turn potentiometer driven by a 200-step-per-turn Slo-Syn stepping motor.[13)] This range of operation was chosen qualitatively to give a change in the ratio of counts of about 1% per motor step at typical operating conditions. The stepping motor can be driven manually or by step commands from the PDP-9. Limit switches are provided (set at $\pm$ 300 mA after the effect of the steering magnet on the beam was measured) so that the beam cannot be steered onto the scintillation counters accidentally.

The stepping motor is of the "bifilar" type containing two pairs of windings. One member of each pair must be energized at all times. The motor is made to move one step by switching the current from one member of a pair to the other member; the next step is obtained by similar switching for the other pair. The direction of motion is determined by the sequence in which the windings are energized. A pair of flip-flops in the stepping motor drive interface (schematic in Appendix D) provide the two-on, two-off states for the high-current transistor "switches" connected to the windings. The motor is made to run by changing these states in a forward or backward sequence by two appropriate commands (pulses) from the PDP-9. Two lamps on the scaler connector panel indicate the direction of motion of the motor while a third lamp blinks ON each time a step is taken.

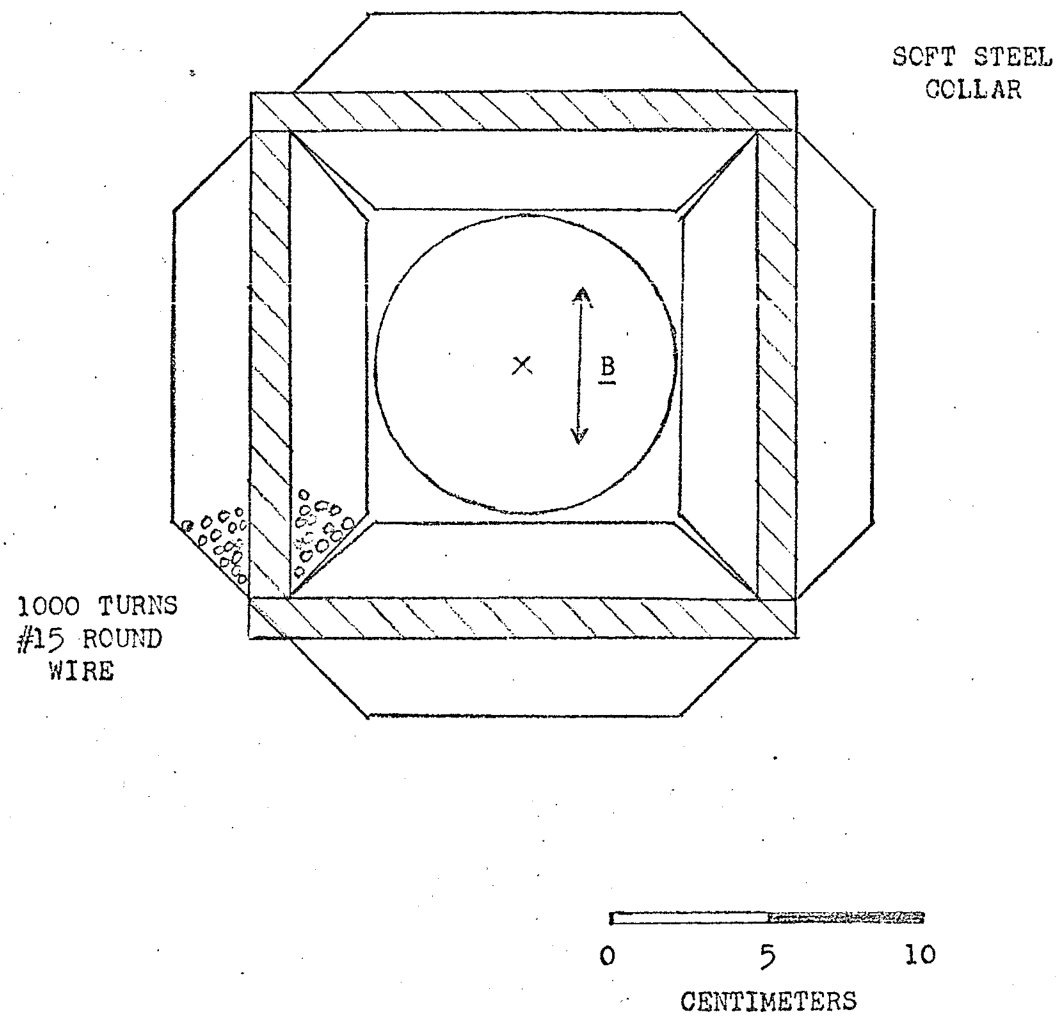
3.5 Software

The computer system[3,4] used for this beam position control system is a PDP-9 made by the Digital Equipment Corporation. It has a memory of 8,192 words (18-bit), a fast Extended Arithmetic Element and Automatic Priority Interrupt. Two teletypes, a high speed paper tape reader, a paper tape punch, a calligraphic display with lightpen and a Calcomp plotter are the main input/out devices. Programs or data can be stored and recalled from two DECtape units. A data link to the IBM 360/65 computer at the University Computer Centre was used to carry out further analyses or parallel processing of data.

Three major PDP-9 programs were written for this control system. All make use of a Symbolic Assembly Language Monitor (SALMON)

Figure 3.5

Cross-sectional view of the steering magnet, looking downstream. A soft steel collar (diagonal shading) surrounds the beam pipe (large circle) along a length of about 15 cm. Each bar of the collar is wrapped with 1000 turns of #15 round wire (e.g. small circles). For this control system the left- and right-hand coils were connected to make the top and bottom steel bars act as magnetic poles whose field B steered the beam to the left or right.


SOFT STEEL
COLLAR
B
1000 TURNS
#15 ROUND
WIRE
0
5
10
CENTIMETERS

written by Mr. D. Reimer[14]) for input/output to the computer peripherals. Commands from the experimenter to these programs proceed via two-character codes on the teletype or via the accumulator switches.

The uses and features of these programs will now be described in turn. The program listings are in the appendices as noted.

(a) Scaler and stepping motor interface tests: This program consists of test routines ranging from the execution of single commands to fairly complex procedure simulations. For a full listing see Appendix E.

For module-by-module checks using an oscilloscope, the program can issue repetitively any of the 7 basic IOT (Input/Output Transfer) commands to any scaler. Special sequences are included to cycle the "read" and "enable/disable" components. Other tests check for any change in the scaler contents caused by the read process itself or for agreement between time intervals obtained from the power line frequency and from the computer cycle time. An extensive routine tests the reliability of the scalers by taking repeated samples of the signal from an external constant frequency pulse generator. The effect of blocking the input pulses during each read is tested by another routine which during a ten-second counting period can read the scalers up to 250,000 times.

The basic motor commands are tested by driving the motor at a speed and direction determined by accumulator switch settings. Backlash and reproducibility are checked by moving the motor a specified number of steps in a specified direction. The response characteristics of the bipolar power supply are measured by stepping the motor a specified number of steps back and forth at a specified rate.

(b) Beam observation program: This program is used either to observe the behaviour of the beam without any beam position control, or to evaluate (using program (c)) the performance of the system when the position control in ON. For a full listing see Appendix F.

Since the accumulator switches are used to stop or hold a run, to change data displays and to select printout options, a convenient teletype code is provided to have a description of the switch functions printed on the teletype.

Observation runs comprising 1,792 timed samples of counts from the left and right scintillation counters can be taken for run times ranging from 0.2 seconds to over one hour. These runs can be taken without controlling the beam position or control may be applied as necessary. The decision to move the motor one step or not after each sample can be based on the ratio of counts from the left and right scintillation counters from the present sample alone or from an average of the most recent samples. To investigate the influence of various cyclotron controls, the third scaler may be used to normalize the samples to a specified amount of charge reaching the Faraday Cup by counting the output pulse of a charge integrator. The tails of the beam seen by the scintillation counters may be examined by a routine which sweeps the beam left and right at a rate specified via the teletype and through a range controllable from the accumulator switches.

The data from each sample are gathered in double precision and scaled to fit into single precision arrays of counts (on the left and on the right) versus sample number. Segments of these data are selected by teletype codes or accumulator switch settings for display on a 1024 x 1024 point screen. A lightpen is available to examine the contents of particular channels or to integrate the counts over some part of the display. Usually the data from all runs are stored on DECtape for later analysis or comparison. Specified parts of the data, or the summary of motor steps taken in the control mode, can be printed on the teletype. Routines are also available to form the left/right ratio for all samples to evaluate the beam stability. These ratios or other data may be scaled for plotting by another program available via the SALMON Monitor on the Calcomp plotter. In addition, runs taken with the control "enabled" have the details of the motor movement coded into the lowest order bit of each data word stored. This information can later be extracted and displayed or plotted to investigate the sample-by-sample actions of the motor.

(c) On-line beam position control routines: These eleven routines are used by the beam observation program described earlier, by programs used to check the operation of the wire chambers, and by the programs used to take the data for the nuclear physics experiment. The complete listing of these routines is found in Appendix G.

The first routine is called at the start of a run to establish the initial conditions of the other routines. The next two "enable" ("disable") the scalers at the start (end) of the run. The fourth detects scaler "overflow" during a run. When such are detected the scalers are reset and the software logic modified to prevent analysis of the beam position data at the end of the sample in which the "overflow" occurred.

The next routine reads the scalers into the computer whenever the wire chambers are sparked. If either scintillation counter produced less than 100 counts the position analysis is again inhibited. These scaler readings can be used alone or can be averaged with the previous 2, 4, 8 or 16 samples to determine the ratio of (counts on the left) to (counts on the right). The left/right ratio is then compared to the acceptable upper and lower limits. If it is outside these limits the appropriate "step left" or "step right" routine is called to help correct the beam position.

With these routines the stepping motor makes at most one step per wire chamber event. During each run a record is kept of the total number of times the motor was not stepped, was stepped left, or was stepped right. Also recorded are the number of times the scalers overflowed and the number of times there was insufficient data. In addition two histograms are made with the abscissa specifying the number of steps the motor made to the left (right) before reversing direction and the ordinate giving the number of occurrences during the run.

CHAPTER IV

PERFORMANCE OF THE SYSTEM COMPONENTS

This chapter presents the results of tests on the components of the beam position control system. Typical operational behaviour is described and any special limitations are noted.

4.1 The Scintillation Counters

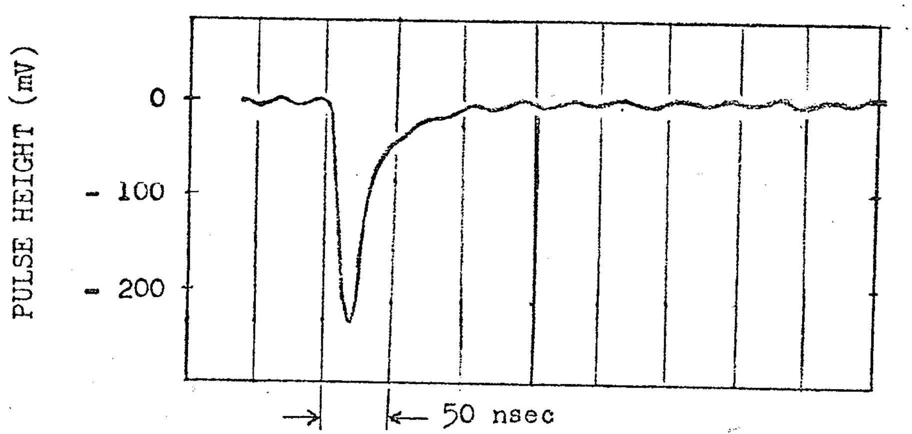
The right-hand scintillation counter was first exposed to the cyclotron beam before any reflective paint was applied to the scintillators and lightpipe. The output pulses were amplified by a factor of four and sent to the control room where their oscilloscope traces were photographed. The output pulses were similarly measured after several coats of light-reflecting paint had been applied to the counter. The pulse heights from all three scintillators on the counter were found to be nearly the same, and furthermore, were nearly the same as the pulse height measured prior to painting. No phototube output pulses could be attributed to ambient light for anode voltages up to 1100 volts. From this it can be concluded that the white reflecting paint (as described in Chapter 3.1) is successful in keeping ambient light out of the scintillation counters while not affecting their output pulses.

Non-uniformity of the height of the phototube pulses has been observed since the counters were completed. Pulses from the top scintillators are now somewhat lower than from the middle scintillators, which are somewhat lower than from the bottom scintillators. This may be due to a combination of circumstances: ageing of the scintillators, potting compound and phototube; degraded pulse heights due to mechanical misalignment of the counter toward the beam; or alterations of the NE 560 reflective paint by the outer layers of white latex paint and, for the right counter, the one coat of blackboard paint (not recommended for future use) between the reflective and latex paints. Another possibility is radiation damage due to an abnormally high flux of protons striking the scintillation counters. Such a flux could be caused by mistuning of the beam, the use of a spot beam instead of a ribbon beam for some measurements, and the scattering of protons from the beam by a tantalum target 25 μ thick used for the calibration of the 22.5 cm x 22.5 cm x 2.5 cm scintillation counters[15)] (see Figure 1.1). Radiation forms "colour centres" which reduce the transparency of the scintillators and, more especially, of the perspex lightpipes. It was anticipated that such damage would not be significant in the first 500 hours of use of the beam positioning counters, but unusual conditions may have shortened this time greatly. Annealing the counters at 60° C may remove the colour centres but this has not been tried. The pulses from all scintillators, however, remain sufficiently large (after approximately 200 hours) to be acceptable to the fast electronics.

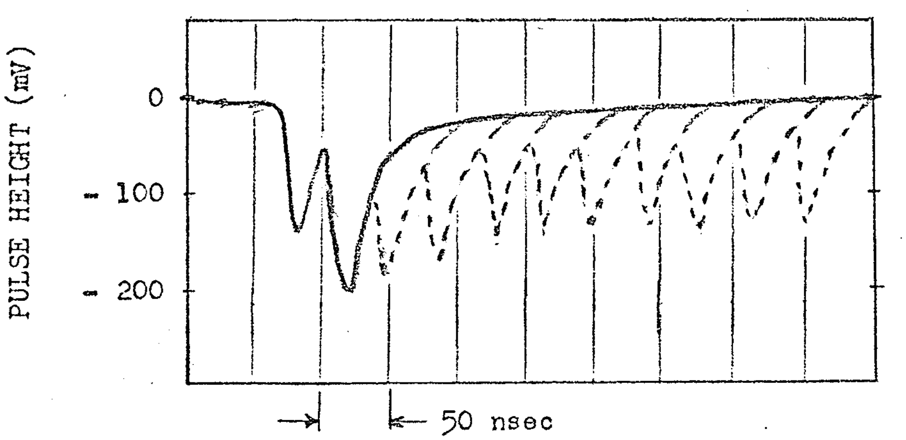
Typical output pulses are shown in Figure 4.1 for both low and high count rates. These pulses were amplified by a factor of four in the Experimental Room (without a clipping-stub) and observed across a 50 ohm terminator in the Control Room. The high-frequency ripple on the traces is due to stray pickup of the cyclotron radio frequency. Note that the puses immediately after the first one are larger because

Figure 4.1

Photomultiplier pulses measured across a 50 ohm terminator in the Control Room for (a) low counting rates and (b) high counting rates. The phototube high voltage was 700 volts. No clipping-stub was used (see Figure 3.3 for that case) but the pulses were amplified by a factor of four in the Experimental Room. Recent observations have shown smaller pulses as well.



(a) LOW PULSE RATES



(b) HIGH PULSE RATES

they are "piled-up" on the tail of earlier pulses.

4.2 The Fast Electronics

It was necessary to adjust the phototube high voltage and to use linear amplifiers in order to make the phototube pulses large enough to operate the EG&G TR104S/N discriminator/trigger module while maintaining low average phototube currents. The 66 cm clipping-stub at the input of the amplifier in the Experimental Room shortened the pulses which were then individually resolved without causing undesirable "extra" pulses due to multiple pulsing of the level-sensitive trigger modules. Typical pulse traces for the fast electronics in the Control Room were shown in Figure 3.3.

The photomultiplier high voltage and the trigger threshold level were determined from the experimental results of Figure 4.2 These were obtained by using the Beam Observation Program to observe the scintillator counts per nC of beam as the high voltage was varied for a particular clipping-stub and the threshold combination. Three criteria were applied: the voltage should be as low as possible to keep the anode current low; the counts per nC should level off as the voltage increases; and the ratio of the normalized counts should be insensitive to changes in the high voltage. On the basis of these results the normal operating conditions for a 5 nA beam through the scattering chamber were chosen to be: trigger threshold = -100 mV, 66 cm clipping-stub at the input of the amplifier in the Experimental Room, and phototube high voltage = -750 volts. These conditions also provided reliable detection of protons in the beam tails without excessive anode current in the phototubes at a beam current of 1 nA.

4.3 The PDP-9 Scalers

These scalers have been tested and found to have satisfactory accuracy, although some unusual characteristics were noted.

Accuracy and reproductibility were checked by allowing both the "Left" and "Right" scaler to count simultaneously the cycles of a one Megahertz sine wave from the transmitter of a nuclear magnetic resonance fluxmeter. For a sample time equal to 60 cycles of the computer clock (nominally one second) the two scalers agreed to within 0.005% of each other. The scaler counts for a series of samples lay within about $\pm$ 0.15% of the average sample count. Much of this spread was due to fluctuations of the line frequency clock itself - a later 10-second test was timed by counting the computer cycle frequency and in that test successive readings for each scaler lay within a range of one part in 10^6.

The use of B200 flip-flop modules for the three low-order bits allows the scalers to handle up to ten million pulses per second. However, if one of these modules fails, the input pulses can "feed through" and produce scaler readings that are twice as large as they should be. In addition, tests have shown that when the scaler contents are read into the computer accumulator, the B200 flip-flops reset themselves to the "0" state. This can lead to errors if the scalers are to be checked (without being cleared) while counting, but caused no difficulty in this experiment.

One requirement is that every command to clear a scaler must be immediately followed (i.e. next instruction) by a command

Figure 4.2

Determination of phototube high voltage and clipping-stub requirements. Four combinations were tried for the setting of the trigger threshold (-100 and -200 mV) and the location of the 66 cm long clipping-stub (at the input of the amplifier in the Control Room and in the Experimental Room). The results shown here were obtained when the clipping-stub was at the input of the amplifier in the Experimental Room. The phototube high voltage was increased manually by 10 volts after each 4 nC of charge reached the Faraday Cup. The beam current was 5 nA and the scintillator separation 12 mm.

Plots (a) and (b) show the normalized counts (arbitrary units) from the left and right counters as a function of high voltage in the range 500 to 1000 volts. The thin line is for a threshold of -100 mV, the thick line for -200 mV.

Plots (c) and (d) show the ratios of the normalized counts as a function of high voltage in the range 500 to 1000 volts.

The most satisfactory combination was found to be: high voltage = -750 volts, trigger threshold = -100 mV, and clipping-stub in the Experimental Room.

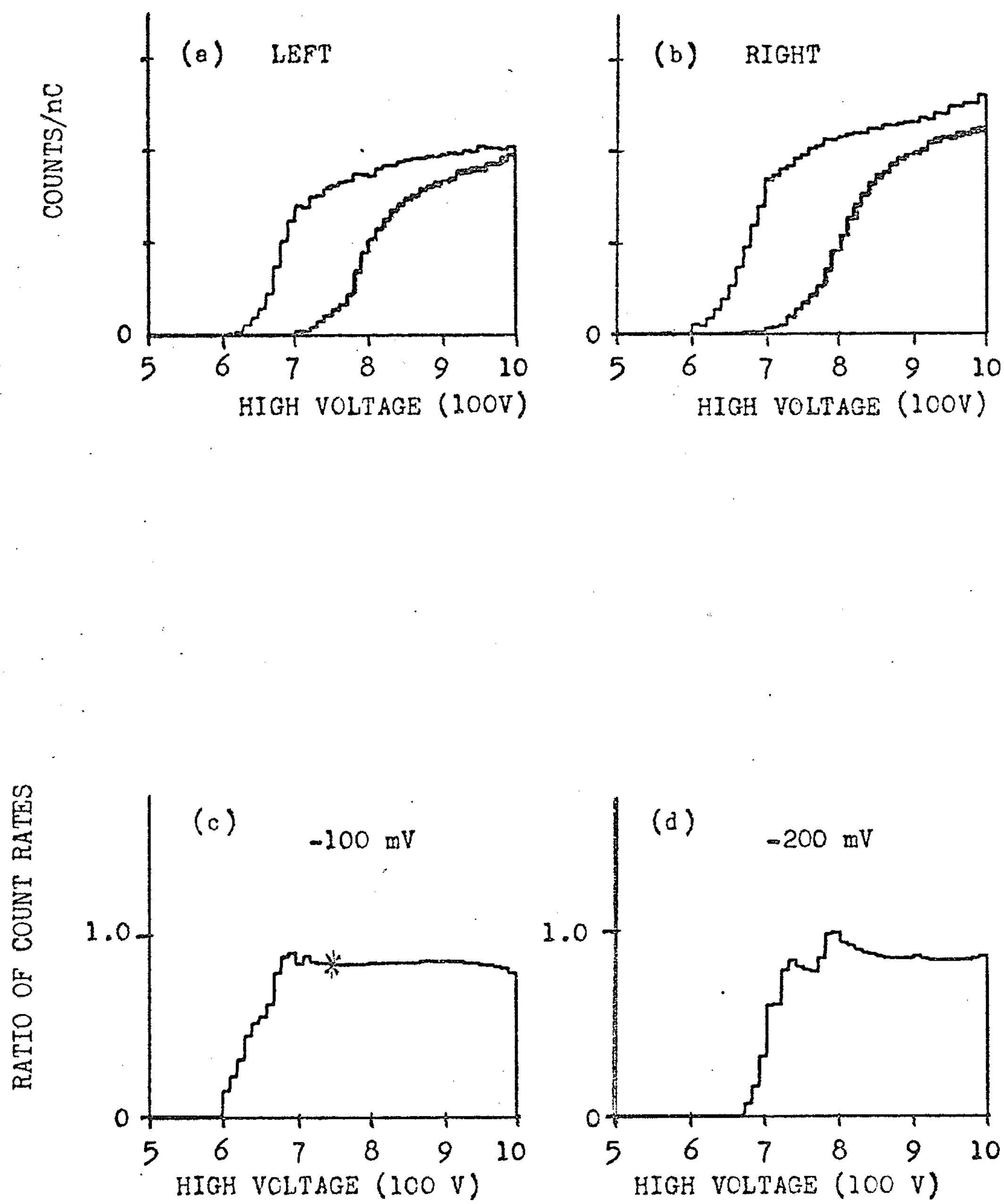
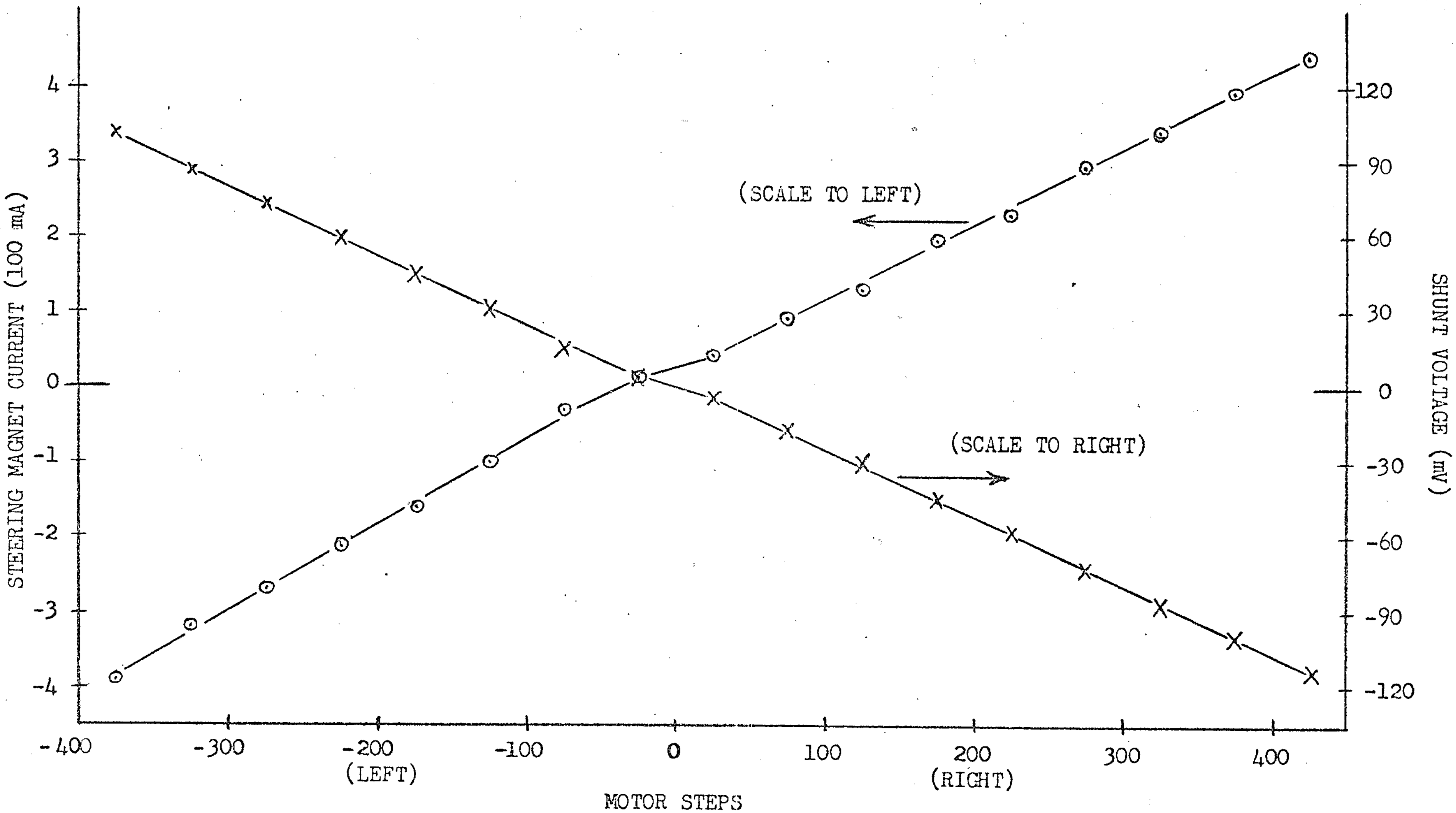

COUNTS/nC
(a) LEFT
0
5 6 7 8 9 10
HIGH VOLTAGE (100V)
(b) RIGHT
0
5 6 7 8 9 10
HIGH VOLTAGE (100V)
RATIO OF COUNT RATES
(c) -100 mV
1.0
0
5 6 7 8 9 10
HIGH VOLTAGE (100 V)
(d) -200 mV
1.0
0
5 6 7 8 9 10
HIGH VOLTAGE (100 V)

Figure 4.3

Steering magnet current (o) and "sensing" voltage (x) as a function of steps of the stepping motor. A 0.25 ohm sensing resistor in series with the steering magnet provides the voltage for the power supply feedback control and for the current-indicating meter. The zero-crossing distortion of the power supply is quite apparent in this calibration.


STEERING MAGNET CURRENT (100 mA)
SHUNT VOLTAGE (mV)
(SCALE TO LEFT)
(SCALE TO RIGHT)
MOTOR STEPS
(LEFT)
(RIGHT)
4
3
2
1
0
-1
-2
-3
-4
120
90
60
30
0
-30
-60
-90
-120
-400
-300
-200
-100
0
100
200
300
400

to reset the scaler's "overflow" indicator. Otherwise, whenever a scaler contained more than 131,071 counts, the clearing of the highest-order bit would set the overflow indicator and falsify the scaler data.

4.4 The Steering Magnet Power Supply

The maximum stepping speed of the motor which adjusts the steering magnet current was found to be about 350 steps per second. This rate is 3 to 5 times the maximum average event rate expected.

The output characteristics of the bipolar power supply are shown in Figure 4.3. Some non-linearity at the zero-crossing point is evident. In normal use the current was in the range $\pm$ 300 mA where the current changed about 1 mA per motor step. The movement of the beam inside the scattering chamber was observed on a zinc sulfide screen. Each motor step moved the beam by 5×10^{-3} mm. Usually this rate of change altered the ratio of scintillator counts by more than the statistical uncertainty in the ratio, but by less than the deviation allowed by the control program. However, if the desired ratio required near-zero current in the steering magnet, the supply sometimes exhibited "zero-crossing" distortion sufficient to cause the system to oscillate. The resulting perturbation of the beam was small and it was not worth trying to cure this occasional misbehaviour.

CHAPTER V

OBSERVED BEHAVIOUR OF THE BEAM WITH NO CONTROL APPLIED

This chapter presents the properties of the proton beam in the scattering chamber and the effects of the beam transport components on the ratio of the count rates from the scintillation counters.

5.1 Horizontal Intensity Profile

Most charged-particle beams are symmetric about a central peak which slopes off into "tails" on either side. In this experiment symmetry was achieved by taking care that the beam transport components affect each side of the beam in a similar fashion. For the Havar foils at the scattering chamber entrance, this impartiality is implicit. For the quadrupole lenses (especially Q5 and Q6), the tuning of the transport system was adjusted so that the beam was on the optic axis. The tuning was normally adjusted such that the left and right halves of slit S1 (see Figure 1.1) intercepted equal amounts of the cyclotron beam and such that the left and right halves of slit S2 were illuminated evenly by one momentum component of the beam.

(a) Profile measured at the upstream end of the reaction volume: The lateral profile of the beam in the scattering chamber was examined by counting protons scattered from a vertical stainless steel wire as it was passed through the beam. For each position of the probe the number of detected protons was normalized to a fixed amount of charge reaching the Faraday Cup. The amount of the beam intercepted or scattered by the wire was never more than about 15 percent. No correction was made for this but its influence on the resulting profile was relatively small and, therefore, unimportant for these measurements.

The results of a measurement in hydrogen gas at 8.9 cm upstream of the centre of the scattering chamber are shown in Figure 5.1. The background counts on either side of the main profile can be attributed to several causes. The anomalous rise on the right-hand side was caused by experimental conditions - the aluminum bracket which supported the stainless steel wire began to move into the beam as the wire was moving out. The dashed extension to the curve shows the profile without this anomalous rise (assuming left-right symmetry). The background on the left-hand side was due partly to single scattering at 30^{o} from the hydrogen gas in the scattering chamber. There also seems to be a small, broad (perhaps symmetric) rise residing under the main peak.

On other occasions beam profiles were obtained in vacuum, hydrogen, helium, or air. The tuning of the cyclotron and the beam transport system can have a large effect on the beam profile. Nonetheless, the profiles in vacuum were generally the most narrow and stood out furthest from the background. Almost all measured profiles appeared as in Figure 5.1 although some were a bit skewed because of poor beam tuning or beam movement during the measurement.

(b) Profile inferred at the scintillation counters: Although a knowledge of the lateral beam profile at the scintillation counters is very desirable, it was not feasible to actually measure the profile there. However, a rough estimate of this profile was made on the basis of two fairly reasonable assumptions. First, that the "shape" of the profile was the same as in Figure 5.1, only the lateral scale changed.

Second, that the beam was 1.25 mm wide (FWHM) at the wire probe, narrowed to zero width at the chamber screen (see Figure 1.2), and then broadened as it approached the beam positioning counters. This implies that the beam divergence was 11.5 mrad, which is in good agreement with the crudely measured value of 10 ± 5 mrad. Simple geometric projection (neglecting scattering by the hydrogen gas) indicates that a 3.8 mm wide slice of the beam (at the wire probe) broadened to span the 12.7 mm separation between the beam positioning counters. This is the basis of the scale at the top of Figure 5.1 showing the inferred beam profile at the scintillation counters. The cross-hatched areas on Figure 5.1 indicate the portions of the inferred profile intercepted by the counters. These areas each correspond to 0.004 of the total beam, in good agreement with the measured fraction, 0.005.

5.2 Influence of the Steering Magnet

In addition to the beam profile shown in Figure 5.1, two others were measured. To obtain them, the stepping motor was moved 200 steps, first to one side of its initial setting, and then the other. At the time of these measurements each motor step changed the current through the steering magnet by 1.4 mA. Thus the measured beam centroid movement, 7.5×10^{-3} mm per motor step, corresponded to 5 mm ($\pm$ 15%) per ampere of current in the steering magnet. This is in good agreement with the earlier result of Chapter 4.4 (obtained by observing the deflection of the beam on the screen inside the scattering chamber).

5.3 The Beam Tails as seen by the Scintillation Counters

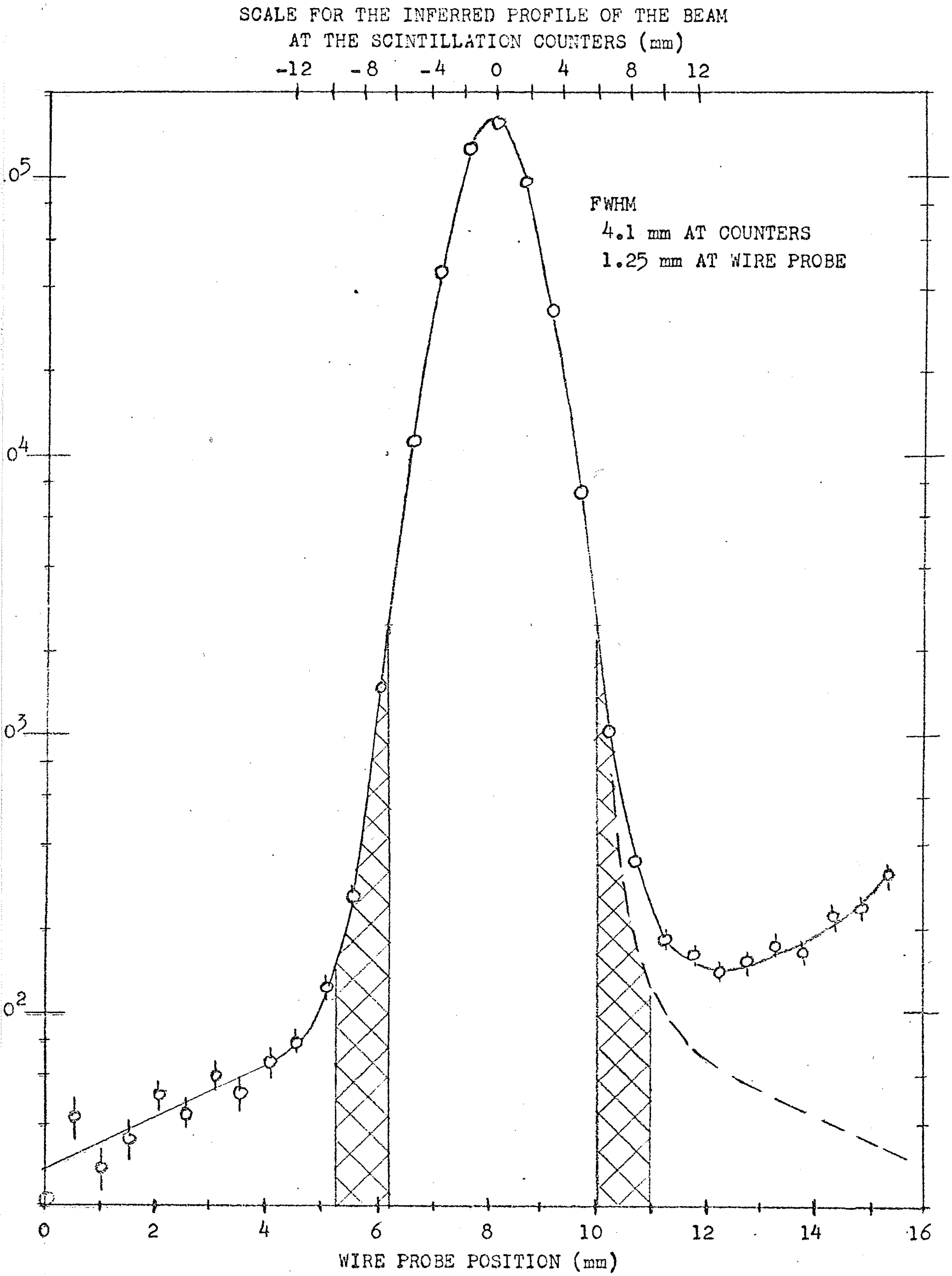
The pulses produced by the scintillation counters come from protons intercepted from the edges of the beam. The behaviour of the

Figure 5.1

Horizontal intensity profile of a 43 Mev beam in the scattering chamber. The horizontal width of the S2 slits was 2.5 mm and Q6 was adjusted to minimize the beam width on a zinc sulfide-coated screen 3.4 cm upstream of the centre of the scattering chamber (Figures 1.1, 1.2).

A 0.88 mm diameter stainless steel wire was mounted vertically on the motor-driven support for the screen inside the scattering chamber. When the support was moved, the wire passed through the beam at a point 8.9 cm upstream of the centre of the scattering chamber. To obtain the data shown on the curves, the wire was positioned laterally (bottom scale) at intervals of 0.5 mm and, while 8 nC of charge was being collected by the Faraday Cup, the protons scattered into a 3 cm x 3 cm area of the spectrometer's right scintillation counter were counted.

At the wire probe the beam had a Full-Width-at-Half-the-Maximum-height (FWHM) of 1.25 mm. On the right side of the curve is an extension (dashed line) showing the beam tail expected on the basis of left-right symmetry. The top scale of the graph is for the inferred profile of the beam (FWHM = 4.1 mm) at the beam positioning counters. The portion of the inferred profile that is sampled by them is indicated by the cross-hatching.


SCALE FOR THE INFERRED PROFILE OF THE BEAM
AT THE SCINTILLATION COUNTERS (mm)
-12
-8
-4
0
4
8
12
FWHM
4.1 mm AT COUNTERS
1.25 mm AT WIRE PROBE
0
2
4
6
8
10
12
14
16
WIRE PROBE POSITION (mm)

ratio of these pulse rates as the beam was moved laterally is shown in Figure 5.2. These data were obtained by sweeping the beam back and forth (by stepping the helipot of the power supply 30 times per second) while recording the pulses from each scintillation counter. For the typical beam sweep shown, the ratio (in the region of 1.00) changed by about 1% for each motor step. This figure also shows some crossover distortion in the bipolar power supply in the region of zero current. A slight hysteresis effect in the magnet response near zero current may be indicated by the small difference ($\pm$ a few percent) in the count rate ratio corresponding to the two occurrences of zero-crossing distortion shown.

An analysis of the expected behaviour of the scintillator count rates as the beam is moved laterally is presented in Appendix A on the assumption that the horizontal intensity profile is Gaussian. Using the known counter separation of 12.7 mm and the inferred FWHM of 4.1 mm (from Figure 5.1), this analysis predicts (see Figure A.2) that the log of the count rate ratio should be a linear function of the beam displacement, with an expected slope of 3.4 mm^{-1}.

The relation shown in Figure 5.2 is approximately linear but the measured slope is 1.9 mm^{-1}. The corresponding plots of log (count rate) versus beam displacement were examined and found to have a somewhat positive second derivative rather than the slightly negative one predicted by Figure A.1. This suggests that part of the background near the beam profile (see Figure 5.1) may be due to a much smaller, broader, symmetric distribution (which may be approximately Gaussian). The source of this smaller distribution might be scattering of the beam from the Havar entrance foils or from the hydrogen in the scattering chamber.

Since the scintillation counters would see a mixture of these two distributions, the FWHM of the beam could not accurately predict the slope of the curve in Figure 5.2. Indeed, the presence of a small background distribution forces the measured slope to be lower than would be the case if only the main profile were present, i.e. when the beam is displaced to the left, the right counter intercepts more protons from the background than from the main profile, thus lowering the left/right ratio of counts. When the beam is to the right, the left counter intercepts more protons from the background than from the main profile and causes the ratio to be higher than it would be if only the main profile were present. These effects are likely sufficient to account for the difference between the expected and the measured slopes.

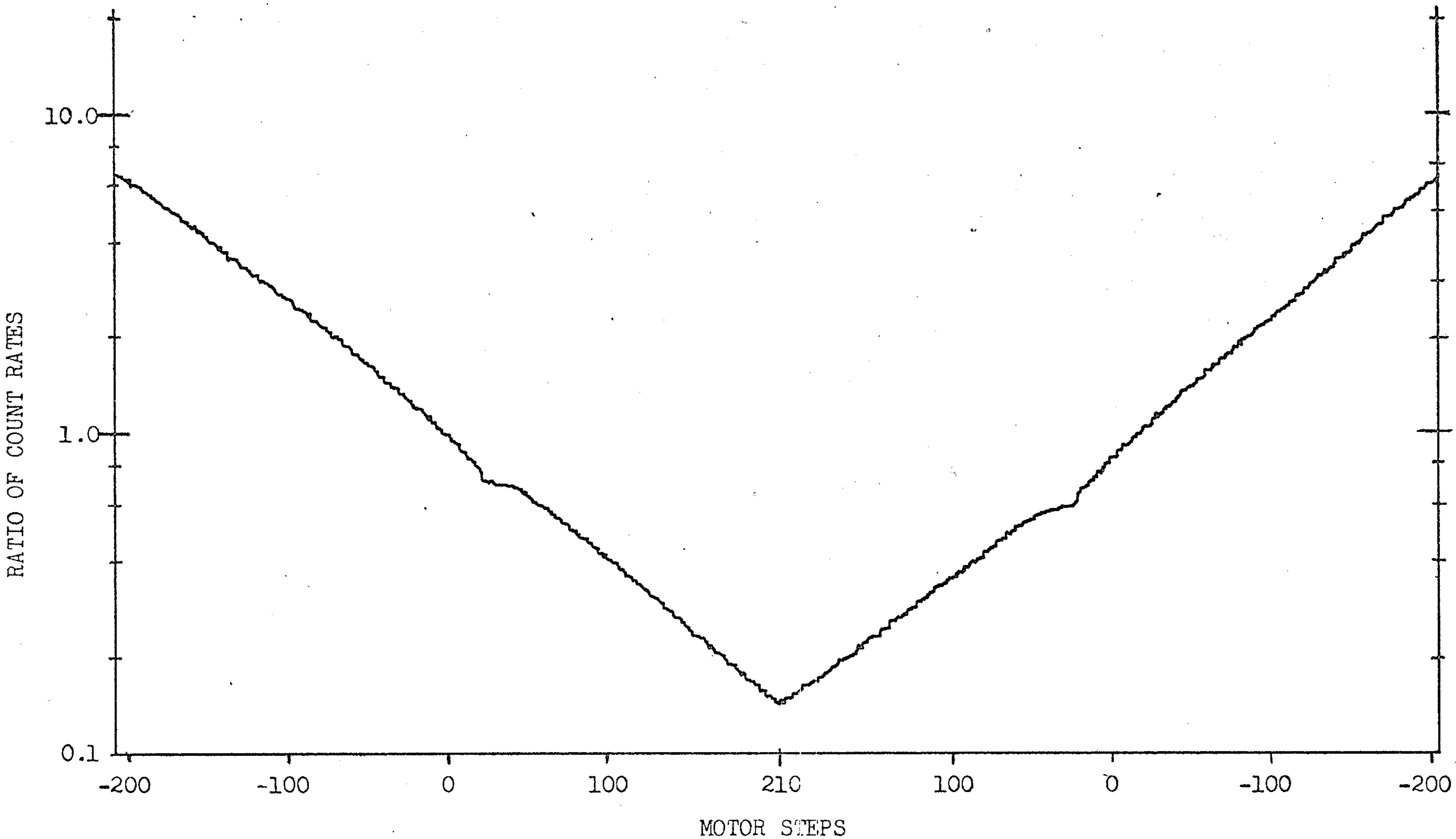
The desired ratio of the count rates for normal operation (discussed in detail in Chapter 6) was usually in the range 0.5 to 2. The influence of the background distribution on the ratio would be negligible under these conditions.

5.4 Spontaneous Instabilities in the Ratio of Count Rates

The stability of the beam inside the scattering chamber depends upon the stable operation of the cyclotron ion source, magnet and radio frequency voltage, as well as all of the focusing and bending magnets of the beam transport. Any variation of these parameters can cause shifts in the beam position which will produce changes in the ratio of count rates. Figure 5.3 shows an observation of such

Figure 5.2

Variations of the ratio of counts from the left and right scintillation counters caused by sweeping the beam from side to side by stepping the steering magnet current. The current in SM3 was set to give equal count rates in both scintillation counters and then the motor was moved 210 steps to left ($L/R > 1$). Next, the motor was stepped to the right at 30 steps per second while the PDP-9 recorded the counts accumulated between steps. After 420 steps (L/R now < 1) the stepping direction was reversed and another 420 steps taken as before. The points were obtained in the order indicated by the arrows.



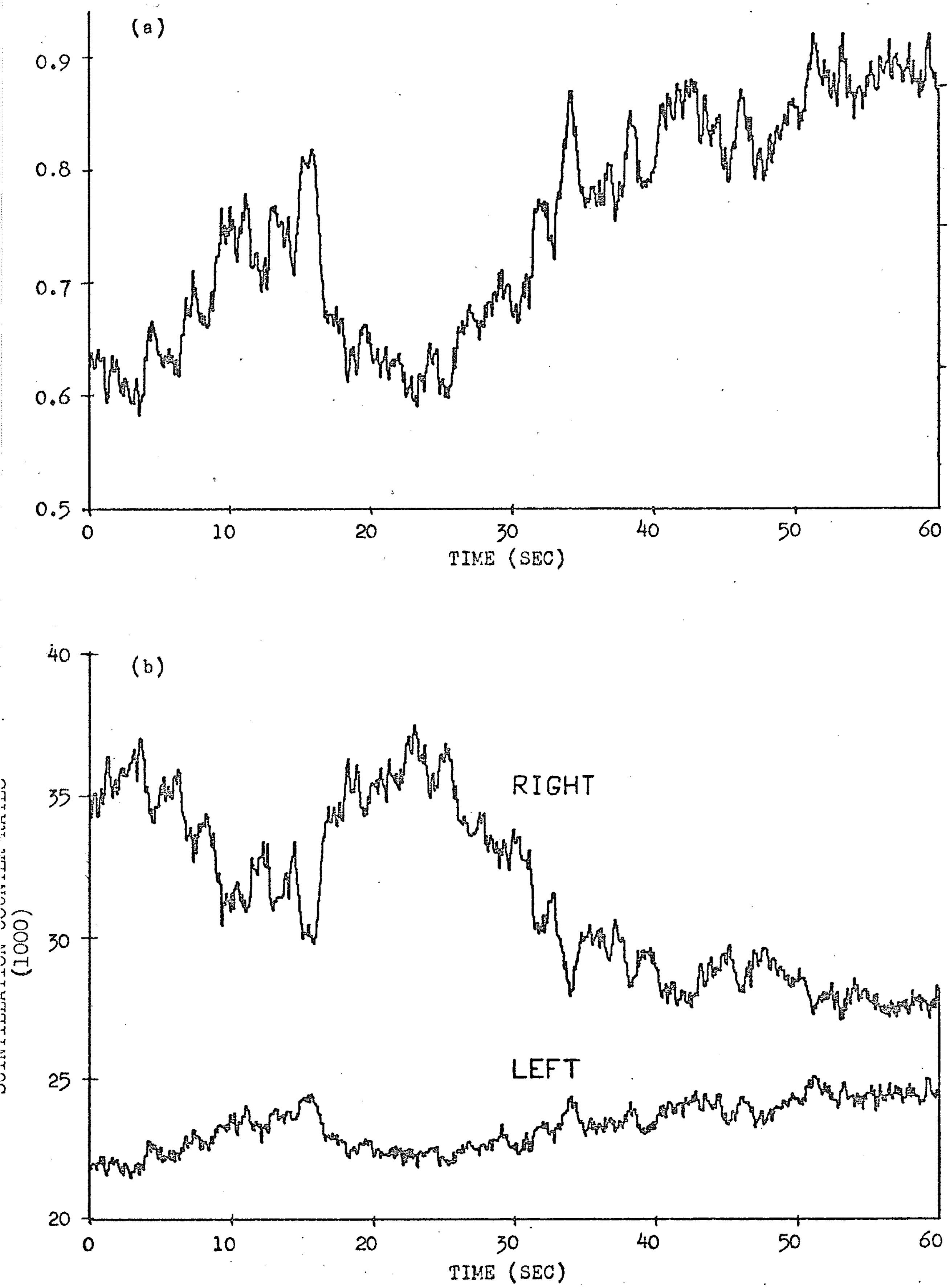
10.0
1.0
0.1
RATIO OF COUNT RATES
-200
-100
0
100
210
100
0
-100
-200
MOTOR STEPS

Figure 5.3

An observation of the instability of the ratio of counts from the scintillation counters over a period of 60 seconds. The Beam Observation Program was used to record the accumulated counts from the scintillation counters every 0.1 second. Control was not applied to the lateral position of the beam during these observations.

(a) ratio = counts from left counter/counts from right counter

(b) counts per 0.1 second from the right counter and from the left counter.


(a)
0.9
0.8
0.7
0.6
0.5
0
10
20
30
40
50
60
TIME (SEC)
(b)
40
35
30
25
20
(1000)
RIGHT
LEFT
0
10
20
30
40
50
60
TIME (SEC)

spontaneous changes as found by the Beam Observation Program operated with no position control applied to the beam. The rapid fluctuations (typically $\pm \frac{1}{2}\%$) caused by the statistical nature of the observations of the count rates is evident. The maximum excursions of the ratio during this run were about $\pm$ 15% which corresponds to a beam wandering (at the scintillation counters) of about $\pm$ 0.1 mm during the observation period of 60 seconds. Over longer periods of time and for less well behaved beam tuning conditions the excursions of the beam position were larger than this.

5.5 Effects of the Cyclotron and Beam Transport Components

Detailed observations were made of the influence of some of the cyclotron and beam transport components on the beam in the scattering chamber. The effects of changes in the components were measured by observing the normalized scintillation count rates as some parameter was systematically varied or by comparing beam profiles or tail sweeps for several values of a particular parameter.

(a) Havar entrance foils: The influence of these foils (total thickness 6 μ) was studied by placing an extra 6 μ foil between them. The normalized count rates in the scintillation counters doubled. However, the graphs showing the logarithms of the ratios of the count rates for side-to-side sweeps of the beam with the extra foil in place and with it removed were found to have the same slope (within the statistical errors). This suggests that the shape of the beam profile in the region sampled by the scintillation counters did not change, but that the density of the beam in this region was proportional to the thickness of the Havar entrance foils.

(b) Quadrupole Q6: This quadrupole focuses the beam to produce a horizontal waist in the vicinity of the scattering chamber. A change in the current through Q6 moves the waist position upstream or downstream. The corresponding change in the normalized count rate is shown in Figure 5.4a. For the 43 Mev beam used, and a certain particular setting of quadrupole Q5, the beam width was a minimum on the screen in the scattering chamber when the Q6 dial was set to 324. However, the minimum count rate in the scintillation counters was obtained when the waist was moved downstream by reducing the Q6 setting to 314. This Figure also shows evidence of beam "steering", i.e. the vertical plane of symmetry of the beam did not lie along the locus of the beam waists. This is shown by the decrease in the (left/right) ratio as the waist was moved downstream, i.e. the beam approached the vertical plane of symmetry of the spectrometer from the right - see Figure 5.4b.

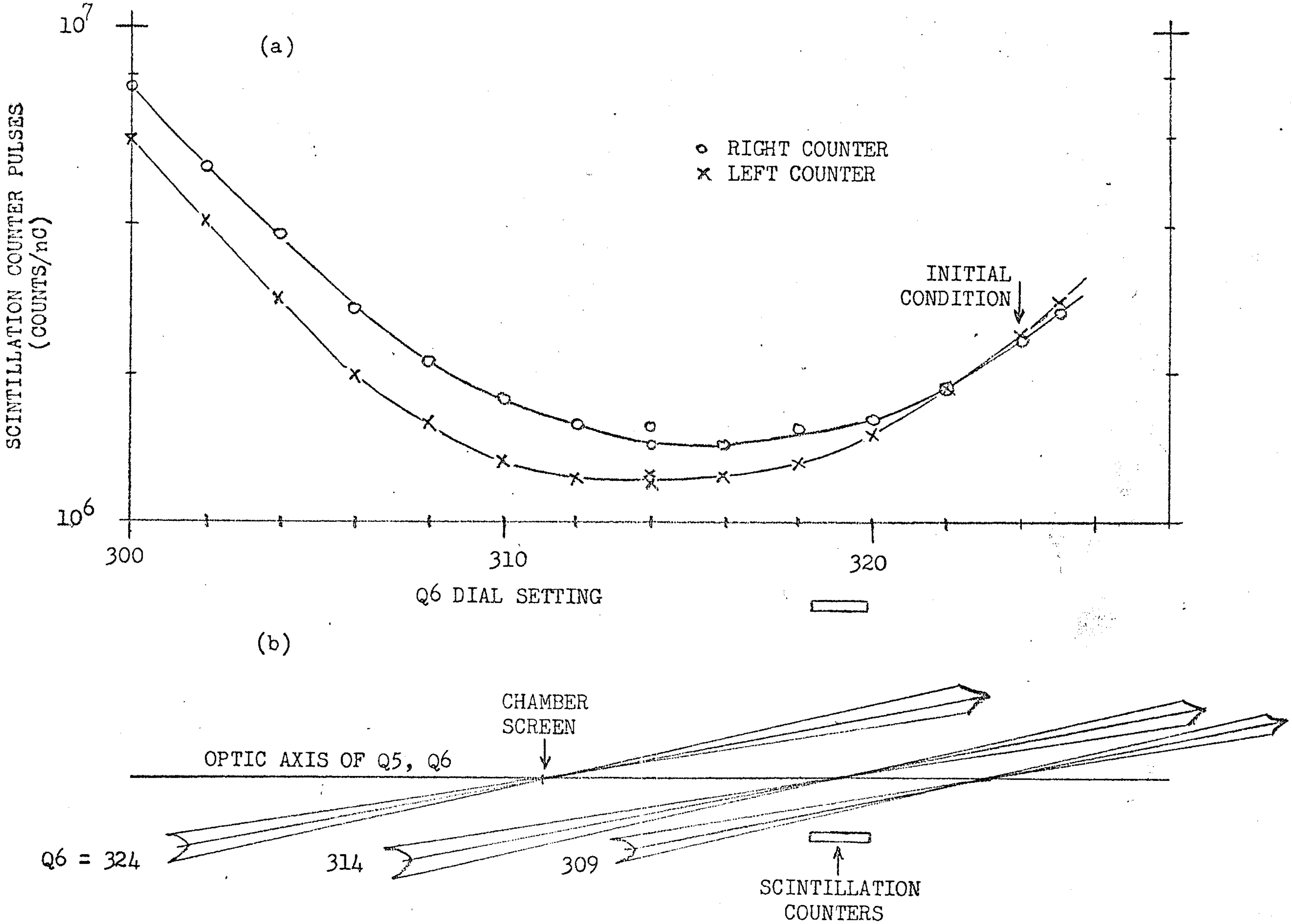
Unexpected results were obtained when a side-to-side sweep of the beam was observed with the Q6 control set at 314 and again at 324. The left and right scintillator count rates were lower at Q6 = 314 (as expected), but the slope of the graph of the logarithms of the ratios was smaller as well. This does not agree with the hypothesis that the beam at the scintillation counters is narrower when Q6 = 314; hence (by Figure A.2) the slope of log (L/R) should be greater for Q6 = 314. The most likely explanation is that when Q6 = 314 the beam profile at the scintillation counters is similar to the measured profile (at the wire probe) in Figure 5.1. This means that the lateral position of the counters is well out on the smaller, broader background distribution.

Figure 5.4

Effect of Q6 current on the normalized count rates from the scintillation counters.

(a) A Q6 dial setting of 324 minimized the width of the ribbon beam on the screen 3.4 cm upstream of the centre of the scattering chamber. The scintillator count rate was minimized for Q6 = 314.

(b) The horizontal beam waist moves downstream as the Q6 setting is reduced. The fact that this led to a greater number of counts per nC from the right-hand counter than from the left-hand counter indicates that the beam in the scattering chamber was approaching the locus of the beam waists from the right (shown exaggerated for clarity).



(a)
10^7
10^6
SCINTILLATION COUNTER PULSES (COUNTS/nC)
o RIGHT COUNTER
x LEFT COUNTER
INITIAL CONDITION
300
310
320
Q6 DIAL SETTING
(b)
CHAMBER SCREEN
OPTIC AXIS OF Q5, Q6
Q6 = 324
314
309
SCINTILLATION COUNTERS

(c) Horizontal slits: The influence of the S1 H (Horizontal) and S2 H slits upon the beam in the scattering chamber was found to be less reproducible than that of the Havar foils. We might expect the S1 H slits to affect only the beam intensity but not its distribution while the S2 H slits should influence both since these slits are the "line object" for the Q5, Q6 quadrupole doublet. However, the nature and extent of these influences seem to be inter-related and affected by the beam tuning as well.

When the beam was well tuned, the beam current through the scattering chamber was proportional to the width (opening) of the slits.

The effect of the width of the S2 H slits on the FWHM of the beam profile in hydrogen gas is shown in Figure 5.5a. The relationship was approximately linear but the curve may have levelled off for S2 H $<$ 5 mm. In any event, there was a non-zero minimum for the attainable FWHM inside the scattering chamber. This is partly a property of all charged particle beams (point focus not attainable in practice) and partly due to additional multiple scattering of the beam by our Havar entrance foils. When the width of the S2 H slits was 2.5 mm, the FWHM of the profile as given by Figure 5.5a was 2.25 mm, which differs from the 1.25 mm given by Figure 5.1. This may have been due to different tuning conditions of the cyclotron beam for these two measurements, or it could have been caused by the wire probe's being non-parallel to the plane of symmetry of the ribbon beam during the measurement shown in Figure 5.5a.

Another measurement, on the same date as that of Figure 5.5a, showed that variations of the S1 H width over the range 2.5 mm to 7.5

mm had no effect on the FWHM of the lateral beam profile inside the scattering chamber.

The effect of the width of the S2 H slits on the normalized count rates in the scintillation counters is shown in Figure 5.5b. The count rates increased approximately linearly as the S2 H slits were opened from 0.5 mm to 8.5 mm. For this measurement Q6 was adjusted for minimum beam width on the screen inside the scattering chamber. The scintillation counters were 10.7 mm apart and each sampled a slice of the beam tail which contained 0.3% of the beam current.

Measurements of the scintillation counter pulse rates were obtained as the beam was swept side-to-side with the S1 H slits open about 3 mm and the S2 H slits open 1.25, 2.5 and 5.1 mm. There were no significant differences among the slopes of the graphs of the "log (left counts/right counts) versus motor steps". This suggests that for small openings ($\lesssim$ 5 mm) of the S2 H slits, the inferred width of the beam at the position of the scintillation counters is, to first order, independent of the width of the S2 H slits.

(d) Cyclotron stripping foil and magnet: It was found that changes in the angle of the stripping foil of $\pm \frac{1}{2}^{\circ}$ made the beam non-parallel to the longitudinal/vertical plane of symmetry of the spectrometer, i.e. the beam was steered and pivoted as in Figure 2.1c. This behaviour was used in tests of the system performance. These will be described in Chapter VI.

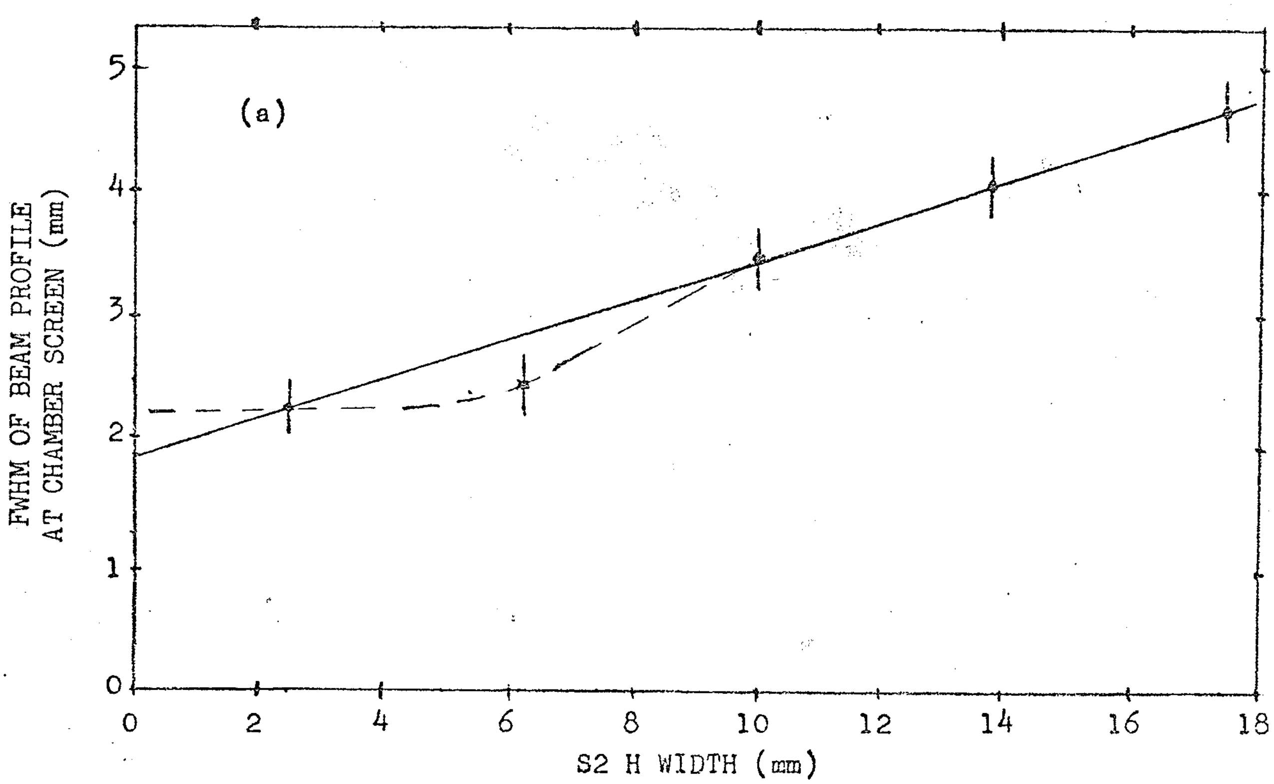
The tuning of the cyclotron magnet strongly affects the quantity and quality of the beam in the scattering chamber. One measure-

Figure 5.5

Effect of the horizontal width of the S2 H slits on the beam in the scattering chamber.

(a) Lateral beam profiles were measured by the method described for Figure 5.1. The FWHM of these profiles is shown as a function of the width of the S2 H slits (the S1 H slits were kept 2.5 mm wide). For S2 H $<$ 5 mm it is not certain whether the linear drop continued or whether the FWHM levelled off at about 2.2 mm (dashed line).

(b) The normalized count rates from the scintillation counters are shown as a function of S2 H while the S1 H slits were kept 2.5 mm wide. These measurements were taken 22 months after (a).


(a)
FWHM OF BEAM PROFILE
AT CHAMBER SCREEN (mm)
0
1
2
3
4
5
0
2
4
6
8
10
12
14
16
18
S2 H WIDTH (mm)

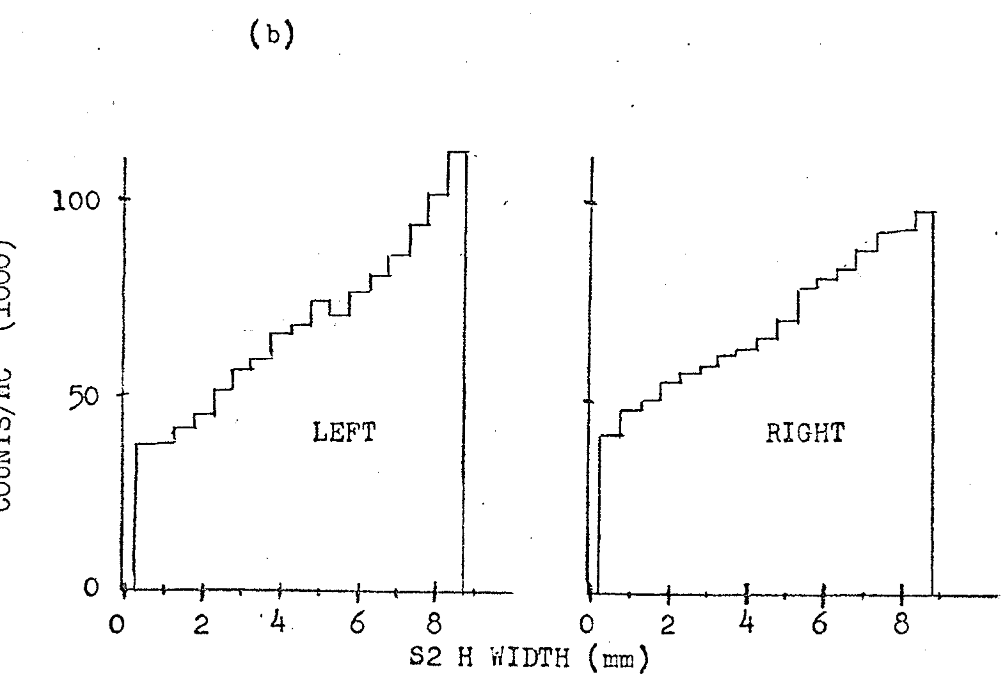

(b)
100
50
0
LEFT
RIGHT
0
2
4
6
8
0
2
4
6
8
S2 H WIDTH (mm)

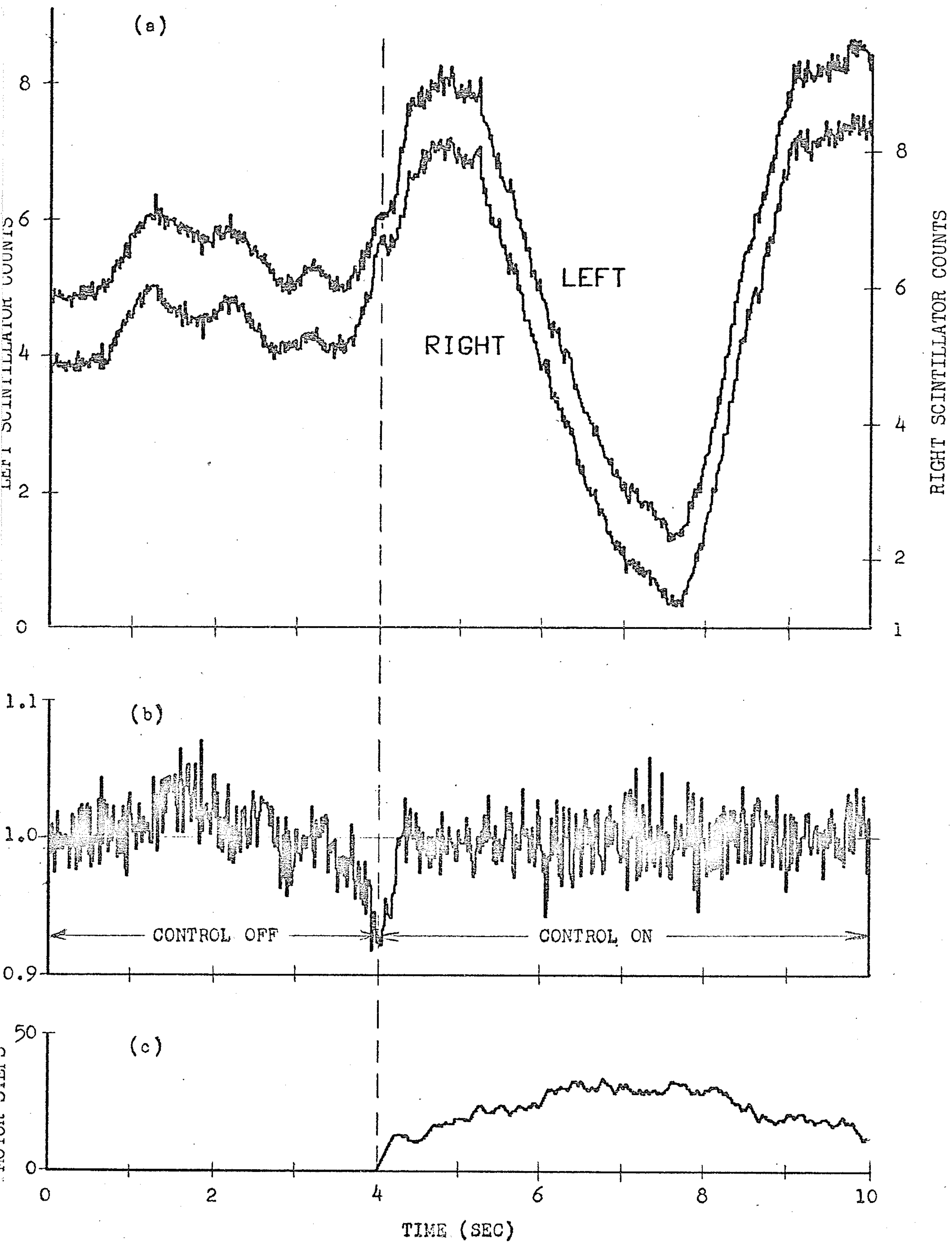
Figure 5.6

Effect of the cyclotron magnet current on the scintillation counter pulse rates.

(a) The counts from the left and right scintillation counters as a function of time are shown. The cyclotron magnet current was manually varied (non-uniformly) during the run (34 seconds long) from which these data (covering 10 seconds) are taken. The variation covered a range of about $\pm$ 200 mA around the optimum current. The curves from the two counters are shown vertically displaced for clarity.

(b) The ratio of the left counts/right counts from (a).

(c) The steps taken by the motor on the bipolar power supply. The control system was OFF for the first 4 seconds, then ON for the next 6 seconds. At the end of the run the motor was 12 steps to the left of its initial position.


(a)
LEFT
RIGHT
RIGHT SCINTILLATOR COUNTS
(b)
CONTROL OFF
CONTROL ON
(c)
TIME (SEC)
0
2
4
6
8
10
1.1
1.0
0.9
50

ment of this is given in Figure 5.6. It shows the variation of the scintillation counter pulse rates during a 10-second interval as the current in the cyclotron magnet was manually varied (non-uniformly) over a range of about 200 mA ($\pm$ 0.01%) around the optimum current.

Initially the beam position control system was OFF and the ratio of the count rates from the left and right scintillation counters was seen to vary within the range of 0.93 to 1.03 even though the actual count rates did not change much (magnet current near resonance). Then, during the time that the beam position control was ON, the scintillation counter rates changed markedly (magnet current off resonance), but the control system maintained the beam position such that the ratio of the count rates generally stayed within $\pm$ 0.02 of the desired value. At the end of this observation the stepping motor on the bipolar power supply was 12 steps to the left of where it started. This corresponds to a correction of the beam position of about 0.1 mm.

CHAPTER VI

PERFORMANCE OF THE CONTROL SYSTEM

This chapter presents the calibration of the position of the proton beam as a function of the specified ratio of counts from the scintillation counters. The influence of software parameters and the stability of the beam under computer control are discussed. An example is given to show the stability of the beam over a period of a few hours.

6.1 Calibration of the Ratio Parameter

Ideally the vertical/longitudinal plane of symmetry of the spectrometer coincides with that of the scattering chamber and the beam sensing scintillation counters lie equidistant on either side of it. In practice it is not possible to position the scintillation counters (with respect to the scattering chamber) such that this desired alignment is assured. The best procedure, therefore, is first to mechanically position the counters as well as possible, and then to calibrate the ratio parameter by measuring the position of the beam corresponding to various count rate ratios.

A piece of D_2-enriched polyethylene (35 mm x 50 mm x 0.15 mm) was placed in the scattering chamber (see Figure 1.2) to intercept the ribbon beam in order to generate events which trigger the wire chamber spectrometer. A brass plate with a 2.5 cm diameter hole in it was placed in the middle of the face of each of the 22.5 cm x 22.5 cm x 2.5 cm scintillation counters. Thus, all protons which scattered from the target and triggered the wire chambers had scattering angles equal to $28^{\circ} \pm 1^{\circ}$. A PDP-9 program incorporating the "On-Line Control Routines" was used to examine the relation between the beam's position and the ratio of the pulse rates from the left and right scintillation counters. This program[2)] performed the vertex analysis of the particle tracks and accumulated a histogram of the longitudinal distance (Z-error) between the points of interception of each track with the assumed beam plane. The lateral position of the centroid of the beam was derived from the measured centroid of the Z-error histogram by a method analogous to Figure 1.3, i.e.

$$\text{beam centroid} = (\text{Z-error centroid})/(\cot \theta_1 + \cot \theta_2)$$

where θ_1 and θ_2 are the scattering angles from the target to the holes in the brass plates over the spectrometer scintillation counters. In this case both θ_1 and θ_2 are equal to 28 degrees.

Examples of the Z-error histograms for several pulse rate ratios are shown in Figure 6.1a. The width of these curves was not particularly affected by the changes in ratio but the location of the centroid clearly was affected. When the geometric corrections were made, the (position) vs (log ratio) relation predicted by Figure A2.b was found experimentally - see Figure 6.1b. These results show that the beam centroid (at 9.2 cm upstream of the centre of the scattering chamber) was on the vertical/longitudinal plane of symmetry of the spectrometer when the ratio of the count rates from the left and right scintillation counters was equal to 1.6.

6.2 Short-Term Stability of the Scintillation Counter Rates

The success of the beam position control system in maintaining the specified ratio of count rates from the two scintillation counters was evaluated by observing the scintillation counter rates (for up to 5 minutes) with the control system OFF for a part of the time.

Observations of the short-term stability of the ratio of counter rates were made at 6 and at 20 samples per second - see Figure 6.2. The scintillation counters at that time were 14 mm apart and giving about 1.2×10^6 pulses per second. Thus, the expected statistical spreads in the ratios of the count rates were $\pm$ 0.2 and $\pm$ 0.4 percent, respectively. The Beam Observation Program allowed the ratio to vary within limits of $\pm$ 0.75 percent without taking corrective action.

For each of these runs, Figure 6.2 shows the ratio of the count rates from the left and right scintillation counters as well as a record of the steps made by the motor to alter the SM3 current. In all cases the measured ratio was closer to the specified ratio (= 1.0) while the control system was ON and wandered much more while the control system was OFF. The observed spread in the ratio was larger and the motor made more steps during the run having the higher number of samples per second.

An example of how the beam position control system maintained the ratio of the count rates from the scintillation counters while the main magnet current was changed has already been given in Figure 5.8.

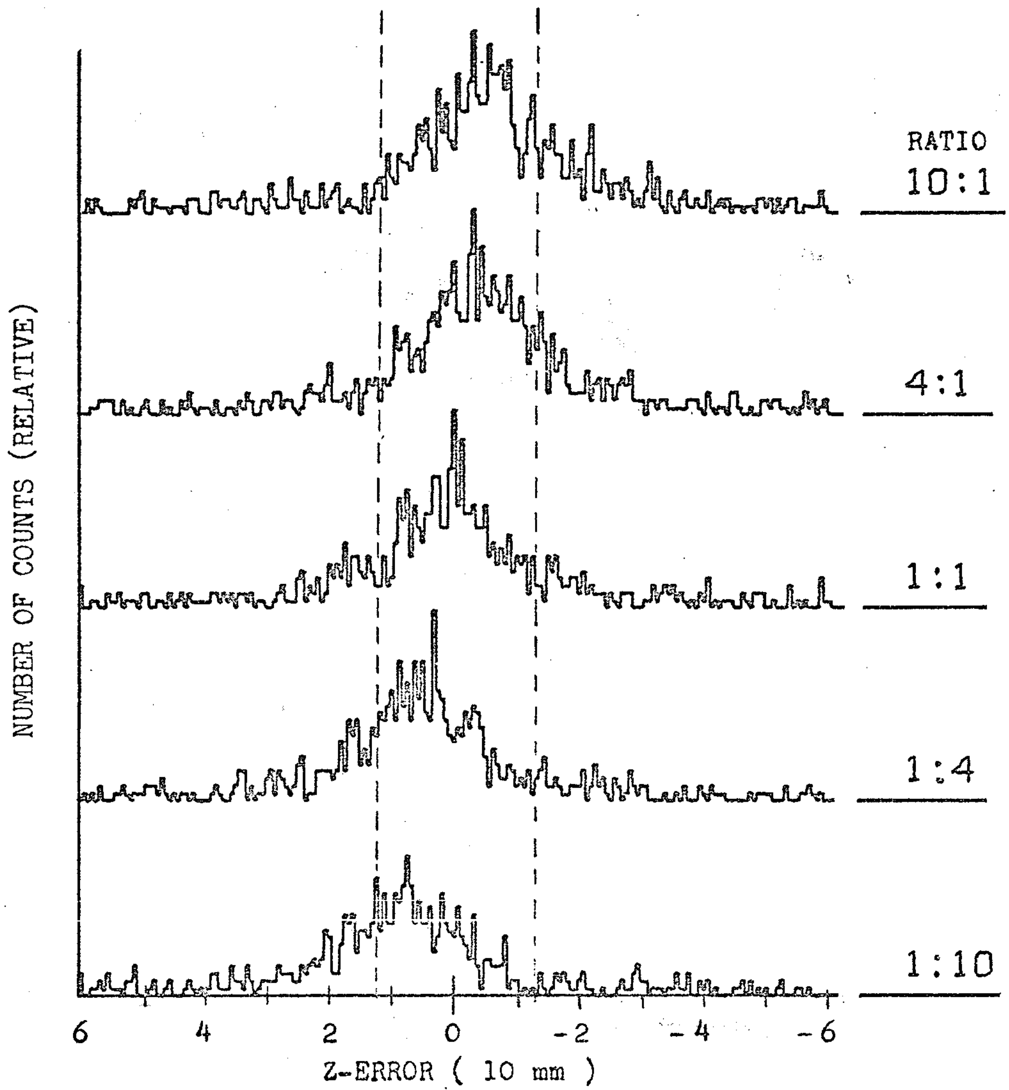
Figure 6.1

Determination of the relation between the lateral position of the beam and the ratio of the count rates from the left and right scintillation counters.

(a) Histograms of the Z vertex error (defined in Figure 1.3) for several ratios of the count rates specified in the beam position control routines in the vertex analysis program. The dashed lines show typical limits of acceptability applied by the vertex analysis and particle kinematics programs. Vertices to the left (right) of the beam plane have a positive (negative) error.

(b) Each point gives the lateral position of the centroid of the Z-error histogram from a CD_2 target (9.2 cm upstream of the centre of the scattering chamber) for one of several count rate ratios. The solid line is a visual fit to these points. The dashed line is the lateral position of the beam centroid as a function of the ratio of the count rates, derived geometrically by a method analogous to Figure 1.3.

(a)


NUMBER OF COUNTS (RELATIVE)
RATIO
10:1
4:1
1:1
1:4
1:10
6
4
2
0
-2
-4
-6
Z-ERROR (10 mm)

(b)

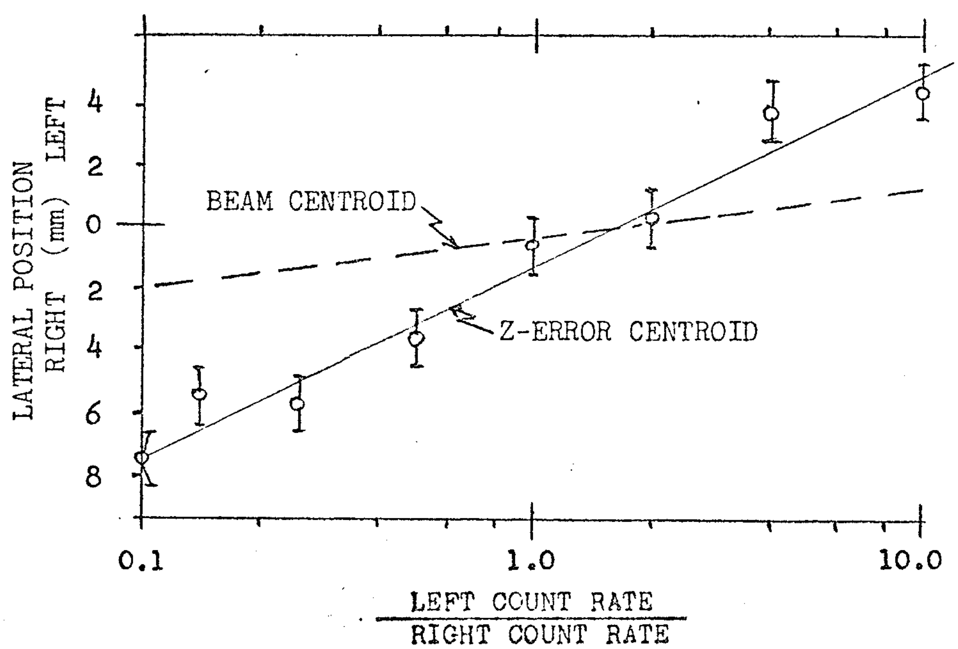
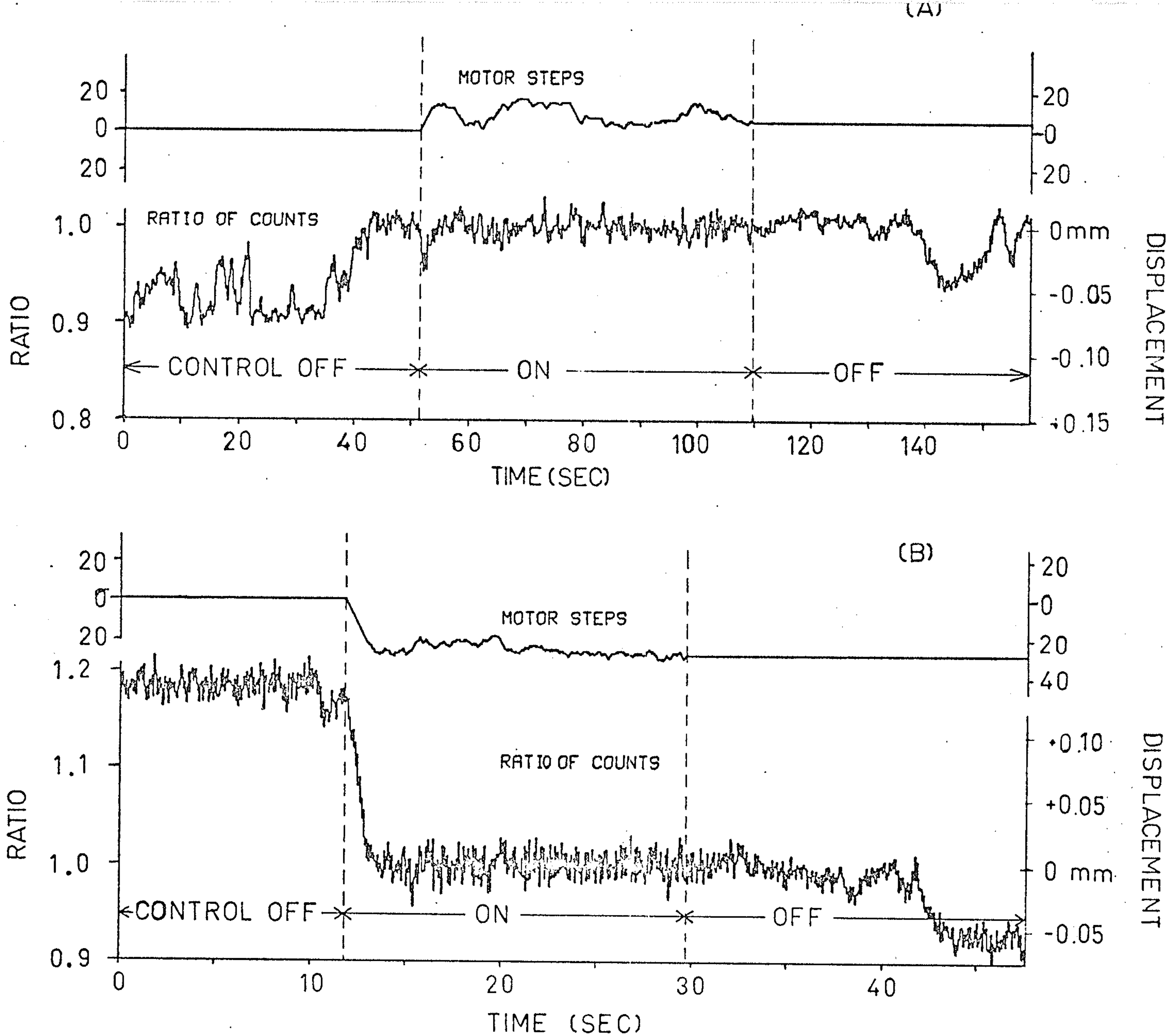

LATERAL POSITION
RIGHT (mm) LEFT
4
2
0
2
4
6
8
BEAM CENTROID
Z-ERROR CENTROID
0.1
1.0
10.0
LEFT COUNT RATE
RIGHT COUNT RATE

Figure 6.2

Observation of the ratio of count rates and the steps of the SM3 current at two sampling rates. The scintillation counters were 14 mm apart and producing about 1.2×10^6 pulses per second each.

(a) 6 samples per second

(b) 20 samples per second.


(A)
MOTOR STEPS
20
0
20
RATIO OF COUNTS
1.0
0.9
0.8
RATIO
CONTROL OFF
ON
OFF
0
20
40
60
80
100
120
140
TIME (SEC)
0mm
-0.05
-0.10
-0.15
DISPLACEMENT
(B)
MOTOR STEPS
20
0
20
40
1.2
1.1
1.0
0.9
RATIO
RATIO OF COUNTS
CONTROL OFF
ON
OFF
0
10
20
30
40
TIME (SEC)
+0.10
+0.05
0 mm
-0.05
DISPLACEMENT

6.3 Influence of Software Parameters

The most important parameters to be specified to the "On-line Beam Position Control Routines" are the desired ratio of the count rates and the allowable limits on that ratio (within which no corrective action will be required). The method of choosing the proper ratio was discussed in the previous section, while the choice of the limits depends primarily on the statistical spread expected in the data.

Figure 6.3 shows the results of measurements to test the response of the control system to the statistical spread in the data. In part (a) observations were taken for several different limit specifications while the beam position was being controlled. The sample rate was 60 per second and the scintillation counter pulse rate was 10^6 per second, therefore, the statistical spread in the data was $\pm$ 0.75%. As expected, the motor made the fewest steps when the limits were large. When they were comparable to the statistical spread in the data, the motor was in almost constant motion. In fact, when the limits were $\pm$ 0.75%, the short term response appeared to be an oscillation of about $\pm$ 2 steps. This may have been caused by a slow response time for SM3, or sluggishness on the part of the bipolar power supply near zero current; in any case such narrow limits are never used in practice.

Measurements were made at 30 samples per second to show the effect of the limits of the ratio on the "motor step histograms". These histograms, accumulated over the length of an observation run, show the number of times the motor made 1, 2, 3, ... steps to the left (right) before a step was made in the other direction. Figure 6.3b shows the average of the left and right histograms for 1, 2, 3 and 4 unidirectional steps as a function of the $\pm$ percentage limits on the ratio. At the lower percentage limits the number of occurrences of 3 or 4 unidirectional steps becomes greater. This was commented on above for the motor step record of the $\pm$ 0.75% limits case.

Two options are available in the "On-Line Beam Position Control Routines" to modify the response of the control system. These are "data averaging" and "trend analysis". In the first, the decision to step the motor is based on the ratio of the average of the data from the latest 2, 4, 8 or 16 samples. In the second, the trend of the data is utilized by requiring that the left (right) limit on the ratio be exceeded for n = 2, 3, ... consecutive samples before one corrective motor step is made.

The data averaging option reduces the number of steps made by the motor but, because of the time lag introduced by using old data, can introduce small oscillations into the ratio of the count rates if more than 2 or 4 samples are averaged. The trend analysis technique can reduce the number of motor steps by up to 25% even when n = 2. In one test at 60 samples per second with n = 2 the ratio of count rates was maintained with no oscillations introduced and without noticeably increasing the statistical spread in the data.

6.4 Tests of the Beam Position Control System

The ability of the control system to regulate the lateral position of the beam in the scattering chamber was tested by changing the azimuthal angle of the cyclotron stripping foil by $\pm \frac{1}{2}^{\circ}$ from the opti-

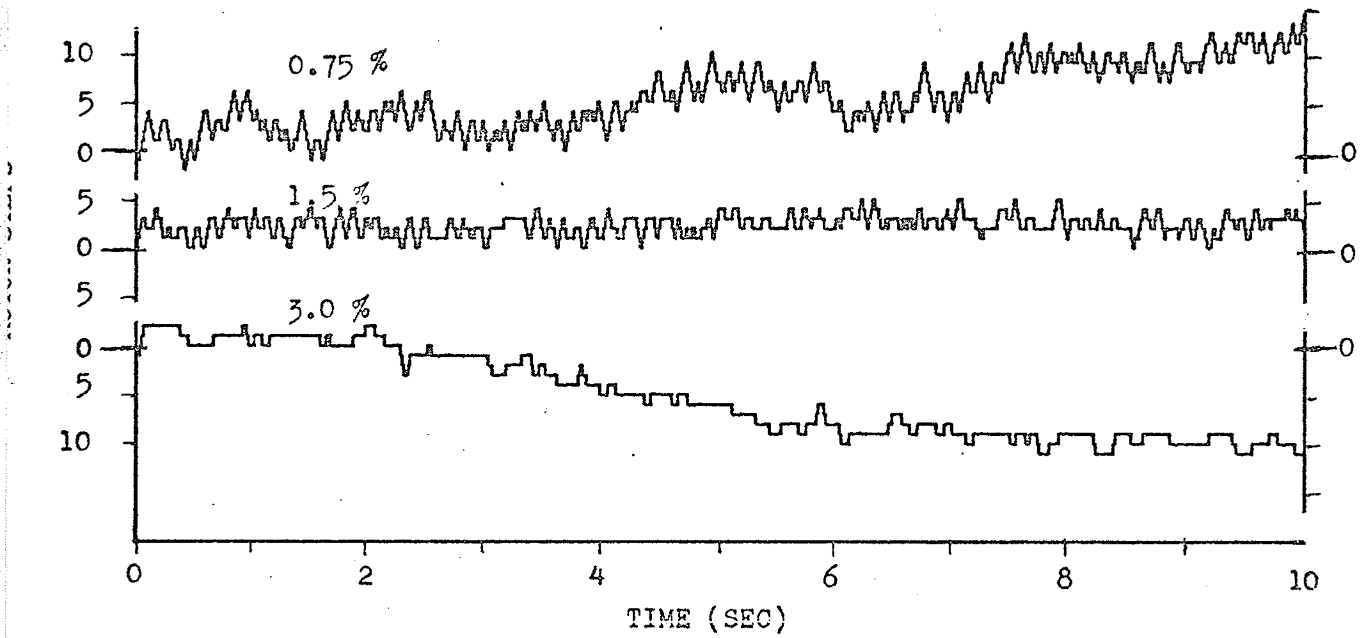
Figure 6.3

Influence of the ratio limits on the stepping motor movements. Tests were run for several values of the allowed "no correction" limits. The scintillation counter pulse rate was 10^6 per second.

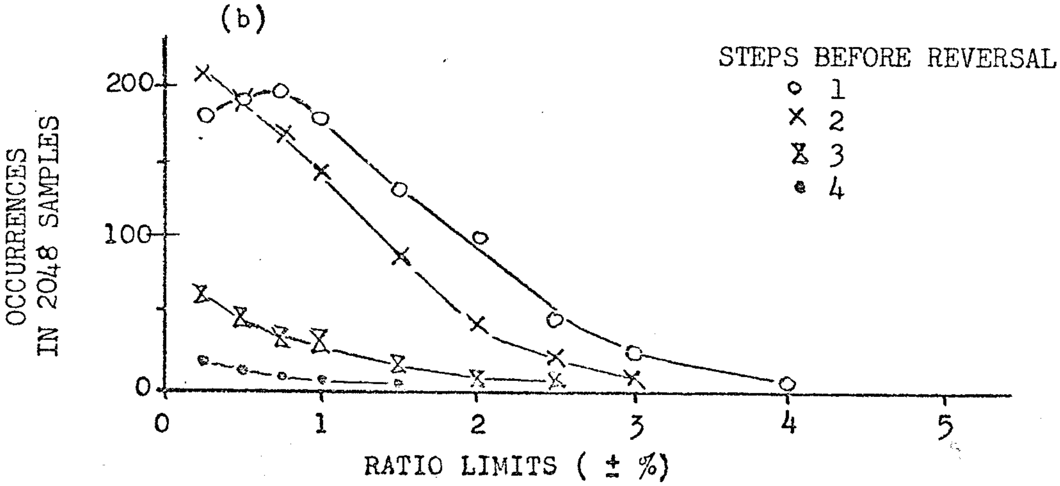
(a) The position of the stepping motor is indicated for 60 sample per second runs with the ratio limits set at $\pm$ 0.75%, $\pm$ 1.5% and $\pm$ 3.0%.

(b) Runs of 2084 samples were taken at 30 samples per second for several percentage limits on the ratio of scintillation counter pulse rates. Records were kept of the number of times the motor made 1, 2, 3 or 4 steps to the left (right) before a step was made in the opposite direction. The left and right data were averaged and shown here as a function of the percentage limits on the ratio.

(a)


0.75 %
1.5 %
3.0 %
10
5
0
5
0
5
0
5
10
0
2
4
6
8
10
TIME (SEC)

(b)


STEPS BEFORE REVERSAL
1
2
3
4
200
100
0
OCCURRENCES
IN 2048 SAMPLES
0
1
2
3
4
5
RATIO LIMITS (± %)

mm (at least 5 times as large as the error that might occur in normal tuning). This caused the beam to "steer" in the scattering chamber, i.e. to pivot laterally about the beam waist. Such a motion is the most difficult to compensate for with only one steering magnet (SM3) - to do the job completely requires two pairs of scintillation counters (one at the entrance and one at the exit of the scattering chamber) plus two separate steering magnets to keep the beam on-axis.

Three locations of the beam waist were tried: upstream of, inside of, and downstream of the reaction volume from which protons are scattered through the wire chamber hodoscopes. The kinematics program[2)] was used to determine directly the lateral position (labelled "A" in Figure 1.3) of the vertices of spectrometer events arising from protons scattered from the CD_2 target (upstream end of the reaction volume) and from the hydrogen target gas (downstream end of the reaction volume) - see Figure 1.2. Figure 6.4 shows an example of the histograms that were used to determine the lateral position of the centroid of the beam at these two points (and hence the path of the beam through the scattering chamber) for various run conditions.

For each location of the beam waist, the path of the beam was found for these 5 cases:

	Stripping Foil Angle	SM3 Current	Position Control
(1)	for good tuning	for ratio $\approx$ 1	yes
(2)	decreased from (1)	as for (1)	no
(3)	decreased from (1)	for ratio $\approx$ 1	yes
(4)	increased from (1)	as for (3)	no
(5)	increased from (1)	for ratio $\approx$ 1	yes

The results of these tests are shown in Figure 6.5. For all locations of the beam waist the lateral position of the beam centroid in the vicinity of the scintillation counters was maintained (when controlled) to within $\pm$ 0.2 mm. When the beam waist was inside the reaction volume this control system could not overcome the steering of the beam caused by the large changes in the stripping foil angle - in fact the displacement of the beam was made worse. However, when the beam waist was upstream or downstream of the reaction volume, the displacement of the beam at the centre of the scattering chamber was reduced by at least half by the operation of the control system. The lateral position of the beam (at the centre of the scattering chamber) was maintained within about $\pm$ 0.6 mm of the "good tuning" case even under these extremely mistuned conditions.

6.5 Long-term Performance

Spectrometer data from a 2.0 hour long proton-proton bremsstrahlung run (carried out in May 1970 without using the beam position control system) was analyzed to show drifts in the position of the centroid of the beam at the downstream end (p-p elastic position) of the reaction volume. The 49,452 events were divided into ten groups and a histogram made for each group showing the number of real elastic events having particular lateral positions. The centroid of each of these histograms was found and plotted in Figure 6.6 to show the variations of the lateral position of the beam. With no control applied, the beam position was found to vary over a range of 0.75 mm during the run.

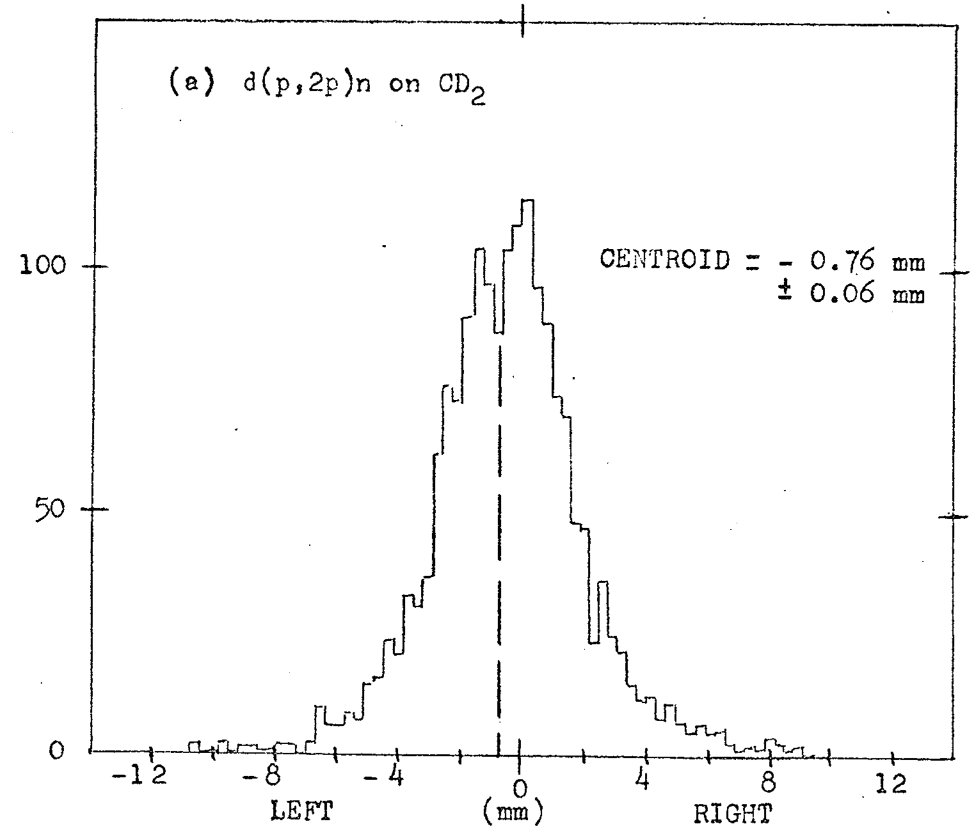
Figure 6.4

Histograms of the lateral position of the vertices of real spectrometer events coming from d(p, 2p)n reactions induced in a CD_2 target and from elastic scattering off the hydrogen gas in the scattering chamber. These data belong to case (b.2) of Figure 6.5. The centroids were determined from the weighted arithmetic means of the data.

(a) from the CD_2 target 9.15 cm upstream of the centre of the scattering chamber.

(b) from p-p elastic scattering from 9.9 cm downstream of the centre of the scattering chamber.

The lateral position of the events are shown relative to the vertical/longitudinal plane of symmetry of the spectrometer, not relative to the position at which the ratio of the count rates is equal to one. The FWHM's of these histograms are larger than the FWHM's of the beam profiles taken with a wire probe because the angular resolution of the wire chambers is not low enough to resolve the beam width.


(a) d(p,2p)n on CD2
CENTROID = - 0.76 mm
± 0.06 mm
100
50
0
-12
-8
-4
0
4
8
12
LEFT
(mm)
RIGHT

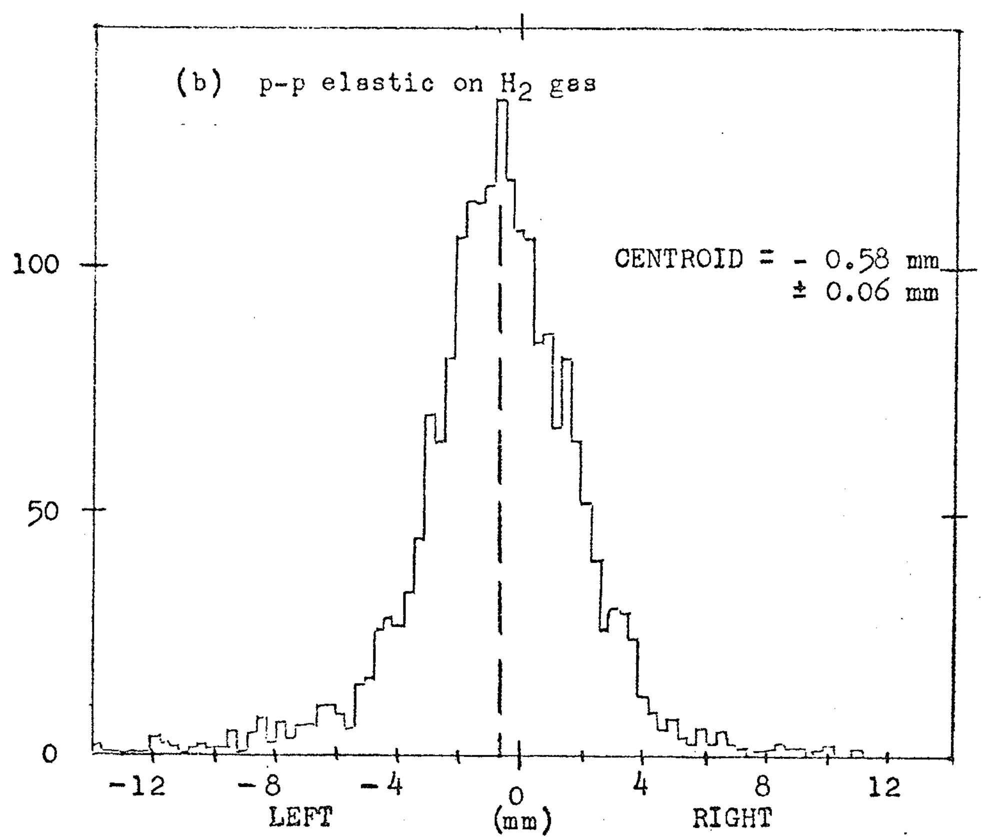

(b) p-p elastic on H2 gas
CENTROID = - 0.58 mm
± 0.06 mm
100
50
0
-12
-8
-4
0
4
8
12
LEFT
(mm)
RIGHT

Figure 6.5

Tests of the control system: correction of beam wandering caused by severe mistuning of the cyclotron. For each test the path of the beam was found from the lateral position of the beam centroid at the CD_2 and p-p elastic targets (see Figure 1.2). The test conditions were: (1) good tuning for scintillation counter pulse rate ratio = 1; (2) too small a stripping foil angle in the cyclotron with beam position control OFF; (3) control ON; (4) too large an angle, control OFF; (5) control ON.

The paths of the beam for each test are shown for:

(a) Q6 = 315. The beam waist was about 25 cm upstream of its location during test (b).

(b) Q6 = 307. The beam waist was inside the reaction volume.

(c) Q6 = 300. The beam waist was about 20 cm downstream of its location during test (b).

The error bars (typical) on the points for test (b.2) were obtained from Figure 6.4.

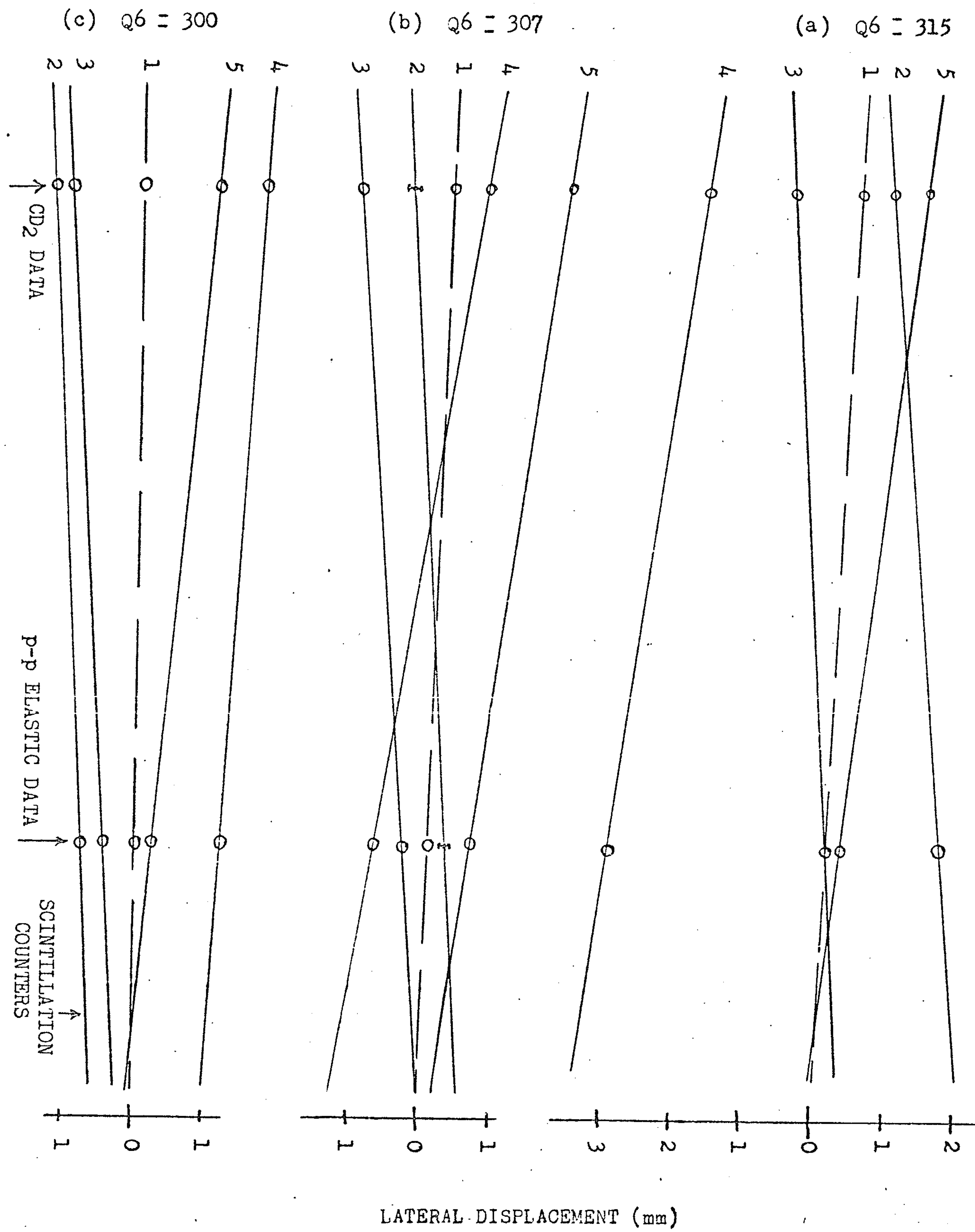
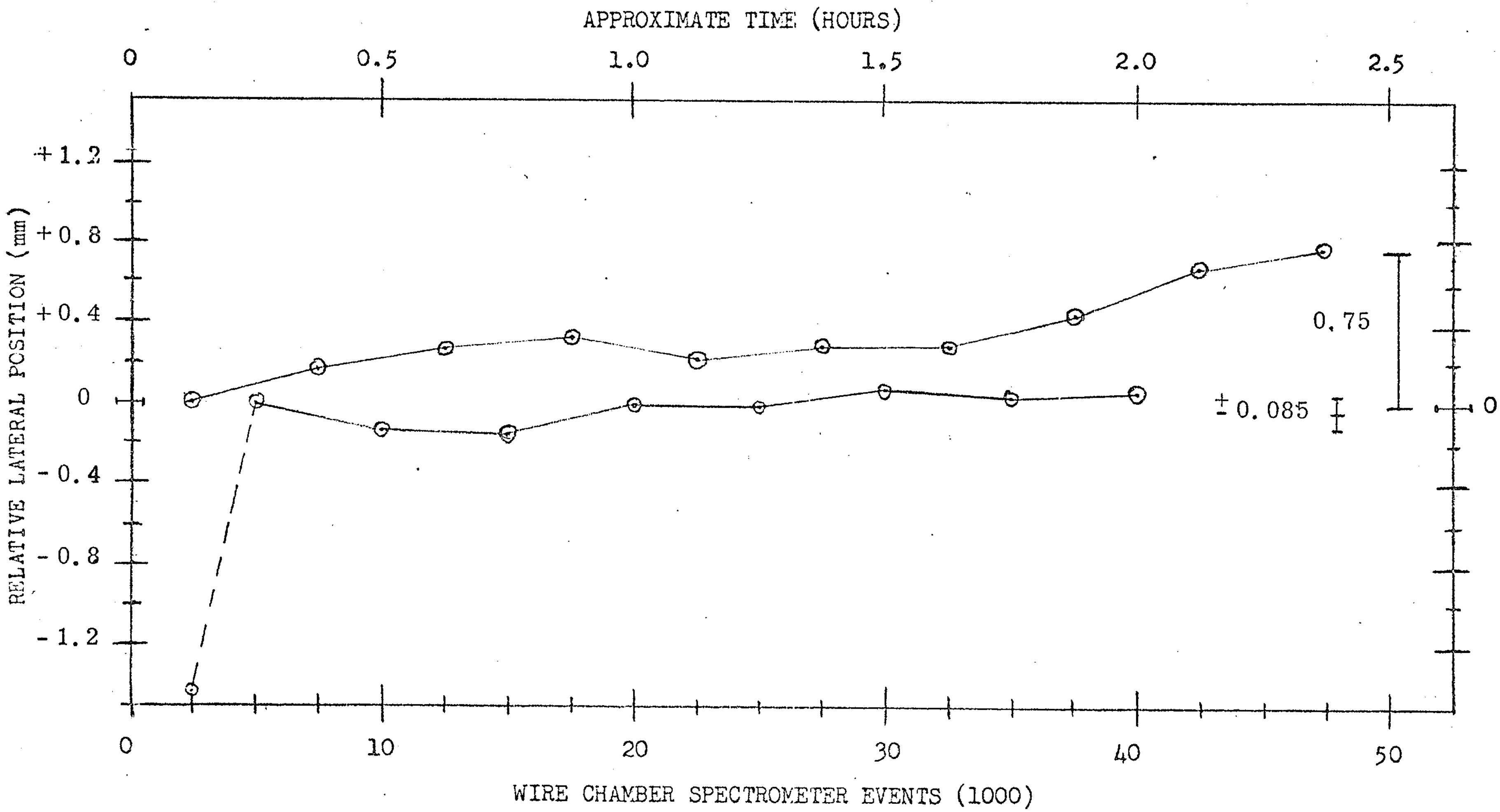

(a) Q6 = 315
(b) Q6 = 307
(c) Q6 = 300
5
2
1
3
4
CD2 DATA
p-p ELASTIC DATA
SCINTILLATION COUNTERS
LATERAL DISPLACEMENT (mm)

Figure 6.6

Variation of the beam centroid during experimental runs with and without control. The data from two runs of the wire chamber spectrometer were each split into sequential groups of 5000 events. For each group a histogram similar to that of Figure 6.4 was made of the lateral distribution of the vertices of the real p-p elastic events. The centroid of each of these distributions was found and a plot made of the location of the centroid throughout the run. The statistical uncertainty in the position of each centroid is smaller than the plotted symbol. The lines joining the data points have no physical significance but merely serve to guide the eye. The range over which the lateral position varied during each run is shown on the right-hand side.

(a) without control.

(b) with control. The dashed line indicates that the beam was being moved from its initial to its controlled position while the first 2500 events were collected.


APPROXIMATE TIME (HOURS)
0
0.5
1.0
1.5
2.0
2.5
RELATIVE LATERAL POSITION (mm)
+1.2
+0.8
+0.4
0
-0.4
-0.8
-1.2
0.75
± 0.085
0
10
20
30
40
50
WIRE CHAMBER SPECTROMETER EVENTS (1000)

A similar 3.0 hour long run with 42,946 events was taken at another time with control applied. Neglecting the first 2500 events (during which the control system was moving the beam to the specified ratio), the beam position was found to have an rms deviation of only ± 0.085 mm from the mean position during the run.

CHAPTER VII

CONCLUSIONS AND SUGGESTIONS

7.1 Conclusions

This thesis has considered a computer-based system for the control of the lateral position of a ribbon beam of protons. Scintillation counters were developed which sampled each side of the beam to detect unwanted lateral motion. Computer interfaces were designed to count the scintillation counter pulses and to change the current through a beam steering magnet. Computer programs were developed to test the interfaces, to make observations of the scintillation counter pulse rates, and to regulate the ratio of the pulse rates from the two counters.

This control system can maintain the lateral position of a symmetric ribbon beam at the scintillation counters to within $\pm$ 0.015 mm, provided that the beam shape does not change with time. This is also true of a slightly asymmetric beam (shape independent of time) if a ratio calibration run was taken first. If the shape of the beam is time dependent, the centroid of the beam could shift without affecting the beam tails proportionately. It was qualitatively estimated that, even in the "worst case", such undetected wandering of the beam at the scintillation counters would not exceed $\pm \frac{1}{2}$ to 1 mm. However, the FWHM of the beam at the scintillation counters is about 4 mm, therefore, even this range of motion would be acceptable for reasonable operation of the control system.

In the wire chamber spectrometer considered here, the reaction volume is about 20 cm long. The beam positioning counters control the lateral beam position only at a location 5 cm further downstream. However, if the beam in wandering remains parallel to the desired path, this control system will maintain the lateral beam position, over the entire reaction volume, within the same range as at the counters. If the beam pivots about the waist in the ribbon beam, the motion is too complex to be completely corrected by a single steering magnet. Depending on the exact location of the waist relative to the reaction volume and the scintillation counters, this control system may improve the average position of the beam or may make it worse.

In one experimental run, taken for about $2\frac{1}{2}$ hours without control of the beam's position, the beam at the scintillation counters wandered laterally over a range of 0.75 mm. In another run of similar length taken a few weeks later, the beam position control maintained the lateral position of the beam within $\pm$ 0.085 mm of its mean position during the run.

7.2 Suggestions for Improvements to and Applications of the System

In future use of this equipment, some means should be provided to shield the scintillators and lightpipes when they are not being used to control the beam. This would eliminate the possibility of radiation damage to them while the beam is being used for tests, calibrations, etc. To improve the operation of the system, new programs can be written to adjust the ratio and the ratio limits during a run. For example, the ratio limits can be periodically updated to equal twice the standard deviation of the latest 1000 values of the ratio. Also, once a position vs ratio calibration has been done, the kinematics data from p-p elastic scattering can be used to update the ratio specification, e.g. after every 1000 elastic vertex events. The first provision will ensure that the system makes a correction only when the asymmetry in count rates is statistically significant. The second will assist the system in following and controlling any shifts of the beam centroid caused by changes in the beam profile.

These scintillation counters could be applied to an investigation of the origin and nature of the beam tails and background. The time structure of the beam could also be investigated, both as to the expected Poisson distribution of the time intervals between scintillator pulses, and as to the ripple introduced into the beam by components of the cyclotron and beam transport. Some qualitative investigations were carried out along these lines but a detailed study is beyond the scope of this thesis.

A beam position control system of the type described here could easily be developed for use with spot beams by using four scintillation counters to detect up-down as well as left-right motion. Two separate systems could be built (with sensors both upstream of and downstream of the reaction volume or target) to control a beam that exhibits steering and pivoting.

The Beam Observation Program developed for this system could easily be adapted to take beam profiles semi-automatically by driving the wire probe with a bifilar stepping motor.

Another possible application would be stabilization of the beam current through the scattering chamber by using the sum of the scintillation counter pulse rates to control the width of the S2 H slits.

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5. K. Johnson, T. Klippert and W.J. Ramler, "A Non-intercepting Accelerator Beam Position Sensor," Nucl. Instr. and Meth. 14, 125 (1961).

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11. Nuclear Enterprises Inc., 935 Terminal Way, San Carlos, California, 94070.

12. Nuclear Instrumentation Division, EG&G Inc., 35 Congress St., Salem, Massachusetts, 01970.

13. The American Superior Electric Co. Ltd., 38 Terlake Cres., Toronto 18, Ontario.

14. D. Reimer. Master's thesis in preparation, The University of Manitoba, Winnipeg.

15. T.W. Millar. "Design and Performance of Large Area Scintillation Counters with Good Energy Resolution." Unpublished Master's thesis, The University of Manitoba, Winnipeg, 1969.

APPENDIX A

A MODEL OF THE LATERAL BEAM INTENSITY PROFILE

A useful model for discussion of the beam intensity profile considers the beam to have a uniform vertical profile and a Gaussian horizontal profile. For this model the horizontal profile has left-right symmetry and decreases monotonically away from the beam centroid. This permits some predictions to be made about the operation of the control system.

Figure A.1 shows one-half of a normalized Gaussian curve together with a curve giving for any abscissa the integral of the gaussian curve from that abscissa to infinity, i.e. the error function erfc(x), normalized to erfc(0) = 0.5. This integral is the area of the "tail" of the Gaussian curve. Two measures of the "width" of the Gaussian curve are available. The "FWHM" (Full-Width-at-Half-the-Maximum-height) is more convenient to measure but the "standard deviation σ" is easier to use in calculations based on the error function. They are related by the following equation:

$$\text{FWHM} = 2(1.175)\sigma$$

If the separation of the counters and the position of the beam centroid are measured in units of σ (see Figure A.2a) the following approximate relationship can be deduced from a tabulation of the error function:*

$$\log \frac{L}{R} = md$$

*Computed in double precision at intervals of $\sigma/100$ on the IBM 360/65 at the University of Manitoba Computer Centre.

Figure A.1

The normalized Gaussian curve. These semi-log plots, based on tabulation of the appropriate functions, show:

(a) The ordinate "y" of the Gaussian curve (right half) versus an abscissa "x" measured in units of the standard deviation σ, where

$$y = (2\pi)^{-\frac{1}{2}} \exp(-x^2/2)$$

(b) The area of the tail of the Gaussian curve = $\int_x^\infty y\,dx$

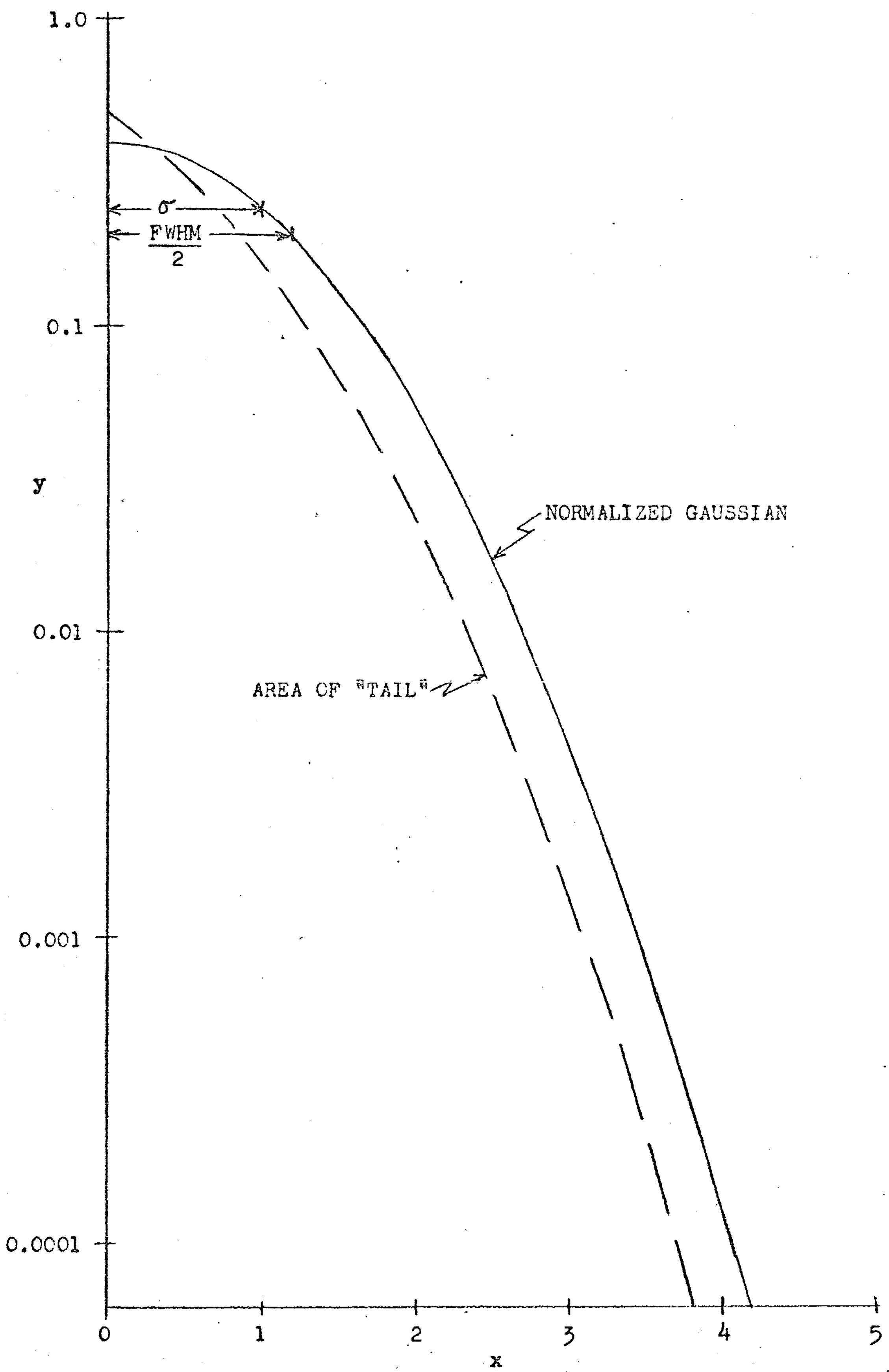

1.0
0.1
0.01
0.001
0.0001
y
σ
FWHM
2
NORMALIZED GAUSSIAN
AREA OF "TAIL"
0
1
2
3
4
5
x

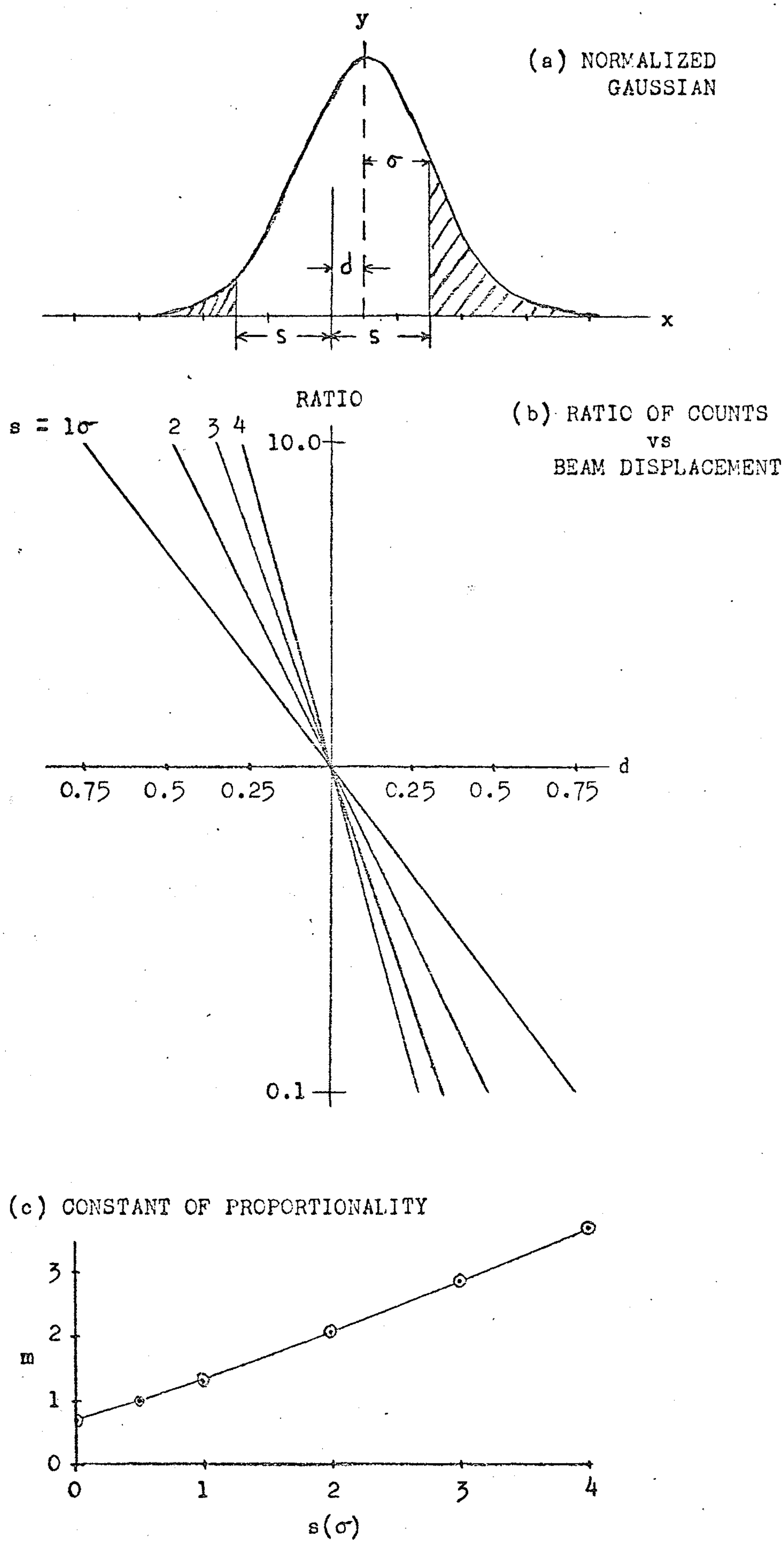
Figure A.2

The Gaussian model of the lateral intensity profile: relating the ratio of the tail areas to the lateral displacement of the beam.

(a) The full Gaussian curve is shown on a linear scale, normalized to area = 1.0. The separation between the scintillation counters is 2s and the distance from their midpoint to the beam centroid is d. The area of the tails, assumed here to be intercepted by the scintillation counters, are shown shaded.

(b) When d and s are measured in units of σ the relation between them is found numerically to be approximately log(left tail area/right tail area) = m(s)d. This log of the ratio of areas as a function of the beam displacement is shown for several values of the separation of the counters.

(c) The constant of proportionality, m(s), is a function of the separation of the counters. For a given s it was found, from tabulated areas under the Gaussian curve, to be a constant (within 1%) for displacements up to $d = \sigma$.


y
(a) NORMALIZED
GAUSSIAN
σ
d
s
s
x
RATIO
s = 1σ
2
3
4
10.0
(b) RATIO OF COUNTS
vs
BEAM DISPLACEMENT
d
0.75
0.5
0.25
0.25
0.5
0.75
0.1
(c) CONSTANT OF PROPORTIONALITY
3
2
m
1
0
0
1
2
3
4
s(σ)

where L = area of the tail on the left of the centroid

R = area of the tail on the right of the centroid

d = distance (in units of σ) from the centroid of the beam to the midpoint of the separation between the two scintillation counters. (Ideally this midpoint is on the vertical/longitudinal plane of symmetry of the spectrometer.)

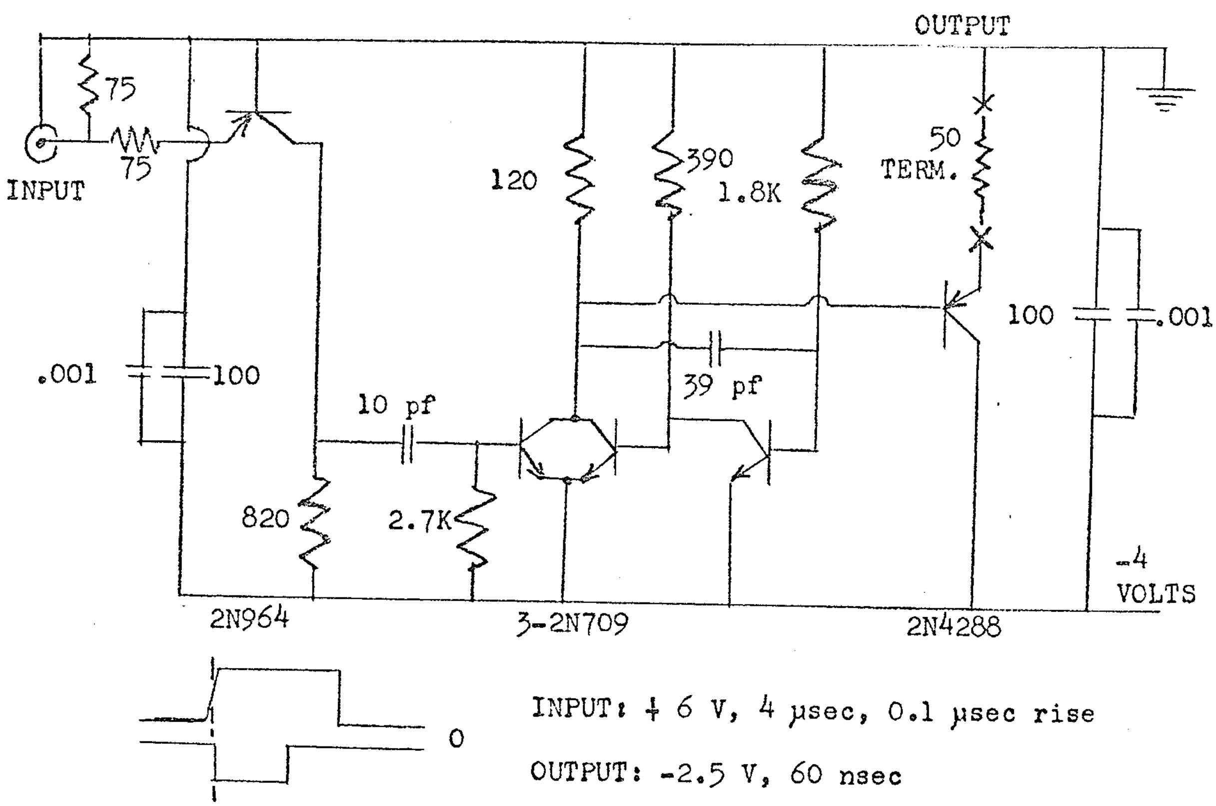
m = a function only of the separation (in unit of σ) between the scintillation counters.

This means that, for any particular separation of the scintillation counters, the log of the ratio of the counts on the left to the counts on the right should vary linearly with the lateral position of the beam. This is shown in Figure A.2b. The relationship between "m" and the separation of the counters is shown in Figure A.2c. Calculations of "m" at s = 1, 2, 3, 4 (units of σ) for several values of "d" indicate that each m(s) is a constant to within 1%.

APPENDIX B

SCHEMATICS OF THE PULSE CONVERTERS FOR INPUTS TO THE PDP-9 SCALERS

Two pulse converters of the type shown in Figure B.1 were designed and built by R. Hamel in the Physics Department Electronics Shop. After every eighth pulse input to the EG&G S100/N Divide-by-8 Prescaler, its output makes a transition from -700 mV to ground. The converter senses this transition and produces a single output pulse of - 2.5 volts for 60 nsec. This pulse is suitable for input to the B-Series modules used in the 18-bit scalers interfaced to the PDP-9 computer. This converter will operate at repetition rates up to 10MHz.



INPUT: + 6 V, 4 μsec, 0.1 μsec rise

OUTPUT: -2.5 V, 60 nsec

Figure B.1

Schematic of circuit to convert output pulses from an S100/N prescaler for input to a DEC B104 module.

One pulse converter of the type shown in Figure B.2 was also designed and built by R. Hamel. It converts the output pulses of a Brookhaven Instrument Corporation (B.I.C.) charge integrator (+ 6 V, 4 μsec pulses at up to 100 per second) into -2.5 V, 60 nsec pulses suitable for input to a PDP-9 scaler.

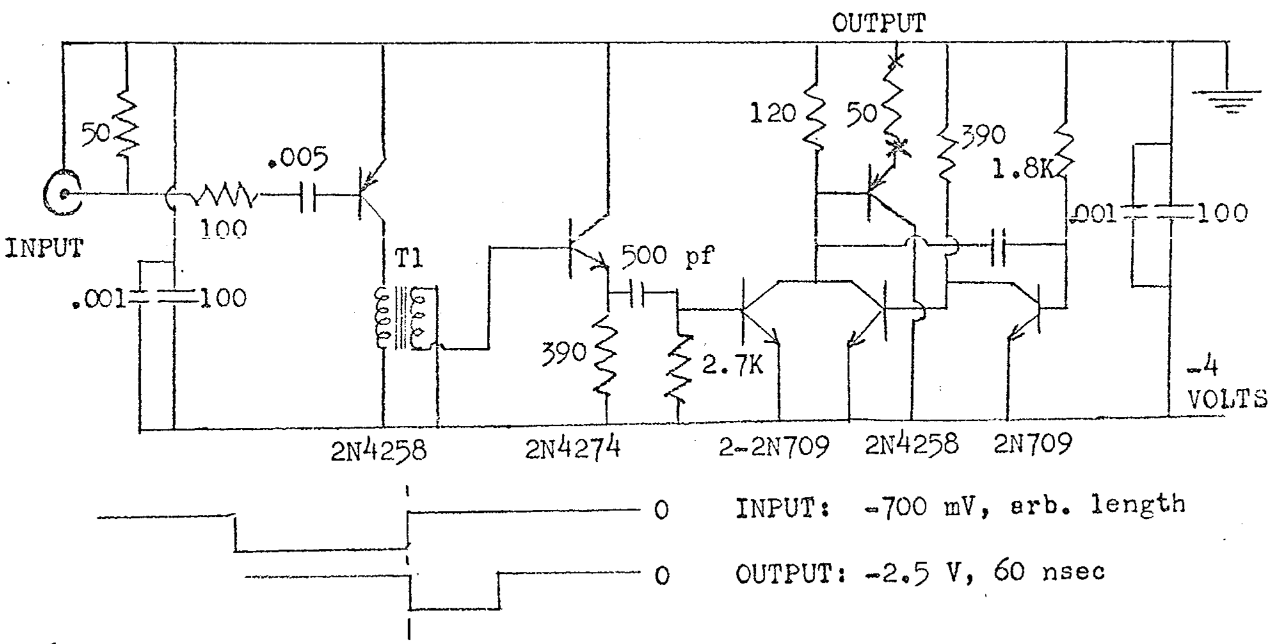


Figure B.2

Schematic of circuit to convert output pulses from a B.I.C. charge integrator for input to a DEC B104 module.

APPENDIX C

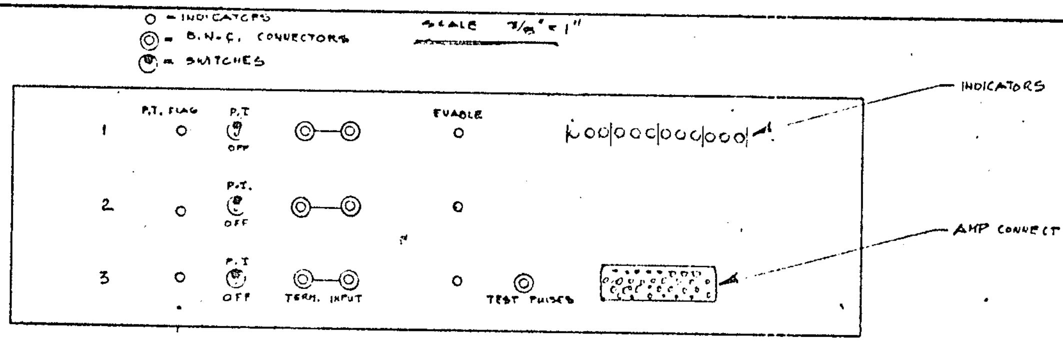
SCHEMATICS OF THE PDP-9 SCALERS

Three 18-bit, 10 MHz scalers were designed and built as input devices for the PDP-9. The functions performed by the program commands were presented in detail in Chapter 3.3. Two of these scalers were used routinely to count the pulses from the left (#1) and right (#2) scintillation counters. The third (#3) was sometimes used to count the pulses produced by a charge integrator in order to normalize the counts of the other two scalers to a specific amount of charge reaching the Faraday Cup.

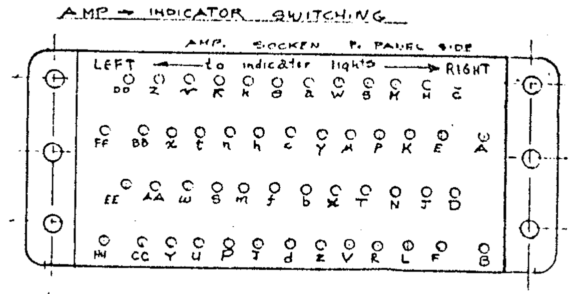
The flow diagram of the scaler logic was presented in Figure 3.4; this Appendix presents the details of the hardware design. All of the symbols used here are standard types used by the Digital Equipment Corporation (DEC) for their PDP-9 schematics. The plug-in logic modules are DEC B-, R-, or W-series. These are fully described in the DEC Logic Handbook 1966/67. This book also contains (p. 101) the schematic of a high-speed counter which served as a model for the three low-order bits of each of these scalers. All logic elements on these drawings are identified both by DEC designations and by their row and slot number in the 3 bins occupied in the PDP-9 cabinet by the scalers.

Twelve indicator lamps are provided on the scaler connector/indicator panel to monitor the operation of the scalers and motor drive (Appendix D) via a patch plug connected to various logic modules.

The patch plug currently available for the indicators assigns them (from left to right) to: Scaler 1 - bits 0, 1, 2, 11; Scaler 2 - bits 0, 1, 2, 11; Scaler 3 - bit 11; Stepping Motor - step, left, right.



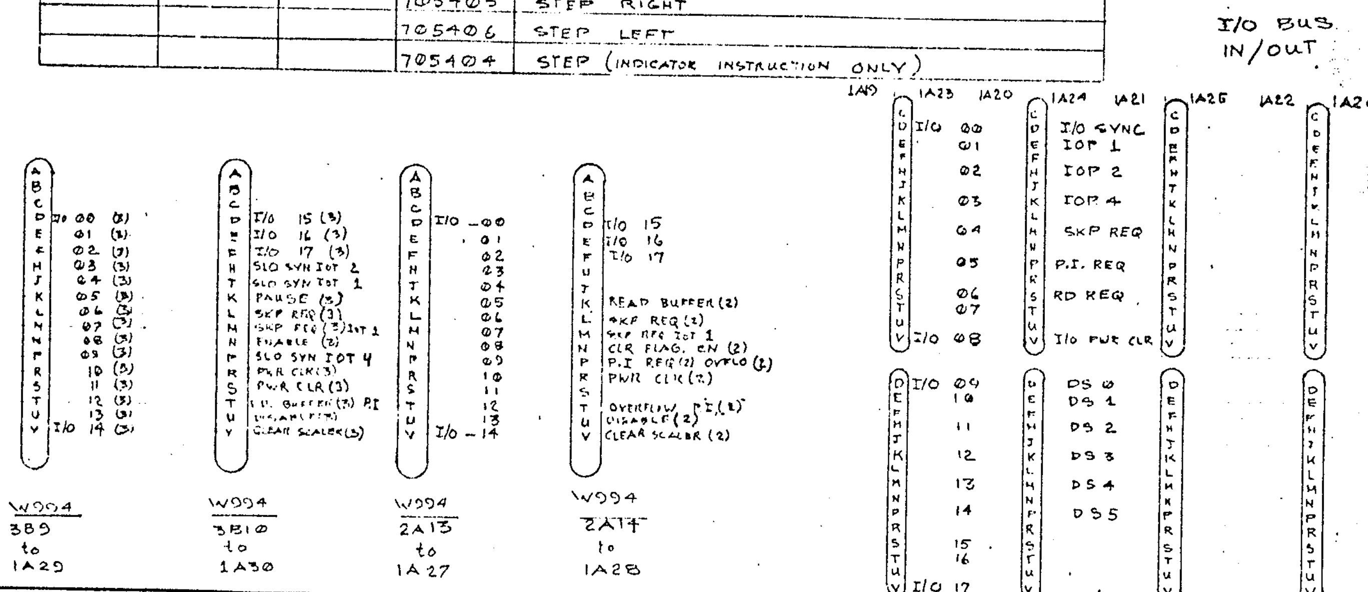
CONNECTOR / INDICATOR PANEL



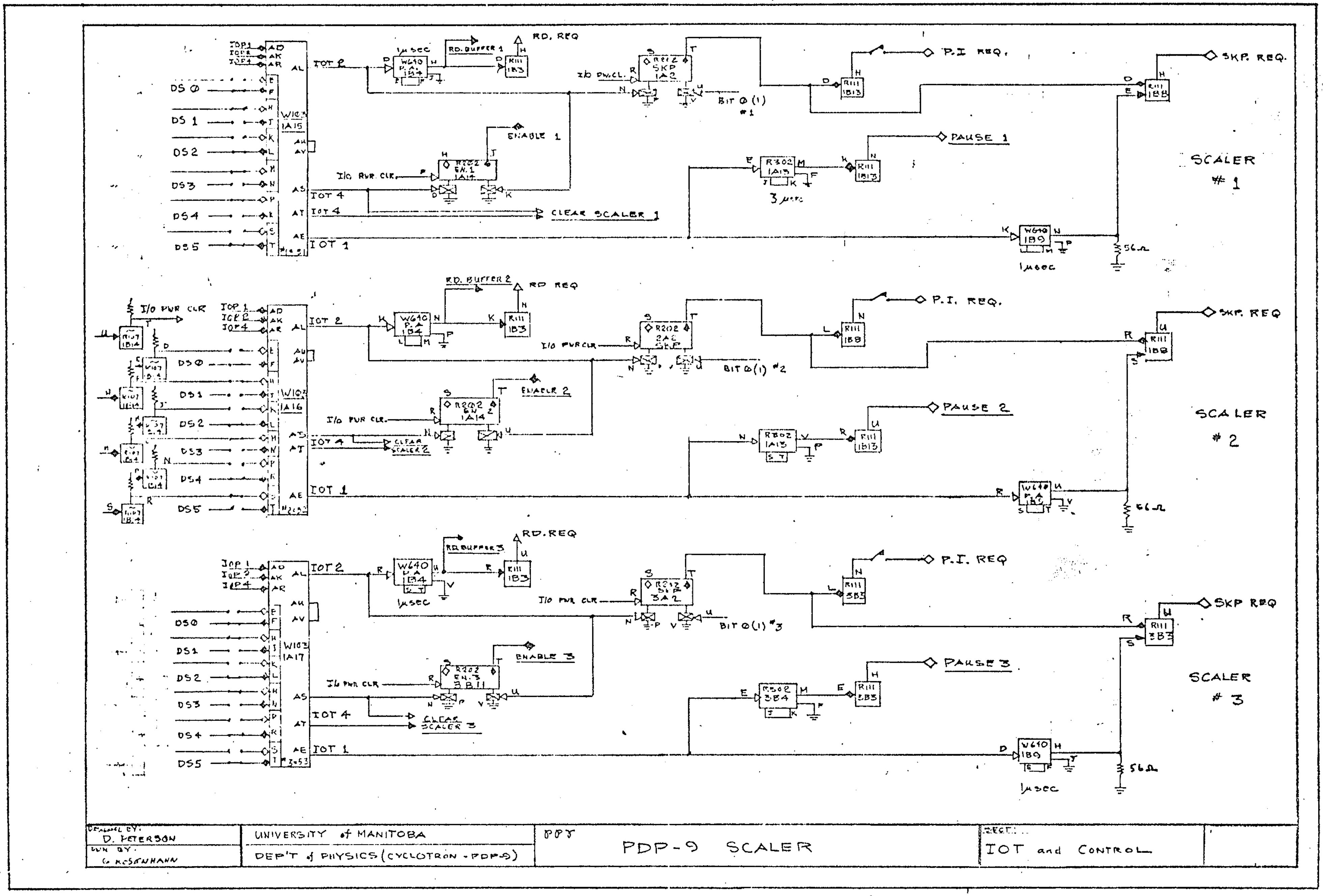
I.O.T. INSTRUCTIONS

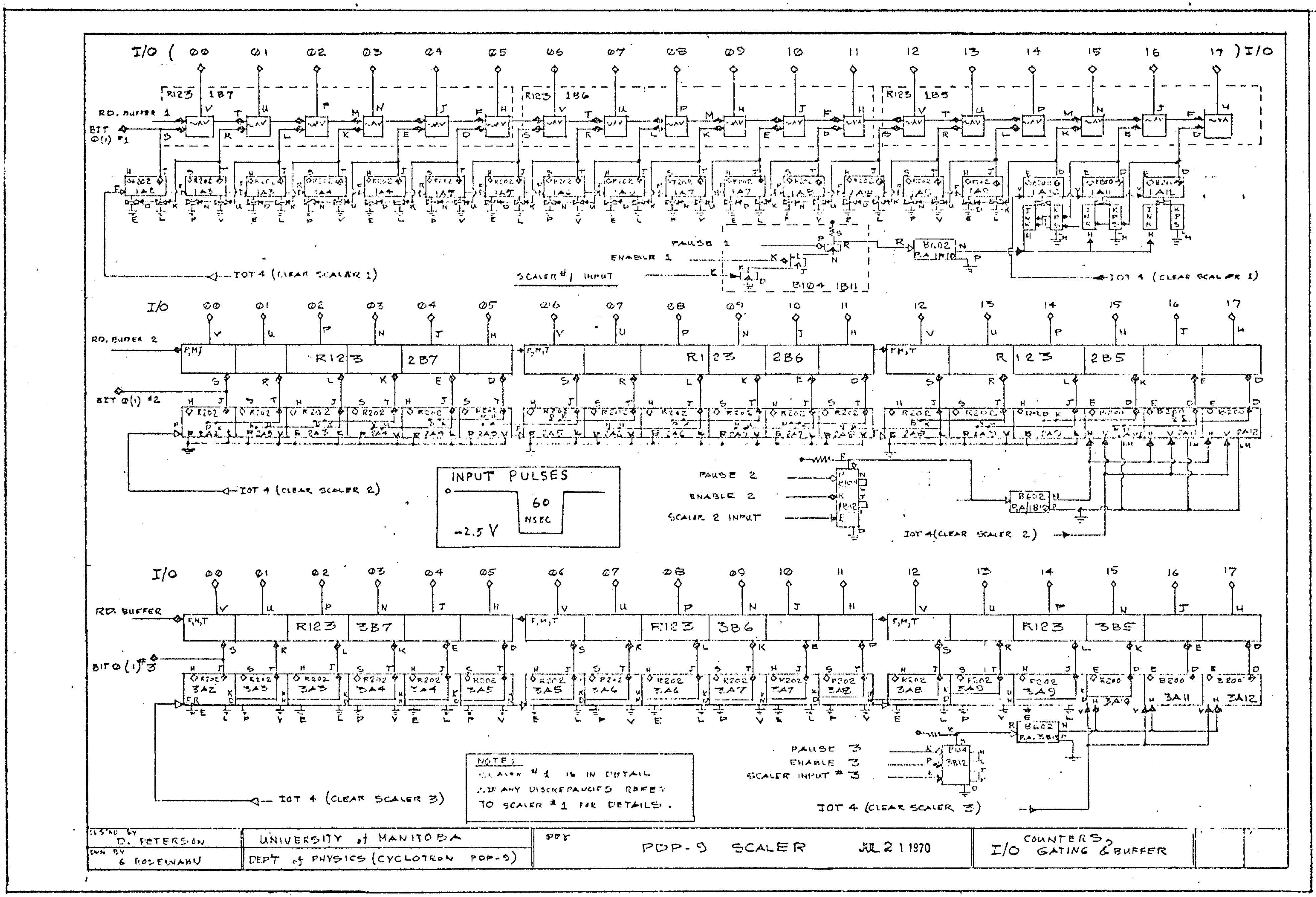
SCALER #1	SCALER #2	SCALER #3	SLO-SYN	FUNCTION
705101	705201	705301		SKP on OVERFLOW / BLOCK SCALER INPUT (DURING READ INSTR.)
705102	705202	705302		ENABLE SCALER / READ SCALER / CLEAR P.I. (OVERFLOW)
705104	705204	705304		CLEAR SCALER / DISABLE SCALER
			705405	STEP RIGHT
			705406	STEP LEFT
			705404	STEP (INDICATOR INSTRUCTION ONLY)

AMP CONTACT	BIT. NO.	SCALER No.	WIRING TERMINAL
DD	11		LEFT
Z	10		INDICATOR
v	9		
r	8		
K	7		DRIVERS
e	6		
a	5		
W	4		
S	3		
M	2		
H	1		
C	0		RIGHT
FF	00	1	1A2T
BB	01	1	1A3T
x	02	1	1A3J
t	03	1	1A4T
n	04	1	1A4J
h	05	1	1A5T
c	0	2	2A[illegible]
Y	1	2	2A[illegible]
A	2	2	2A[illegible]
P	00	3	[illegible]
K	01	3	3A[illegible]
E	02	3	3A3T
A	11	3	3A5T
EE	06	1	1A5J
AA	07	1	1A6T
w	08	1	1A6J
S	09	1	1A7T
m	10	1	1A7J
f	11	1	1A8T
b	12	1	1A8J
X	13	1	1A9T
T	14	1	1A9J
N	15	1	1A10F
J	16	1	1A11F
D	17	1	1A12F
HH	12	3	3A[illegible]
CC	13	3	3A[illegible]
Y	14	3	3A[illegible]
U	STEP		3B4Y
P	LEFT		3B11J
J	RIGHT		3B11H
d	11	2	2A[illegible]
z	12	2	2A8J
V	13	2	2A[illegible]T
R	14	2	2A9J
L	15	2	2A10F
F	16	2	2A11F
B	17	2	2A12F

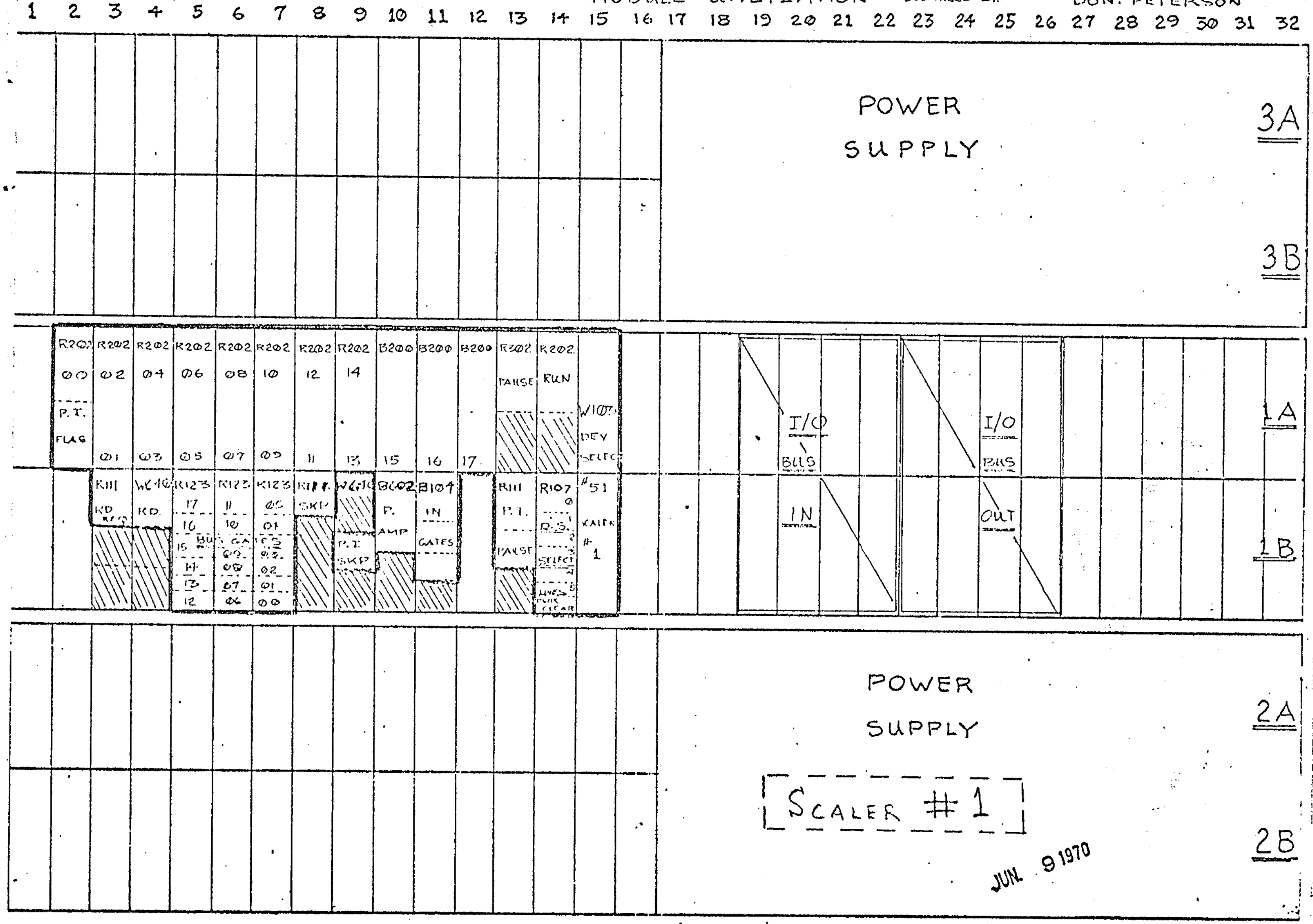


DRAWN BY: DON PETERSON	UNIVERSITY of MANITOBA	PPY	PDP-9 SCALER JUL 2 1970
CHK BY: G. HEIDENMANN	DEP'T PHYSICS (CYCLOTRON - PDP-9)		WIRING LISTS/IOT's/PANEL


RD. REQ
P.I. REQ.
SKP. REQ.
ENABLE 1
PAUSE 1
CLEAR SCALER 1
SCALER # 1
IOT 2
IOT 4
IOT 1
DS 0
DS 1
DS 2
DS 3
DS 4
DS 5
RD. BUFFER 2
ENABLE 2
PAUSE 2
SCALER # 2
BIT 0 (1) #2
RD. REQ
RD BUFFER 3
P.I. REQ
SKP REQ
ENABLE 3
PAUSE 3
CLEAR SCALER 3
SCALER # 3
BIT 0 (1) #3
1μsec
56Ω
D. PETERSON
UNIVERSITY of MANITOBA
DEP'T of PHYSICS (CYCLOTRON - PDP-9)
PDP-9 SCALER
IOT and CONTROL


I/O
RD. BUFFER 1
BIT Ø(1) #1
R123 1B7
R123 1B6
R123 1B5
PAUSE 1
ENABLE 1
SCALER #1 INPUT
B602 P.A. 1B10
B104 1B11
IOT 4 (CLEAR SCALER 1)
RD. BUFFER 2
BIT Ø(1) #2
R123 2B7
R123 2B6
R123 2B5
PAUSE 2
ENABLE 2
SCALER 2 INPUT
B602 P.A. 1B12
IOT 4 (CLEAR SCALER 2)
INPUT PULSES
60 NSEC
-2.5 V
RD. BUFFER
BIT Ø(1) #3
R123 3B7
R123 3B6
R123 3B5
PAUSE 3
ENABLE 3
SCALER INPUT #3
IOT 4 (CLEAR SCALER 3)
NOTE:
SCALER #1 IS IN DETAIL
∴ IF ANY DISCREPANCIES REFER TO SCALER #1 FOR DETAILS.
D. PETERSON
G. ROSENWAHN
UNIVERSITY of MANITOBA
DEPT of PHYSICS (CYCLOTRON PDP-9)
PDP-9 SCALER
JUL 21 1970
I/O COUNTERS, GATING & BUFFER

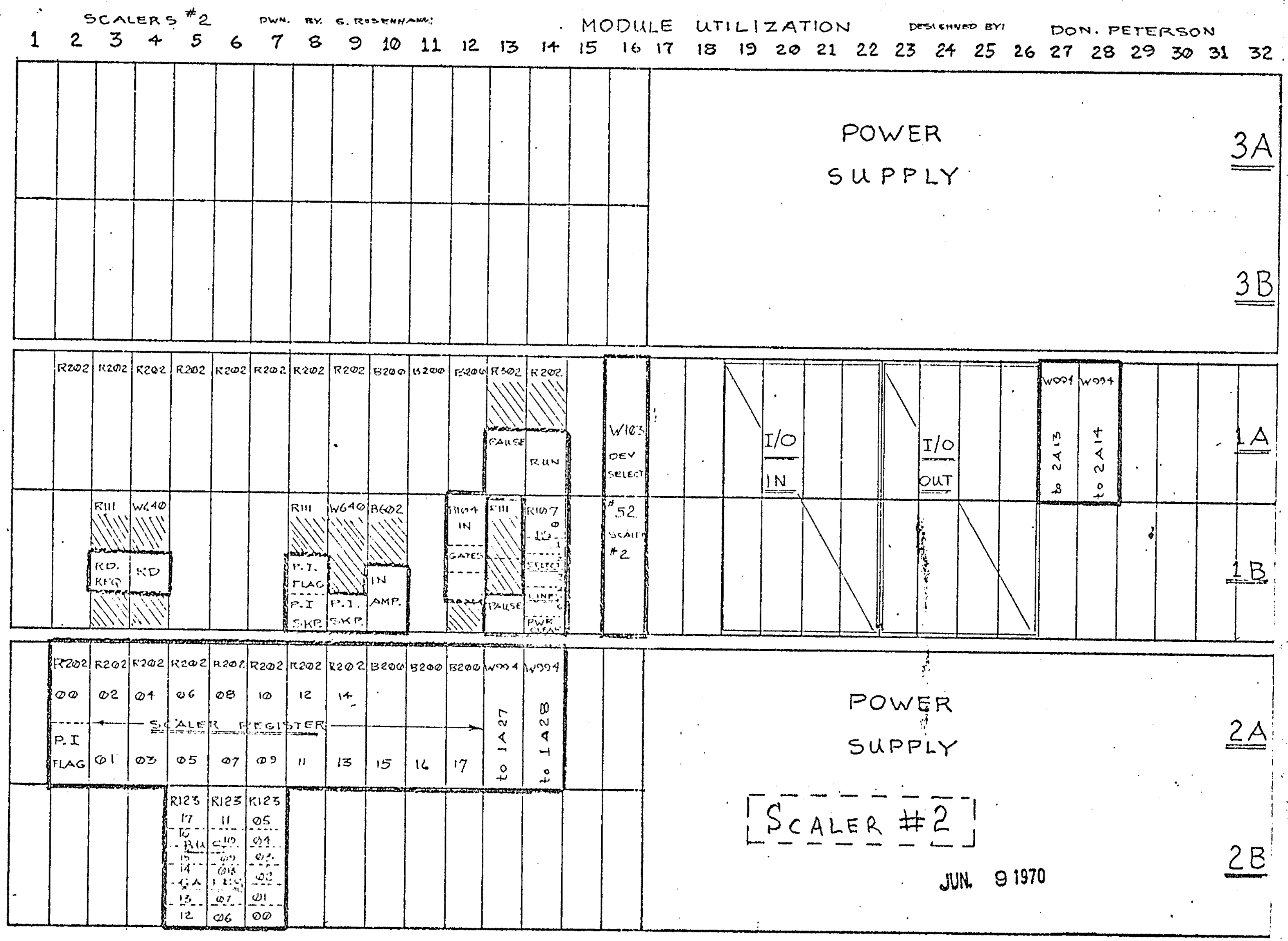
SCALERS #1 DWN BY: G. [illegible] MODULE UTILIZATION DESIGNED BY: DON. PETERSON



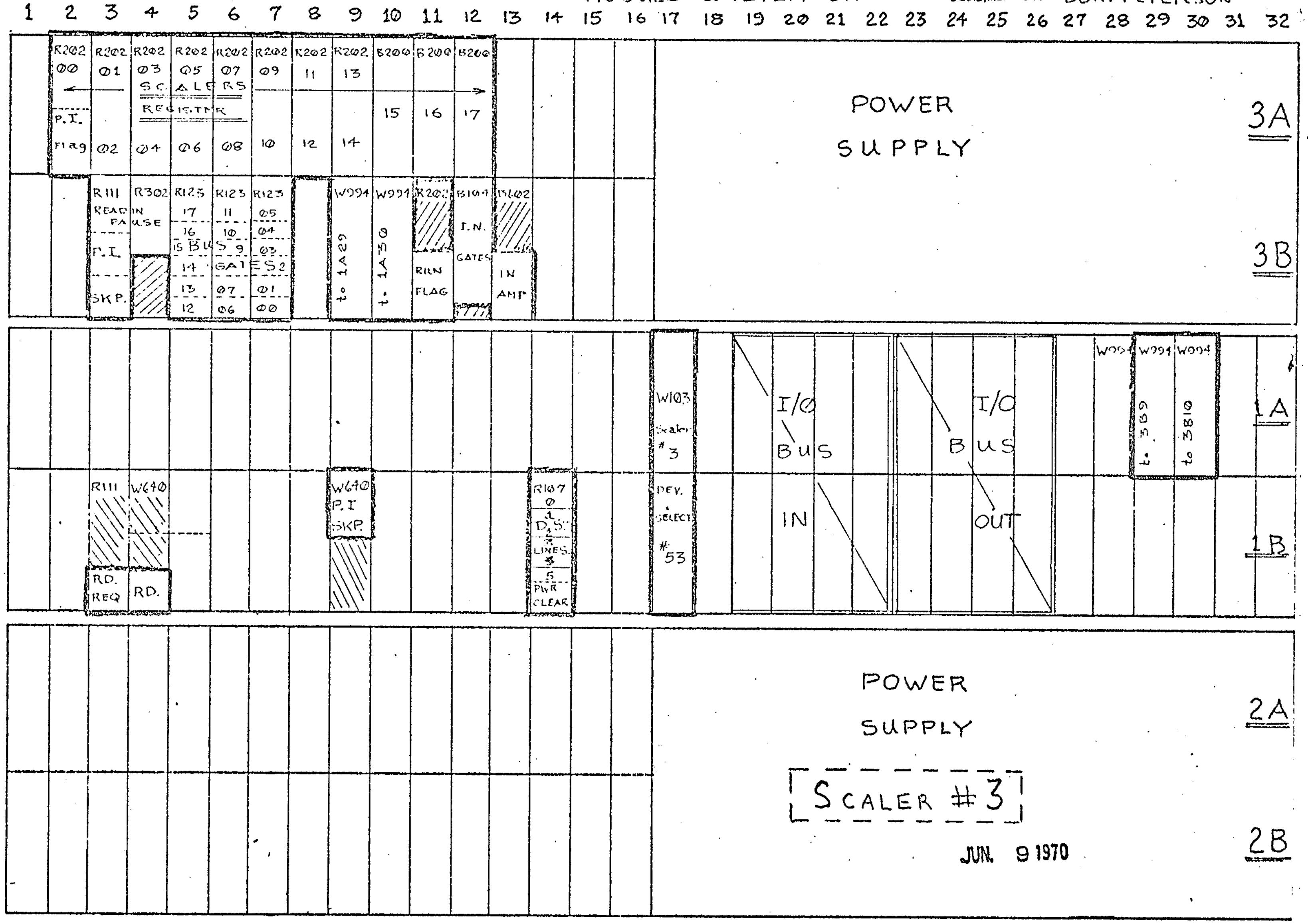
JUN. 9 1970

APPENDIX C

APPENDIX C


SCALERS #2
DWN. BY. G. ROSENHANK
MODULE UTILIZATION
DESIGNED BY: DON. PETERSON
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
POWER SUPPLY
3A
3B
R202 R202 R202 R202 R202 R202 R202 R202 B200 B200 B200 R302 R202
PAUSE
RUN
W103 DEV SELECT #52 SCALER #2
I/O IN
I/O OUT
W994 W994
to 2A13
to 2A14
1A
R111 W640
RD. REQ
RD
R111 W640 B602
P.I. FLAG
P.I. SKP
P.I. SKP
IN AMP.
B104 IN
GATES
R111
PAUSE
R107
SELECT
PWR CLEAR
1B
R202 R202 R202 R202 R202 R202 R202 R202 B200 B200 B200 W994 W994
00 02 04 06 08 10 12 14
SCALER REGISTER
P.I FLAG
01 03 05 07 09 11 13 15 16 17
to 1A27
to 1A28
POWER SUPPLY
2A
R123 R123 R123
17 11 05
16 10 04
15 09 03
14 08 02
13 07 01
12 06 00
SCALER #2
JUN. 9 1970
2B

SCALERS #3 DWN. BY: G. ROSENHAHN. MODULE UTILIZATION DESIGNED BY: DON. PETERSON

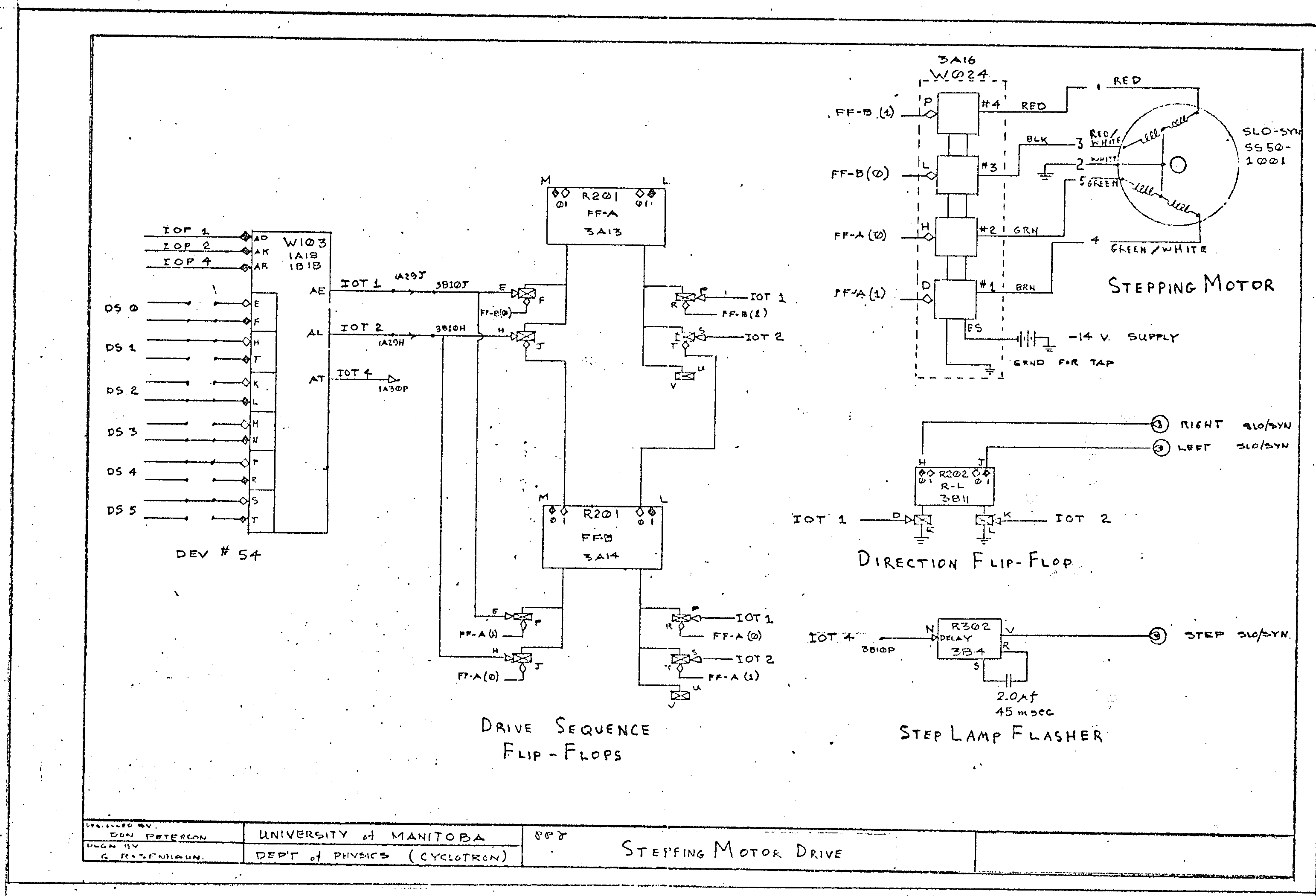


APPENDIX C

APPENDIX D

SCHEMATIC OF THE STEPPING MOTOR DRIVE

The operation of this interface was described in Chapter 3.4. The symbols are drawn according to DEC PDP-9 standards. The lamps shown here are on the connector/indicator panel for the PDP-9 Scalers. The motor drive modules occupy slots in the scaler module bins.


W103
1A18
1B18
IOP 1
IOP 2
IOP 4
IOT 1
IOT 2
IOT 4
DS 0
DS 1
DS 2
DS 3
DS 4
DS 5
DEV # 54
R201
FF-A
3A13
R201
FF-B
3A14
DRIVE SEQUENCE FLIP-FLOPS
3A16
W024
FF-B (1)
FF-B (0)
FF-A (0)
FF-A (1)
RED
BLK
GRN
BRN
GREEN / WHITE
SLO-SYN
SS50-
1001
STEPPING MOTOR
-14 V. SUPPLY
GRND FOR TAP
RIGHT SLO/SYN
LEFT SLO/SYN
R202
R-L
3B11
DIRECTION FLIP-FLOP
R302
DELAY
3B4
STEP SLO/SYN
2.0 μf
45 msec
STEP LAMP FLASHER
DESIGNED BY
DON PETERSON
DRAWN BY
G. ROSENHAHN
UNIVERSITY of MANITOBA
DEP'T of PHYSICS (CYCLOTRON)
STEPPING MOTOR DRIVE

SCALERS DWN BY G. ROSENMANN. MODULE UTILIZATION DESIGNED BY DON. PETERSON

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3A		R202	R202	R202	R202	R202	R202	R202	R202	B200	B200	B200	R201 FF-A STEP. SLO. SYN.	R201 FF-B STEP. SLO. SYN.	W024	
3B			R111	R302 SLO SYN DELAY	R123	R123	R123		W994 to 1A29	W994 to 1A30	R202 SLO SYN R-L	B104	B602			
1A		R202	R102	R202	R202	R202	R202	R202	R202	B200	B200	B200	R302	R202	SCALER #1 W103	SCALER #2 W103
1B			R111	W640	R123	R123	R123	R111	W640	B602	B104	B104	R111	R107	DEV. 51	DEV. 52
2A		R202	R202	R202	R202	R202	R202	R202	R202	B200	B200	B200	W994 to 1A27	W994 to 1A28		
2B					R123	R123	R123					B401 1 MHZ TEST CLOCK				

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
3A	POWER SUPPLY															
3B																
1A	SCALER #3 W103	SLO SYN. W103	I/O				I/O				W994 to 2A13	W994 to 2A14	W994 to 3B9	W994 to 3B10	R302	R401
1B	DEV. 53	DEV. 54	IN				OUT									
2A	POWER SUPPLY															
2B																

SLO-SYN STEPPING MOTOR DRIVE

JUN. 9 1970

APPENDIX E

PROGRAM FOR SCALER AND STEPPING MOTOR INTERFACE TESTS

The uses of this program were described in Chapter 3.5a. Each routine in the listing whose execution is initiated from the SALMON Monitor or by a typed command is identified by a comment whose first six characters are "/***** (slash plus 5 asterisks). The relationships between the various routines in the program is shown in Figure E.1. A description of each routine follows:

Functional Description of Test Routines:

Service user's Program Interrupts - called by SALMON[14)] to initiate the appropriate service routines when a scaler or a command on the teletype causes a program interrupt.

Program setup - establishes initial conditions and sets up linkage to SALMON Monitor.

Mnemonic code interpretation - two-letter mnemonics from the teletype are decoded and the appropriate action initiated.

Device and IOT selection - code "S1, S2, S3 or MD" followed by "T1, T2, T3, T4, T5, T6 or T7" - issues any of 7 IOT's to any scaler or to the motor drive for hardware module tests using an oscilloscope.

Move the motor with variable speed and direction - "MV" - crude test of the motor drive with speed and direction determined from the accumulator switches.

Move the motor a specified number of steps left or right - "MM" - upon teletype command moves the motor at 100 steps/second.

Oscillate motor back-and-forth - "SM" - for a specified number of steps in each direction at a specified number of steps per second. Checks smoothness of bipolar power supply response.

Turn program interrupt ON or OFF - "ON" or "OF" -

Cycle through a scaler* "read" sequence - "PS" - for scope checks of the timing of the scaler read operations.

*All scaler "cycle" or "test" routines are executed for the last scaler specified via the "Device and IOT selection" routine.

Cycle through an "enable/disable" sequence - "RF" - for scope checks of the timing of the scaler enable and disable operations.

Test effect of scaler "read" on the contents of the scaler - "RI" - after a specified counting period, reads the scaler twice in quick succession and then halts for a comparison of the two readings.

Program interrupt service routine - can be used to check for interrupt requests from the scalers.

Clear and disable the scalers - "SS" -

Compare internal cycle time with 60 Hz line frequency - "IC" - counts the number of PDP-9 clock signals that occur during 10^7 computer cycles (10 seconds).

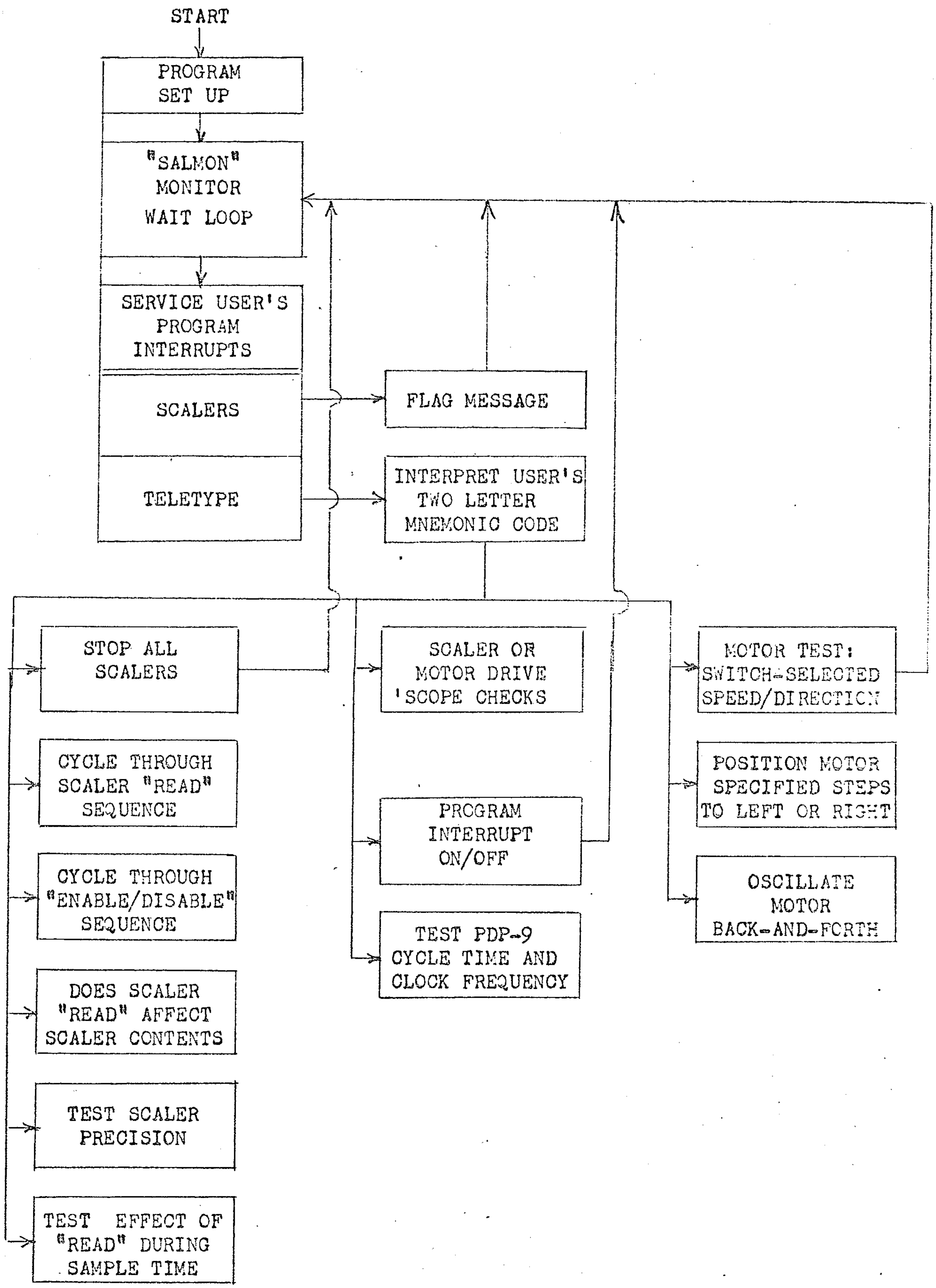
Test scaler precision - "SV" - take repeated 10-second samples of an external pulse generator. For each sample, the scaler being tested is read twice, 6 usec apart and both readings, plus the elapsed PDP-9 clock counts, are printed on the teletype.

Test effect of "read" during sample time - "SD" - during a 10-second sample, the scaler is read up to 25,000 times per second. Each "read" blocks the input pulses for 2 usec and can clear the P.I. request before it can be serviced. The scaler contents, the elapsed clock counts and the interval between successive readings of the scaler are printed on the teletype.

Figure E.1

Flow diagram of the Program for Scaler and Motor Drive Interface Tests. Several tests of the scaler and motor drive functions are available. All routines (except those that return to SALMON as shown) remain in their test loop until the operator intervenes to return control to the monitor. The Program Interrupt service routine for the scalers can be activated by suitably modifying the first location of the routine that sets up the program parameters.

APPENDIX E


START
PROGRAM SET UP
"SALMON" MONITOR WAIT LOOP
SERVICE USER'S PROGRAM INTERRUPTS
SCALERS
TELETYPE
FLAG MESSAGE
INTERPRET USER'S TWO LETTER MNEMONIC CODE
STOP ALL SCALERS
CYCLE THROUGH SCALER "READ" SEQUENCE
CYCLE THROUGH "ENABLE/DISABLE" SEQUENCE
DOES SCALER "READ" AFFECT SCALER CONTENTS
TEST SCALER PRECISION
TEST EFFECT OF "READ" DURING SAMPLE TIME
SCALER OR MOTOR DRIVE 'SCOPE CHECKS
PROGRAM INTERRUPT ON/OFF
TEST PDP-9 CYCLE TIME AND CLOCK FREQUENCY
MOTOR TEST: SWITCH-SELECTED SPEED/DIRECTION
POSITION MOTOR SPECIFIED STEPS TO LEFT OR RIGHT
OSCILLATE MOTOR BACK-AND-FORTH

```
//SCALER AND STEPPING MOTOR INTERFACE TESTS  07.8.70 DP.................
/TO BE RUN UNDER CONTROL OF THE "SALMON" MONITOR
/ASSEMBLE WITH "SOFTWARE DIAGNOSTICS AND UTILITIES 07.8.70 DP"
/"LIGHTPEN SERVICE, DUBOUT  07.8.70 DP"
/"ARITHMETIC COMPARISONS 07.8.70"
/"MONITOR 2.1 ADDRESSES APR 10/68"
/
/TO ISSUE IN A REPETITIVE LOOP ANY COMBINATION OF IOT'S (MICROCODED
/ INTO ONE INSTRUCTION) TO ANY ONE OF THE 3 SCALERS OR THE SLO-SYN
/ MOTOR, UNDER KEYBOARD SELECTION BY 2-LETTER MNEUMONIC
/TESTS "PAUSE", "ENABLE/DISABLE", "READIN"
/TESTS INTERNAL CLOCK, SCALER VALIDITY, SCALER DEADTIME LOSSES
/TESTS MOTOR AT VARIABLE SPEED, DIRECTION
/
/SCALER IOT FUNCTIONS
/           IOT1-TEST FOR PROGRAM INTERRUPT FLAG
/                PAUSE IN COUNTING TO ALLOW SCALER TO SETTLE BEFORE READ
/           IOT2-ENABLE SCALER
/                READ SCALER
/                CLEAR PROGRAM INTERRUPT FLAG
/           IOT4-DISABLE SCALER
/                CLEAR SCALER (SETS P.I. FLAG IF SCALER IS
/                         MORE THAN HALF FULL!!)
/TO READ THE SCALER 'ON THE FLY', USE IOT 13 SO THAT ALL BIT CARRIES
/      ARE COMPLETED BEFORE THE SCALER IS STROBED INTO THE ACCUMULATOR
/
/
/
/***** PROGRAM SETUP
3000/          LAC (NOP     /TO AVOID FLAG MESSAGE, ELSE "JMP SCALPI"
               DAC PISER2
               LAC (XX      DAC PISER2 2
               LAC (JMP STMNEU          DAC REENT2   /EXTEND CODE CHAIN
               DZM 2763     /DISABLE TELY #2
               CLOF         /TURN CLOCK OFF
               IOT 5104     IOT 5106
               IOT 5204     IOT 5206
               IOT 5304     IOT 5306
               NOP          NOP         NOP
               JMP REENTR
. 20/
/
/
/***** MNEMONIC CODE INTERPRETATION *****
CODE,          0            /TEMP STORAGE OF MNEUMONIC CODE
CODCNT,        0            /CODE-LOOKUP COUNTER
STMNEU,        DAC CODE
               LAM-15 1     DAC CODCNT  /# OF CODES IN CODE TABLE
               LAC (CODTBL-2            /CODE TABLE INITIAL ADDRESS-2
               DAC 10
CDLOAD,        ISZ 10       SKP         JMS BPSER    /BREAKPOINT = ERROR
               LAC I 10     /LOAD AC WITH CODE FROM TABLE
               SAD CODE     /IS THIS THE MNEUMONIC JUST TYPED IN
               XCT I 10     /YES - JUMP TO SERVICE ROUTINE
               ISZ 10       SKP         JMS BPSER    /BREAKPOINT = ERROR
               ISZ CODCNT   /NO, BUT IS IT LAST CODE IN TABLE
               JMP CDLOAD   /NO - CHECK OTHER CODES IN TABLE
               LAC CODE
               JMP OTHER    /YES - LOOK AT CODES OUTSIDE TABLE
               NOP
               NOP
CODTBL,        323261       JMP SCALER   IOT 5100     /S1=TEST SCALER #1
323262         JMP SCALER                IOT 5200     /S2=TEST SCALER #2
323263         JMP SCALER                IOT 5300     /S3=TEST SCALER #3
315304         JMP MOTOR                 IOT 5404     /MD=TEST MOTOR DRIVE
324261         JMP IOPULSE 1             /T1=IOT 1
324262         JMP IOPULSE 2             /T2=IOT 2
324263         JMP IOPULSE 3             /T3=IOT 1 AND IOT 2
324264         JMP IOPULSE 4             /T4=IOT 4
324265         JMP IOPULSE 5             /T5=IOT1 AND IOT 4
324266         JMP IOPULSE 6             /T6=IOT2 AND IOT4
324267         JMP IOPULSE 7             /T7=IOT 1 AND IOT 2 AND IOT 4
332331         JMP CLEARAC               /ZA=ZERO ACCUMULATOR WITH IOT
. 20/
/
```

```
/
OTHER,        SAD (MV       JMP MOTVAR  /MV=VARIABLE SPEED/DIRECTION
              SAD (MM       JMP MOVMOT  /MOVE MOTOR SPECIFIED # STEPS L,R
              SAD (SM       JMP RSPONS  /SM POWER SUPPLY RESPONSE
              SAD (317316   JMP PION    /ON=P.I. ON
              SAD (317306   JMP PIOFF   /OF=P.I. OFF
              SAD (320323   JMP PAUSE   /PS=TEST PAUSE-ON-READIN
              SAD (322306   JMP RUNFLG  /RF=TEST ENABLE/DISABLE
              SAD (322311   JMP READIN  /RI=TEST READIN
              SAD (SS       JMP STOPSC  /STOP SCALERS+CLEAR ALL
                                        /ENABLE AND PI FLAGS
              SAD (IC       JMP INTCLK  /CHECK INTERNAL CLOCK
              SAD (SV       JMP SCAVAL  /10 SECOND COUNT
              SAD (SD       JMP SCLRDT  /10 SEC COUNT WITH READIN DEADTIME
              JMS SOFBUG    /DIAGNOSTIC ROUTINES FOR SOFTWARE BUGS
              NOP           NOP
              JMP ERROR     /UNRECOGNIZABLE CODE
.+20/
/
/
/
/***** SUBROUTINE FOR DEVICE SELECTION *** TYPE "S1","S2","S3","MD" ***
SCALER,       LAC I 10      DAC SCLR
              LAC (JMP SCLR             DAC SCLR 2
              JMP REENTR
/
TENTO4,       23420         /10,000 (DEC)
MOTOR,        LAC I 10      DAC SCLR
              LAC (LAC TENTO4           DAC SCLR 2
              JMP SCLR
              / LIMIT MOTOR TO 100 STEPS/SECOND
/
/*****SUBROUTINE FOR IOT SELECTION** TYPE T1 OR T2, T3, T4, T5, T6, T7 *
IOPULSE,      LAC SCLR      AND (707760
              TAD I 10      DAC SCLR
              AND (707761   NOP         /COULD DAC INTO A
                                        /SKIP-ON-FLAG ROUTINE
              JMP SCLR
/
/***** ZERO AC WITH IOT *** TYPE "ZA" ****
CLEARAC,      LAC SCLR      TAD (10     DAC SCLR
              JMP SCLR
/
/
/IOT LOOP ROUTINE
ACATPI,       0
SCLR,         XX
              OPR           XX          JMS MICSEC
              JMP SCLR
              NOP           NOP         NOP         NOP
/
/
/
```

```
/
/***** VARIABLE SPEED AND DIRECTION TEST OF MOTOR *****TYPE "MV" ****
/ACS17 UP = LEFT; DOWN = RIGHT
MV=315326
MOTVAR,         LAS .           AND (1          TAD (705405
                DAC . 1         XX              /MOTOR DIRECTION FROM BIT 17
                LAS             JMS MICSEC      /DELAY BETWEEN STEPS (MIN=5400 OCT)
                                / APPROX. 350 STEPS/SEC
                JMP MOTVAR
/
/
/
/
/
/
/***** MOVE MOTOR SPECIFIED # OF STEPS L OR R ***** TYPE "MM" ****
MM=315315
STEPS,          0
MOVMOT,         TCR             DECNMB          /#STEPS
                CMA             TAD (1          DAC STEPS
                JMS 1042        GIC             /DIRECTION L OR R
                SAD (314        SKP             JMP . 3
                LAC (IOT 5406                   JMP . 5         /L
                SAD (322        SKP             JMP MOVMOT+5
                LAC (IOT 5405                   /R
                DAC . 1
                JMS ERRMES      /MOTOR STEP INSTRUCTION
                LAC (23420      /10000 (DEC) = 100 STEPS/SECOND
                JMS MICSEC
                ISZ STEPS       JMP .-4
                JMP MOVMOT      /REPEAT
/
/
/***** STEERING MAGNET POWER SUPPLY RESPONSE ***** SM ***
/CAUSE MOTOR TO OSCILLATE A SPECIFIED NUMBER OF STEPS IN EACH DIRECTION
/AT A SPECIFIED NUMBER OF STEPS/SECOND
/SHUNT VOLTAGE CHANGE IS ABOUT 0.25 MILLIVOLT PER MOTOR STEP
/
SM = 323315
/
STPDIR,         0               /STEPS IN EACH DIRECTION
PEROSC,         0               /MICROSEC PER STEP
STPX,           0               /STEP INDEX
/
/
RSPONS,         LAC (SSM-1      TTEXT           / STEPS/SEC
                DECNMB          DAC NOS
                LAC (SDM-1      TTEXT           /STEPS IN EACH DIRECTION
                DECNMB          CMA             TAD (1          DAC STPDIR
/
                LAC (64100      LMQ             LAC (3          /1 MILLION
                CLL
                DIV
NOS,            XX              LACQ
                DAC PEROSC
/
NLNR,           LAC STPDIR      DAC STPX
                JMS SLEFT                       /STEPS LEFT
                ISZ STPX        JMP .-2
/
                LAC STPDIR      DAC STPX
                JMS SRIGHT                      /STEPS RIGHT
                ISZ STPX        JMP .-2
/
                JMP NLNR        /BEGIN NEXT CYCLE
/
/
SLEFT,          0               LAC PEROSC      JMS MICSEC
                IOT 5406        JMP I SLEFT
/
SRIGHT,         0               LAC PEROSC      JMS MICSEC
                IOT 5405        JMP I SRIGHT
/
/" STEPS/SEC ="
SSM,            240323          324305          320323
257323          305303          240275          000000

/"  FOR STEPS EACH DIRECTION ="
SDM,            240240          306317          322240          323324
305320          323240          305301          303310          240304
311322          305303          324311          317316          240275
000000
/
.+20/
/
/
```

```
/
/***** PROGRAM INTERRUPT ON/OFF*** TYPE "ON" OR "OF" ***
/
/
PION,       JMP REENTR-1
PIOFF,      IOF         JMP REENTR
/
/
/
/***** TEST PAUSE-ON-READIN ***** TYPE "PS" *****
PAWSE,      LAC SCLR    AND (707760 /KEEP ONLY "IOT+DEVICE #"
            TAD (12     DAC PAWSEN
            TAD (4      DAC PECD+1
            TAD (1      DAC PECD
PECD,       XX          /PAUSE AND READ (IOT XX17)
            XX          /CLEAR AND DISABLE SCALER (IOT XX16)
PAWSEN,     XX          /ENABLE (IOT XX12)
            LAS         JMS MICSEC
            JMP PECD
.+5/
/
/
/
/***** TEST ENABLE AND DISABLE ***** TYPE "RF" *****
RUNFLG,     LAC SCLR    AND (707760 /KEEP ONLY "IOT+DEVICE #"
            TAD (2      DAC RUNEN
            TAD (2      DAC RUNDI   DAC RUNDI+1
RUNEN,      XX          /ENABLE = IOT XX02
            NOP         NOP         NOP         NOP
RUNDI,      XX          /DISABLE = IOT XX04
            XX          /IOT XX04
            NOP         NOP
            JMP RUNEN
.+5/
/
/
/***** TEST READIN*** TYPE "RI" ***
CONINT,     0
READIN,     LAC SCLR    AND (707760 /KEEP ONLY "IOT+DEVICE #"
            TAD (2      DAC READEN
            TAD (11     DAC READPS  DAC READP2
            TAD (3      DAC READ2   DAC READP2+3        DAC READP2+4
READ2,      XX          /CLEAR PI AND SCALER; DISABLE SCALER (IOT XX 16)
READEN,     XX          /ENABLE SCALER AND CLEAR P.I. FLAG (IOT XX 12)
            LAS         JMS MICSEC  /SWITCH SELECTED COUNTING PERIOD
READPS,     XX          /PAUSE AND READIN (IOT XX 13)
            OPR
            LMQ         /FIRST READ STORED IN MQ
READP2,     XX          /IOT XX13   SECOND READ STORED IN AC
            OPR
            DAC CONINT
            XX          /IOT XX16 - DISABLE
            XX          /IOT XX16
            LAC CONINT
            XX          /HALT TO SEE IF AC = MQ + COUNTS BETWEEN READS
            JMP READ2
.+10/
/
/
/
/***** PROGRAM INTERRUPT SERVICE ROUTINE FOR SCALERS(NOT TOO USEFUL)
ACSVPI=2265             /INMONITOR 2.1 APR 10/68 DR
SCALPI,     CLA
            IOT 5101    SKP         JMP SCL1    /TEST SCALER #1
            IOT 5201    SKP         JMP SCL2    / #2
            IOT 5301    SKP         JMP SCL3    / #3
            JMP PISER3              /TEST OTHER DEVICES
SCL1,       TAD (1      JMP INTOUT
SCL2,       TAD (2      JMP INTOUT
SCL3,       TAD (4
INTOUT,     LMQ         TCR         LACQ
            OCTPNT      LAC (SOFMES-1           TTEXT       /" FLAG"
            TYT         LAC ACSVPI  OCTPNT
            CAF
            JMP DISMIS
            NOP
            NOP
            NOP
            JMP PISER3
/" FLAG"
SOFMES,     240306      314301      307000
/
/
/
/***** STOP SCALERS *****TYPE "SS" *****
SS = 323323
STOPSC,     IOT 5104    IOT 5106
            IOT 5204    IOT 5206
            IOT 5304    IOT 5306
            CLOF
            JMP REENTR
            NOP         NOP         NOP
/
/
```

```
/
/*** TEN-SECOND DELAY SUBROUTINE *****
/ 10.000256 SECONDS, INCLUDING CALL TO 'TENSEC' AND RETURN
SECKS,      0
TENSEC,     0
            LAM-62 1    /50(DEC)
            DAC SECK5
            LAC (606500 /200,000 MICROSEC
            JMS MICSEC
            ISZ SECK5   JMP .-3
            JMP I TENSEC            /TEN SECONDS ARE UP
/
/
/
/***** TEST OF PDP-9 INTERNAL CLOCK *****TYPE "IC" ****
IC=311303
INTCLK,     DZM 7       /ZERO CLOCK
            TCR
            CLON        /START CLOCK
            JMS TENSEC  /DELAY 10 SECONDS
            CLOF        LAC 7       DECPNT      /OUTPUT CLOCK (600'S)
            JMP INTCLK 2
/
/
/
/***** TEST OF SCALER VALIDITY FOR REPEATED 10-SEC COUNT PERIODS **"SV"
/AFTER USING THIS ROUTINE "SS" DOES NOT WORK UNLESS "ST 3000" USED FIRST
SV=323326
SVHI,       0
SVLO,       0
SVLO2,      0
SCAVAL,     IOT 5104    IOT 5106    /RESET ALL SCALERS
            IOT 5204    IOT 5206
            IOT 5304    IOT 5306
            LAC SCLR    AND (707760
            TAD (1      DAC PISER2
            TAD (1      DAC SVNABL  /ENABLE
            DAC FLGCLR              /CLEAR PI FLAG
            TAD(11      DAC SVREAD  /READ
            DAC SVRD2
            TAD (3      DAC SVHLT1  DAC SVHLT1+1
                                    /CLEAR+HALT=IOT XX16
            DAC SVHLT2  DAC SVHLT2+1
            LAC (JMP SVPI           DAC PISER2+2            /SET UP
                                    /PROGRAM INTERRUPT.
SVHLT1,     XX          /CLEAR THE SCALER AND PI FLAGS- IOT XX 16
            XX
            DZM SVHI    DZM 7       DZM SVLO    DZM SVLO2
            CLON
SVNABL,     XX          /ENABLE=IOT XX 02
            JMS TENSEC
            CLOF
SVREAD,     XX          /READ LOW-ORDER COUNTS =IOT XX 13
            OPR         /IN CASE FLAG IS UP
            DAC SVLO
SVRD2,      XX          /READ LOW ORDER COUNTS AGAIN = IOT XX 13
            OPR
            DAC SVLO2
SVHLT2,     XX          /STOP THE SCALER=IOT XX 16
            XX          /TO PREVENT ERRONEOUS P.I. INTERRUPTS=IOT XX 16
            TCR
            LAC SVLO    LMQ
            LAC SVHI
            JMS DUBOUT  /OUTPUT SCALER COUNTS
            TYT
            LAC SVLO2   LMQ
            LAC SVHI
            JMS DUBOUT  /SECOND READ
            TYT         /SHOULD = FIRST READ + COUNTS BETWEEN READS
            LAC 7       DECPNT      /OUTPUT INTERNAL CLOCK COUNTS
            OPR         /HLT
            JMP SVHLT1  /REPEAT TEST
SVPI,       ISZ SVHI    /INCREMENT HIGH-ORDER COUNTS
            OPR
FLGCLR,     XX          /CLEAR PI FLAG
            JMP DISMIS
SVPTCH,     0           /20(DEC)LOCATIONS FOR PATCHES
.+21/
/
/
```

```
/
/***** TEST OF SCALER DEADTIME DURING TEN-SECOND COUNT *****TYPE "SD"
/AC SWITCHES =# OF MICROSEC BETWEEN PAUSE-ON-READ'S (MIN = 40 MICROSEC)
/AFTER USING THIS ROUTINE "SS" DOES NOT WORK UNLESS "ST 3000" USED FIRST
SD=323304
DTHI,       0
DTLO,       0
CNTIME,     0
TIME2,      0
SCLRDT,     IOT 5104    IOT 5106
            IOT 5204    IOT 5206
            IOT 5304    IOT 5306
            LAC SCLR    AND (707760
            TAD (1      DAC PISER2  /SETUP P.I.= IOT XX 01
            TAD (1      DAC DTNABL  /ENABLE = IOT XX 02
            DAC DTFLG               /CLEAR P.I. FLAG
            TAD (11     DAC DTROF   /READ-ON FLY = IOT XX 13
                        DAC DTROF2
            TAD (3      DAC DTHLT1  DAC DTHLT1+1
                        /READ, CLEAR, DISABLE = IOT XX16
                        DAC DTHLT2  DAC DTHLT2+1
            LAC (JMP DTPI           DAC PISER2+2            /SET UP PI
ACSDLY,     LAS         /DELAY BETWEEN READS
            AC.LT.      50          LAC (50
                        /MIN = 50 (OCT) FOR VALID DIV
            DAC TIMECT
            LAC (113200 LMQ
            LAC (46     /AC+MQ = 10 MILLION (DEC)
            CLL
            DIV
TIMECT,     XX          /10 MILLION (DEC)=SAMPLE TIME IN MICSEC
            SZL         JMS ERRMES  /OVERFLOW
            DAC TIME2
            LACQ        CMA         TAD (1
            DAC CNTTME  /# OF READ-ON-FLY'S
DTHLT1,     XX          /CLEAR AND DISABLE= IOT XX 16
            XX          /TO PREVENT ERRONEOUSP.I. INTERRUPT
            DZM 7       CLON        DZM DTHI
            NOP         NOP
DTNABL,     XX          /ENABLE = IOT XX 02
            LAM-13+1    /CORRECT FOR TIME SPENT IN THIS LOOP
            TAD TIMECT  JMS MICSEC
DTROF,      XX          /READ-ON-FLY =IOT XX 13
            OPR         /IN CASE FLAG IS UP
            ISZ CNTTME
            JMP .-6
            OPR         /NEC FOR TIMING
            LAM-3+1
            TAD TIME2   JMS MICSEC
DTROF2,     XX          /READ LOW ORDER = IOT XX 13
            OPR
            DAC DTLO    /STORE LOW-ORDER COUNTS
            NOP         NOP
DTHLT2,     XX          /DISABLE - IOT XX 16
            XX          / TO PREVENT ERRONEOUS P.I. INTERRUPT =IOT XX 16
            CLOF
            TCR
            LAC DTLO    LMQ
            LAC DTHI
            JMS DUBOUT  /OUTPUT SCALER COUNTS

            TYT         LAC 7       DECPNT      /OUTPUT INTERNAL
                                                /CLOCK COUNTS
            TYT
            LAC TIMECT
            DECPNT      /ACS= TIME BETWEEN READ-ON-FLY'S
            XX          /TO ALLOW TIME TO SET AC SWITCHES
            JMP ACSDLY  /REPEAT TEST
DTPI,       ISZ DTHI    /INCREMENT HIGH-ORDER COUNTS
            OPR
DTFLG,      XX          /CLEAR PI FLAG
            JMP DISMIS
DTPTCH,     0           /RESERVED FOR PATCHES
.+21/
/
/
/
PAUSE
```

APPENDIX F

BEAM OBSERVATION PROGRAM

This program is used to take 1792 samples of the counts from the left and right scintillation counters as a function of time or as a function of the counts in the third PDP-9 scaler. The "On-Line Beam Position Control Routines" are incorporated in this program and may be used to control the ratio of scintillation counter rates if desired. The data from the samples may be displayed on the screen, printed on the teletype, or plotted. A complete description of the uses of this program were given in Chapter 3.5b.

The program was written in the PDP-9 Basic machine language. The listings (to follow) of the symbolic paper tapes of all of the various program routines are segmented into functional program blocks for ease of understanding. Two unique character sequences have been incorporated in the format of the program listings to identify these functional blocks. First, the titles of all symbolic paper tapes begin with a double slash, contain the date on which the tape was made, and conclude with a series of dots. Second, a distinctive comment is placed at the head of any program block whose execution is initiated by the setting of an accumulator switch or by the typing in of a two-letter command mnemonic. Such comments always begin with the 6 characters "/xxxxx".

A brief description of the Beam Stability vs Time Routines (see Figure F.1) follows:

For Data Taking:

Slow Run - teletype mnemonic "SR" - takes 1792 timed samples of the left (#1) and right (#2) scalers. The sample time is equal to an integral number of PDP-9 clock counts specified from the teletype, i.e. units of 16.67 milliseconds. There is no position control or data display during the run.

Fast Run - "FR" - takes 1792 timed samples of the left and right scalers. The sample time is equal to an integral number of microseconds specified from the teletype. There is no position control or data display during the run.

Control Beam position while accumulator switch 4 is up - "CB" - sets up position control (for SR or FR) based on each separate sample. Motor step data is coded into the low-order bit of each data word.

control Average Beam position while accumulator switch 4 is up - "AB" - sets up position control (for SR FR) based on the average of the latest 2, 4, 8 or 16 samples (default = 8). Motor step data is coded into the low-order bit of each data word.

scalers #1 and #2 VerSus #3 - "VS" - takes 1792 samples of the left and right scalers. Each sample continues until a specified number of counts has been collected in scaler #3.

Beam Sweep from side-to-side - "BS" - the initial displacement of the motor (number of steps and direction L or R) is specified from the teletype. Then BS takes 1792 samples as per SR with 1 motor step after each sample (left or right accordingly as accumulator switch 17 is up or down).

Terminate Run - "TR" - disables the scalers and the PDP-9 clock. Normally used only to shut down after an interrupted run.

Move Motor - "MM" - for calibrating the bipolar power supply as to mA/step and mV/step.

For Manipulation of Data Stored in the Computer:

Left/Right ratio - "LR" - this ratio is formed for each sample and stored in place of the right scaler data.

LoGarithm - "LG" - takes base-10 logarithm of each data word in a specified region of memory. Mantissa is four decimal digits but the two low-order ones are not too reliable.

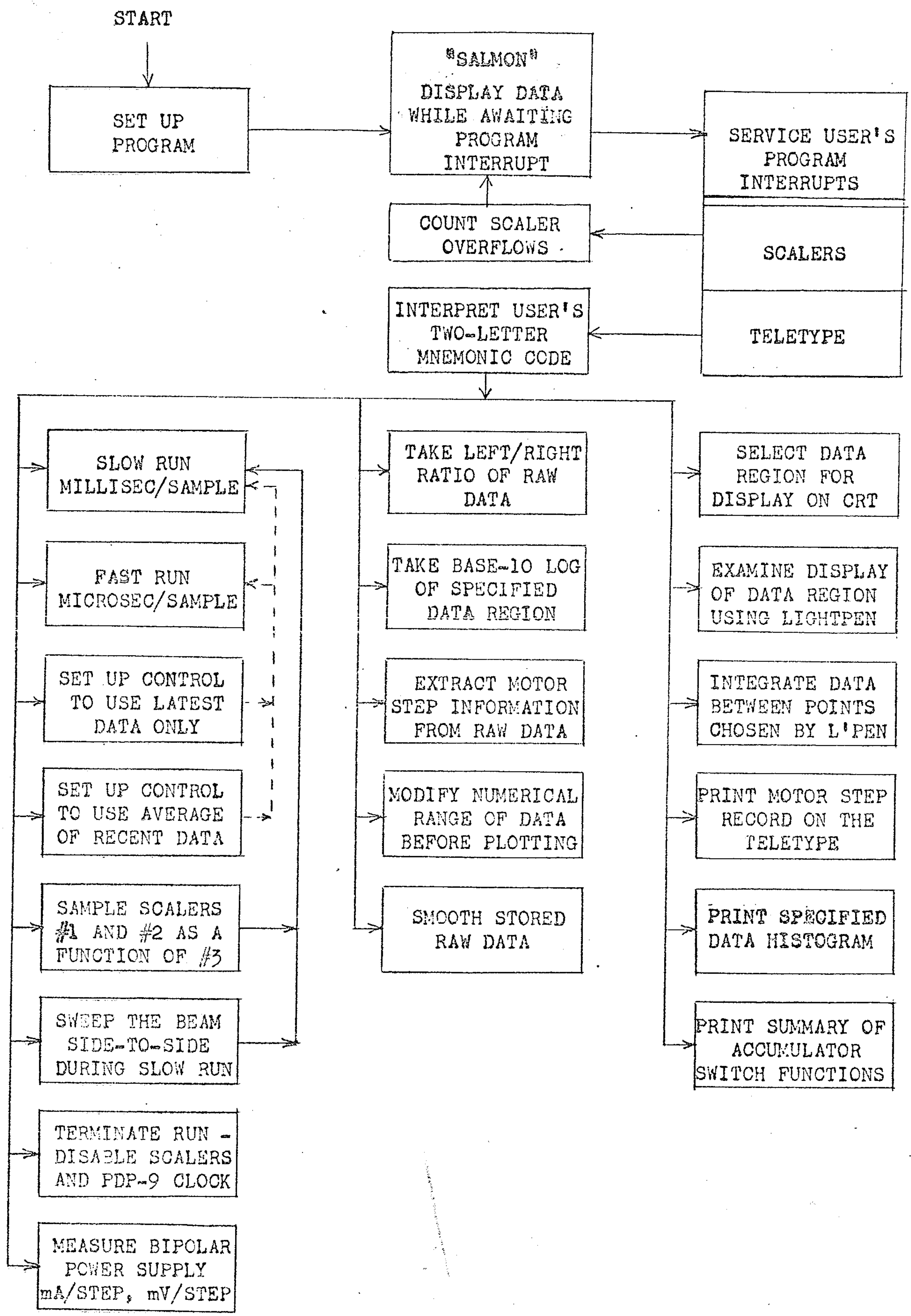
eXTract motor step information - "XT" - interprets the code from the low-order bit of each data word. Determines for each sample whether the position control was ON or OFF and whether the motor stepped left, right or not at all. The sample-by-sample motor step data is stored in place of the left scaler data. The net number of steps (after each sample) is stored in place of the right scaler data.

Smooth Data - "SD" - smooths the data stored in the computer by passing a software "window" filter over it.

Figure F.1

Flow diagram of the Beam Observation Program showing its linkage with the resident monitor "SALMON". The function of these routines is (a) to gather data from the PDP-9 scalers (beam positioning counters), (b) to manipulate that data, or (c) to output data on the teletype or display.

Unless otherwise shown, all routines return to the "SALMON" Monitor upon completion. The dashed lines indicate that the routines to set up the beam position control can be followed by a "slow" or a "fast" run.


START
SET UP PROGRAM
"SALMON" DISPLAY DATA WHILE AWAITING PROGRAM INTERRUPT
SERVICE USER'S PROGRAM INTERRUPTS
COUNT SCALER OVERFLOWS
SCALERS
INTERPRET USER'S TWO-LETTER MNEMONIC CODE
TELETYPE
SLOW RUN MILLISEC/SAMPLE
FAST RUN MICROSEC/SAMPLE
SET UP CONTROL TO USE LATEST DATA ONLY
SET UP CONTROL TO USE AVERAGE OF RECENT DATA
SAMPLE SCALERS #1 AND #2 AS A FUNCTION OF #3
SWEEP THE BEAM SIDE-TO-SIDE DURING SLOW RUN
TERMINATE RUN - DISABLE SCALERS AND PDP-9 CLOCK
MEASURE BIPOLAR POWER SUPPLY mA/STEP, mV/STEP
TAKE LEFT/RIGHT RATIO OF RAW DATA
TAKE BASE-10 LOG OF SPECIFIED DATA REGION
EXTRACT MOTOR STEP INFORMATION FROM RAW DATA
MODIFY NUMERICAL RANGE OF DATA BEFORE PLOTTING
SMOOTH STORED RAW DATA
SELECT DATA REGION FOR DISPLAY ON CRT
EXAMINE DISPLAY OF DATA REGION USING LIGHTPEN
INTEGRATE DATA BETWEEN POINTS CHOSEN BY L'PEN
PRINT MOTOR STEP RECORD ON THE TELETYPE
PRINT SPECIFIED DATA HISTOGRAM
PRINT SUMMARY OF ACCUMULATOR SWITCH FUNCTIONS

For Data Output:

select data region for display - "L1, L2, R1, R2" - sets up the parameters of the routine to display the first or second half of the left or right data region.

Light Pen interrogation of display - "LP" - prints out the channel numbers and contents of the last two points of the display that were selected by the lightpen.

InteGrate a portion of the display - "IG" - prints on the teletype the double-precision sum of the contents of all the channels (including the endpoints) between two channels selected by the lightpen.

print Motor Step record - "MS" - prints a summary of the actions of the stepping motor on the helipot of the bipolar power supply.

pRinT data histogram - "RT" - prints the contents of every n^{th} (n = 1, 2, 3, ...) channel of a histogram.

print summary of accumulator SWitch functions - "SW" -

```
//BEAM STABILITY VS TIME  20.8.70 DP  TAPE 1 OF 4....................
/
/INITIALIZATION, MNEMONIC CODES, P.I. SERVICE, SLOW RUN, FAST RUN,
/READ SCALERS.

/ASSEMBLE WITH THESE SYMBOLIC TAPES:
/"BEAM STABILITY VS TIME  19.8.70 DP  TAPE 2 OF 4"
/"BEAM STABILITY VS TIME  19.8.70 DP  TAPE 3 OF 4"
/"BEAM STABILITY VS TIME  19.8.70 DP  TAPE 4 OF 4"
/"ARITHMETIC COMPARISONS 07.8.70 DP"
/"ON-LINE BEAM POSITION CONTROL ROUTINES 19.8.70 DP"
/"LIGHTPEN SERVICE, "DUBOUT" 07.8.70 DP"
/"SINGLE HIST DISPL. 07.8.70 DP"
/"LOG SCALE OF DATA REGION 07.8.70 DP"
/"SOFTWARE DIAGNOSTICS AND UTILITIES 07.8.70 DP"
/"MONITOR 2.1 ADDRESSES APR 10.68 DR"
/"CALCOMP PROGRAM "CC"" MUST BE LOADED FROM THE "SALMON" TAPE
/     WHEN PLOT OUTPUT IS DESIRED"

/SCALER #1 = LEFT SCINTILLATION COUNTER
/SCALER #2 = RIGHT SCINTILLATION COUNTER
/SCALER #3 = COUNTS FROM BROOKHAVEN INSTR. CORP. INTEGRATOR

/SCALER IOT'S (COMMANDS TO DEVICE 51, 52 OR 53)
/           IOT 1 = TEST PI FLAG
/                 = PAUSE BEFORE READ
/           IOT 2 = ENABLE SCALER
/                 = READ SCALER
/                 = CLEAR P.I. FLAG
/           IOT 4 = CLEAR SCALER (WILL SET P.I. IF SCALER > 131071)
/                 = DISABLE SCALER
/           IOT 10= CLEAR AC AT EVENT TIME 1
/
/SLO-SYN STEPPING MOTOR IOT'S
/           IOT 5405 = MOVE MOTOR ONE STEP RIGHT
/           IOT 5406 = MOVE MOTOR ONE STEP LEFT
/
/ACCUMULATOR SWITCH FUNCTIONS
ACS1 = 200000          /TERMINATE RUN
ACS23 = 140000         /ACS2,3 = 1,0 - DISPLAY LEFT REGION #1
                        /         1,1 -    "      "       "   #2
                        /         0,0 -    "    RIGHT     "   #1
                        /         0,1 -    "      "       "   #2
ACS2 = 100000
ACS3 = 40000
ACS4 = 20000           /UP=YES DURING 'CONTROL BEAM' RUN ('AB' OR 'CB')
ACS5 =  10000          /HOLD RUN WHILE ACS5 UP
ACS6 =   4000          /PRINT SCALER READINGS FROM EACH SAMPLE
ACS8 =   1000          /PRINT COUNT RATE (HZ) AFTER EACH SAMPLE

/ENTER TIME INTERVAL FROM THE TELETYPE
/PROG. TAKES UP TO 1792 SAMPLES AND DISPLAYS THE
/           COUNTS FROM SCALERS #1 AND #2 ON THE SCOPE
/OPTIONAL OUTPUT ON TELETYPE OF COUNTS/SAMPLE AND/OR COUNTS/SEC
/IN DOUBLE PRECISION.

11000/
LEFTD,      0              /PRIOR TO JULY 1970, THE DATA REGIONS WERE:
                           /LEFT (10000 - 13777), RIGHT (14000 - 17777)

14400/
RIGHTD,     0
.+3377/

/***** PROGRAM SETUP ***

3000/
BSINIT,     JMS ALLOFF  /CLEAR AND DISABLE; CLEAR P.I.
            DZM 2763    /DISABLE TELY #2
            DZM RUNFLG              /NO RUN
            LAC (JMP SCLRPI         DAC PISER2  /SET-UP PI SERVICE
            LAC (XX     DAC PISER2+2
            LAC (JMP BSMNEU         DAC REENT2  /EXTEND MNEUMONICS
            LAC (JMP ACSOPT
            DAC BPDSUB  /DEFAULT = NO MOTOR MOVEMENT
            LAC (ACS2
            JMS DISP    /SETUP DISPLAY = LEFT #1
            LAC (ACS23  /SWITCHES USED TO MODIFY DISPLAY
            JMS DISPLS  /DISPLAY
            LAC (JMS CLKAPI         DAC 51      /SET-UP CLOCK API
            LAC (PENSER             DAC 54      /SET-UP LIGHTPEN API

            NOP         NOP
            JMP REENTR

INPTCH,     0           /ROOM FOR PATCHES
 .+10/
```

```
/***** DESCRIBE AC SWITCHES **** TYPE "SW" ****
SW = 323327
ACSTEL,         TCR             LAC (ACSTEL+3            TTEXT
                JMP REENTR
301303          323215          212240          /ACS
261240          240240          240305          316304      / 1    END RUN
240322          325316          215212
240262          254263          240304          / 2,3  DISPLAY REGION
311323          320314          301331
240322          305307          311317
316215          212240
264240          240240          240303          / 4    CONTROL
317316          324322          317314
215212          240265          240240          / 5    HOLD RUN
240240
310317          314304          240322
325316          215212
240266          240240          240240          / 6    TYPE SAMPLE
324331          320305          240323
301315          320314          305215
212240          270240          240240          / 8    TYPE HZ
240324          331320          305240
310332          215212
240260          254271          255261          / 0,9-17  DISPLAY SCALE
267240          240304          311323
320314          301331          240323
303301          314305          000000
/
/
/MNEUMONIC CODES
SR = 323322             /START RUN
FR = 306322             /FAST RUN
TR = 324322             /TERMINATE RUN
LP = 314320
IG = 311307


/***** INTERPRETATION OF MNEMONIC CODE FROM TELETYPE
BSMNEU,     JMS CODCHK  /BEAM STABILITY VS TIME CODES
            JMS SOFBUG  /SOFTWARE DIAGNOSTIC UTILITY ROUTINES
            NOP         NOP         NOP
            JMP ERROR   /NOT RECOGNIZED
/
/IF CODE IS IN TABLE, CORRESPONDING ACTION IS TAKEN
MNEM,       0           /CODE LOOKUP
CAX,        0           /CODE.ACTION INDEX
CAADDR,     CODEAC      /CODE.ACTION TABLE (INITIAL ADDRESS)
CAP,        0           /CODE.ACTION POINTER
CODCHK,     0           /MNEMONIC-CODE CHECK
            DAC MNEM    /SAVE 2 LETTER CODE
            LAM-26-1    /(# OF CODES)
            DAC CAX     /SET UP TABLE INDEX
            LAC CAADDR
            DAC CAP     /SET UP TABLE POINTER TO FIRST CODE
            LAC I CAP   /BRING CODE INTO AC
            ISZ CAP     /SHIFT POINTER TO "ACTION"
            SAD MNEM    /IS CODE = MNEMONIC
            JMP FOUND   /YES - TAKE ACTION
            ISZ CAP     /NO; SHIFT POINTER TO NEXT CODE
            ISZ CAX     /HAVE ALL CODES BEEN TESTED
            JMP .-6     /NO; TEST NEXT
            LAC MNEM    /YES; MNEMONIC NOT IN TABLE
            JMP I CODCHK            /RETURN TO CALLING PROGRAM

FOUND,      XCT I CAP   /ACTION CAN BE JMP, JMS, OR ANY INSTR.
            JMP REENTR

/TABLE OF MNEMONIC CODES AND CORRESPONDING ACTIONS

CODEAC,     SR          JMP SLORUN  /STARTS SLOW RUN(34 SEC TO 12000 HR
FR          JMP FSTRUN  /START FAST RUN (0.2 - 550 SEC)
CB          JMP NAVGBC  /SETUP TO CONTROL BEAM POSITION (NO AVERAGE)
AB          JMP AVGBC   /SETUP TO CONTROL BEAM AVERAGE POSITION
VS          JMP VERSUS  /SLOW RUN; SCALER 1 AND 2 VS. #3
BS          JMP SWEEP   /"MM"+SLOW RUN; 1 STEP L OR R AFTER EACH SAMPLE
MM          JMP RVMOT   /MOVE MOTOR # STEPS L OR R (CALIBRATE PWR SPLY)
TR          JMP TERMRN  /TERMINATE RUN
L1          JMP DSPL1   /DISPLAY FIRST (SECOND) HALF OF LEFT (RIGHT)DA
L2          JMP DSPL2
R1          JMP DSPR1
R2          JMP DSPR2
MS          JMP STPHST  /PRINT MOTOR STEP DATA
LR          JMP LBYR    /FORM RATIO L/R
LG          JMP LOGSCL  /BASE-10 LOG ROUTINE
XT          JMP XTRACT  /EXTRACT MOTOR STEP INFORMATION
PS          JMP PLTSEG  /PREPARE SEGMENT OF DATA FOR PLOT
RT          JMP TTYRAT  /OUTPUT DATA ON TELETYPE
LP          JMP LGPEN   /PRINT LIGHTPEN LOC. AND CONTENTS
IG          JMP INTEG   /INTEGRATE BET. LIGHTPEN LOC'NS.
SD          JMS AVGOLD  /SMOOTH STORED DATA
SW          JMP ACSTEL  /DESCRIBE FUNCTION OF AC SWITCHES
ACMORE,     0           /ROOM FOR MORE CODES
.+10/
```

```
/***** P.I. SERVICE FOR SCALER AND CLOCK OVERFLOWS

SCLRPI,      IOT 5101      /TEST FOR SCALER #1
             JMP S2PI      /NO
             CLA           /YES; IS RUNFLG > 0
             SAD RUNFLG    JMS ERRMES   /ERROR IN PI
             ISZ LHI2      SKP          JMS ERRMES   /ERROR OVERFLOW
             IOT 5102      /CLEAR PI FLAG #1
             JMP DISMIS
             NOP           NOP          NOP

S2PI,        IOT 5201      /SCALER #2
             JMP S3PI      /NO
             CLA           /YES; IS RUNFLG > 0
             SAD RUNFLG    JMS ERRMES   /ERROR IN PI
             ISZ RHI2      SKP          JMS ERRMES   /ERROR
             IOT 5202      /CLEAR PI FLAG #2
             JMP DISMIS
             NOP           NOP          NOP

S3PI,        IOT 5301      /SCALER #3
             JMP CLCKPI    /NO
             CLA           /YES; IS RUNFLG > 0
             SAD RUNFLG    JMS ERRMES   /ERROR IN PI
             ISZ HI32      SKP          JMS ERRMES   /ERROR
             IOT 5302      /CLEAR PI FLAG #3
             JMP DISMIS
             NOP           NOP          NOP

CLCKPI,      CLSF
             JMP PISER3    /CHECK OTHER DEVICES
             ISZ CLKHI     /INC. HI-ORDER CLOCK
             SKP           JMS ERRMES   /ERROR
             JMP DISMIS
             XX

/API CLOCK SERVICE
CLKAPI,      0
             CLOF          CLON
             NOP           NOP
             DBR
             JMP I CLKAPI

/BEAM STABILITY VS TIME DATA
RUNFLG,      0             /1=RUN; 0=NO RUN
ADDRL,       0             /ADDRESS OF LOC. INTO WHICH L(R)
ADDRR,       0             /COUNTER WILL BE PUT FOR DISPLAY
CLKLO,       0             /LOW-ORDER CLOCK COUNTS
CLKHI,       0             /HI-ORDER COUNTS
LLO,         0             /DOUBLE PRECISION STORAGE
LHI,         0             /OF LEFT,RIGHT, AND #3
RLO,         0             /VALUES AT END OF SAMPLE
RHI,         0
LO3,         0
HI3,         0
LHI2,        0             /CURRENT VALUES OF LEFT,RIGHT, #3 HIGH-ORDER
RHI2,        0
HI32,        0
SCRATCH,     0             /TEMP. STORAGE

/***** SLOW RUN (34 SEC TO 12000 HOURS FOR 1792 SAMPLES) * TYPE "SR" **
SLORUN,      LAC (JMP INCLK             DAC GORUN
             LAC (JMP SAMPLE            DAC NXTOBS
             NOP           NOP          NOP          NOP
             JMP RUN

/***** FAST RUN (0.2 SEC TO 550 SEC FOR 1 92 SAMPLES) * TYPE "FR" **
FSTRUN,      LAC (JMP FSTSPL            DAC GORUN
             LAC (JMP FSTRN             DAC NXTOBS
/
RUN,         JMS ALLOFF    /DISABLE SCALERS
             CLL           JMS CLEAR    /CLEAR SAMPLE DATA
             JMS ZERDAT
             JMS BPINIT    /INITIALIZE 'ON-LINE' ROUTINES
/
GORUN,       XX            /GO TO FAST OR SLOW RUN ("FSTSPL" OR "INCLK")

ALLOFF,      0
             IOT 5104      IOT 5106     /CLEAR SCALERS AND DISABLE
             IOT 5204      IOT 5206
             IOT 5304      IOT 5306
             CLOF          JMP I ALLOFF

CLEAR,       0
             DZM LHI       DZM LLO
             DZM RHI       DZM RLO
             DZM HI3       DZM LO3
             DZM LHI2      DZM RHI2     DZM HI32
             NOP           NOP
             SZL           JMP I CLEAR  /CLEAR ONLY SCALER DATA
             DZM CLKHI     DZM CLKLO    DZM 7
             DZM NEWCLK    DZM OLDCLK
             DZM SMPLNO    DZM CHGTOT
             NOP           NOP          JMP I CLEAR
```

```
ZERDAT,     0
            LAC (LEFTD                  DAC SCRATCH /HIST. START
            LAC DATLEN
            TAD DATLEN
            CMA
            TAD (1      DAC COUNTS  /HIST. LENGTH
            DZM I SCRATCH           /ZERO HIST
            ISZ SCRATCH ISZ COUNTS  JMP .-3
            NOP         NOP         NOP
            JMP I ZERDAT


TURNON,     0
            CLON        /START THE CLOCK (FOR SLOW RUN)
            IOT 5104    IOT 5102    /START THE SCALERS
            IOT 5204    IOT 5202
            IOT 5304    IOT 5302
            NOP         NOP         JMP I TURNON
/INPUT CLOCK COUNTS PER SAMPLE (SLOW RUN)
INCLK,      TYT         LAC (CCPS-1 TTEXT
            DECNMB      DAC TIME
            SNA         JMP INCLK
            DZM OLDCLK
            TCR2
            JMP BSRUN

STPTCH,     0           /ROOM FOR PATCHES
 .+10/

/"CLOCK COUNTS PER SAMPLE = "
CCPS,       303314      317303      313240      303317
325316      324323      240320      305322      240323
301315      320314      305240      275240      000000

/RUN FOR 1792 (DEC) SAMPLES
FMUL,       141520      /DISPLAY MULTIPLIER = 50K(FAST RUN)
SMPLNO,     0           /SAMPLE NUMBER
/
/SETUP DISPLAY
BSRUN,      ISZ RUNFLG
            TCR         LAC (DDM-1  TTEXT       /"DISPLAY = DATA"
            LAC TIME
DSPMUL=.+1 AC:L1:       3           /"SLOW RUN" DISPLAY MULTIPLIER
            JMP SLOW1
            LAC (OPR    /TIME/SAMPLE >=50 MILLISEC
            DAC GODISP
            LAW 257     JMS OTY     /"/"
            LAC TIME
            NOP
            DAC DIV3
            DECPNT
            LAW 252     JMS OTY     /"*"
            LAC DSPMUL
            NOP
            DAC MUL3
            DECPNT
            TCR
            JMP SAMPLE-1
SLOW1,      LAC (JMP GODISP+14      /TIME/SAMPLE<50 MILLISEC
            DAC GODISP
            LAW 252     JMS OTY     /"*"
            LAC DSPMUL  OPR         DAC MUL1
            DECPNT
            LAW 257     JMS OTY     /"/"
            LAC TIME    OPR         DAC DIV1
            DECPNT      TCR         JMP SAMPLE-1


/
/"DISPLAY = DATA"
DDM,        304311      323320      314301      331240
275240      304301      324301      0
/
            JMS TURNON  /START CLOCK AND SCALERS
/END OF SLOW SAMPLE YET (DISPLAY DURING RUN WOULD GIVE TIME JITTER)
SAMPLE,     LAC 7
            CLL
            IDIV
TIME,       XX          /CLOCK COUNTS/SAMPLE
            LACQ
            SAD SMPLNO  JMP SAMPLE  /NO
NEWSAM,     DAC SMPLNO  /YES
            TAD (LEFTD-1            DAC ADDRL
            TAD DATLEN  DAC ADDRR   /SET-UP DISPLAY POINTERS
            JMP READSC  /READ SCALERS
            NOP         NOP         NOP
```

```
/FAST SAMPLE (0.2-550 SEC FOR 2048 SAMPLES)
CNTIME,     0           /SAMPLE DELAY
CNTTM,      0           /SAMPLE LENGTH
FSTSPL,     TCR         LAC (MSECN-1                TTEXT
            DECNMB
            AC.LT.      145         LAC (145        /100 MICROSEC = MIN.
            DAC CNTTM
            TAD (-144+1
            DAC CNTTME

            ISZ RUNFLG

/SETUP DISPLAY
            LAC (LEFTD-1            DAC ADDRL       /SET-UP DISPLAY
            LAC (RIGHTD-1           DAC ADDRR
            TCR         LAC (DDM-1  TTEXT           /"DISPLAY = DATA"
            LAC CNTTM
            AC.LT.      141520      JMP FAST1
            LAC (OPR    /TIME/SAMPLE >=50 MILLISEC
            DAC GODISP
            LAW 257     JMS OTY     /"/"
            LAC CNTTM
            NOP
            DAC DIV3    DECPNT
            LAW 252     JMS OTY     /"*"
            LAC FMUL    /50,000(DEC)
            NOP
            DAC MUL3    DECPNT      TCR
            JMP FSTRN-1
FAST1,      LAC (JMP GODISP+14      /TIME/SAMPLE<50 MILLISEC
            DAC GODISP
            LAW 252     JMS OTY     /"*"
            LAC FMUL    NOP         DAC MUL1        DECPNT
            LAW 257     JMS OTY     /"/"
            LAC CNTTM   NOP         DAC DIV1        DECPNT
            TCR

            JMS TURNON  /TURN ON THE SCALERS AND CLOCK
FSTRN,      ISZ SMPLNO  SKP         JMS ERRMES      /ERROR=MESSAGE
            LAC CNTTME
            JMS MICSEC  /COUNTING PERIOD
            ISZ ADDRL   ISZ ADDRR
            JMP READSC  /END OF FAST SAMPLE; READ SCALERS

.+10/       /ROOM FOR PATCHES

/"MICROSEC PER SAMPLE (MIN.=100) = "

MSECN,      315311      303322      317323      305303
240320      305322      240323      301315
320314      305240
240250      315311      316256      240275
240261      260260      240251      240275      240000
.+10/

/READ THE SCALERS AND CLOCK
READSC,     IOT 5113    DAC LLO     IOT 5104    IOT 5102
            IOT 5213    DAC RLO     IOT 5204    IOT 5202
            IOT 5313    DAC LO3     IOT 5304    IOT 5302
            LAC NEWCLK  DAC OLDCLK
            LAC 7       DAC CLKLO   DAC NEWCLK


            LAC LHI2    DAC LHI     DZM LHI2    /SAVE CURRENT VALUE
            LAC RHI2    DAC RHI     DZM RHI2
            LAC HI32    DAC HI3     DZM HI32

            NOP         NOP
            NOP         NOP
            NOP         NOP
            OPR         /DZM 7 FOR "1 AND 2 VERSUS 3"
BELL,       SKP         JMS OTY     /LAW 207    ←BELL   ("VS")

GODISP,     XX          /"OPR" OR "JMP GODISP+14"
            LAC LLO     LMQ         LAC LHI
            JMS HIDISP
            DAC I ADDRL
            LAC RLO     LMQ         LAC RHI
            JMS HIDISP
            DAC I ADDRR
            JMP BPDSUB
            LAC LLO     JMS LODISP  DAC I ADDRL
            LAC RLO     JMS LODISP  DAC I ADDRR
            JMP BPDSUB

.+20/
PAUSE
```

```
//BEAM STABILITY VS TIME  19.8.70 DP  TAPE 2 OF 4....................
/
/ADD DATA TO DISPLAY, BEAM SWEEP, ACS OPTIONS, DISPLAY SETUP
/OUTPUT COUNTS, OUTPUT COUNT RATE,
/TERMINATE RUN, HOLD RUN
/

/ADD THE NEW DATA TO THE DISPLAY *****

/LOW NUMBER OF COUNTS/SAMPLE

LODISP,     0
            CLL         MUL
MUL1,       XX          /3 OR 50000(DEC)
            CLL         DIV
DIV1,       XX          /"TIME" OR "CNTTME"
            SZL         JMS ERRMES  /OVERFLOW=MESSAGE
            LACQ
            NOP
            JMP I LODISP

.+20/

/LARGE NUMBER OF COUNTS/SAMPLE

HIDISP,     0
            CLL         DIV
DIV3,       XX          /"TIME"=CLOCK COUNTS OR "CNTTME"=MICROSECONDS
            SZL         JMS ERRMES  /ERROR=MESSAGE
            LACQ
            CLL         MUL
MUL3,       XX          /3 OR 50000(DEC) = 141520(OCT)
            SZA         JMS ERRMES  /ERROR=MESSAGE
            LACQ
            NOP
            JMP I HIDISP


BPDSUB,     XX          /'JMP ACSOPT' BY 'BSINIT'
                        /'NOP' BY "BS" FOR SWEEP (1 STEP PER SAMPLE)
                        /'JMP BPSYS' BY "AB" OR "CB" FOR CONTROL
            LAS         AND (1      /CHECK BIT 17 FOR DIRECTION
            SZA         JMP .+3
            JMS MRIGHT  JMP ACSOPT  /0=RIGHT
            JMS MLEFT   JMP ACSOPT  /1=LEFT

/***** BEAM SWEEP ROUTINE ***** TYPE "BS" ***
BS = 302323
SWEEP,      LAC (NOP    DAC BPDSUB  /SETUP SWEEP
            JMS NMOT    /POSITION MOTOR (BEAM) INITIALLY
            JMP SLORUN  /START SLORUN


/CHECK ACCUMULATOR SWITCH OPTIONS *****
ACSOPT,     NOP
            LAS         AND (ACS23  SZA         JMS DISPA
            LAS         AND (ACS6   SZA         JMS SMPLTT
            LAS         AND (ACS8   SZA         JMS CNTRAT
            LAS         AND (ACS5   SZA         JMS HLDRUN
            LAS         AND (ACS1   SZA         JMP TERMRN
            NOP

ENDRN,      LAC SMPLNO
            AC.GT.      3377        JMP TERMRN  /END OF RUN
            OPR         /DZM SMPLNO = CONTINUOUS RUN
NXTOBS,     XX          /CONTINUE TILL 1792 SAMPLES DONE
                        /"JMP SAMPLE" OR "JMP FSTRN"

ACSPTH,     0           /ROOM FOR PATCHES
.+10/

/***** SET UP DISPLAY OF LEFT AND RIGHT LOW-ORDER (VIA TELY OR AC
/     SWITCHES)
/           COUNTS FOR 1792 (DEC) EVENTS

DISPA,      0           /IS REGION TO BE CHANGED
            JMS DISP
            LAC (ACS23  /CODE
            JMS DISPLS  /CHANGE PARAMETERS
            JMP I DISPA

L1 = 314261
L2 = 314262
R1 = 322261
R2 = 322262

DSPL1,      LAC (ACS2   JMS DISPA   JMP REENTR
DSPL2,      LAC (ACS23  JMP DSPL1+1
DSPR1,      CLA         JMP DSPL1+1
DSPR2,      LAC (ACS3   JMP DSPL1+1
```

```
/CODE FOR WHICH OF 4 REGIONS DISPLAYED
DIOF4,      0
DISPAD,     RIGHTD-1              /ACS23 = 00
            RIGHTD+1600-1         /      = 01
            LEFTD-1               /      = 10
            LEFTD+1600-1          /      = 11
DISP,       0        SAD DIOF4    JMP I DISP   /SAME REGION
             DAC DIOF4   /NEW REGION
            CLL          LRS+16
            TAD (LAC DISPAD        DAC .+1
            XX           DAC PARMDS+1
REGSIZ,     LAM-1600+1   DAC PARMDS+2
            JMP I DISP
.+10/

/***** OUTPUT COUNTS FROM SCALERS AND CLOCK FOR EACH SAMPLE ** ACS6 UP*
TSP = JMS 1042          /TYPE A SPACE (SALMON APR 10/68 DR)

COUNTS,     0
SMPLTT,     0
            LAC (CLKLO   DAC SCRATCH
            LAM-3 1      DAC COUNTS   /3 READINGS (MAKE = 4 IF
                         /SCALER #3 IS USED)
            TCR
SCLOUT,     LAC I SCRATCH           LMQ        /LOW-ORDER IN MQ
            ISZ SCRATCH             /HIGH-ORDER IN AC
            LAC I SCRATCH           ISZ SCRATCH
            JMS DUBOUT              /DOUBLE PRECISION OUTPUT
            TSP          TSP
            ISZ COUNTS   /OUTPUT LEFT,RIGHT,#3,TIME YET
            JMP SCLOUT   /NO
CNTSDN,     JMP I SMPLTT            /YES (OR MODIFIED TO 'NOP' BY 'VS')
            TYT          DECNMB     /ENTER ORDINATE
            CLL          JMS CLEAR  /ZERO SCALER DATA
            JMS TURNON   /TURN SCALERS ON
            JMP I SMPLTT
.+10/

/***** OUTPUT COUNT RATE  (SLOW RUN ONLY) ***** ACS8 UP **

OLDCLK,     0
NEWCLK,     0
RSHIFT,     0            /R.SHIFTS FOR VALID DIVISIONS
CNTRAT,     0
            LAC (LLO     DAC SCRATCH
            LAM-2 1      DAC COUNTS   /LEFT,RIGHT COUNT RATE
            LAC OLDCLK   CMA          TAD NEWCLK   DAC PERYD3
            TAD (1       DAC PERYD4
            TCR          TSP          TSP
RATOUT,     DZM RSHIFT
            LAC I SCRATCH             LMQ          ISZ SCRATCH
            LAC I SCRATCH             ISZ SCRATCH
            JMP PERYD3-1

HIGH,       CLL          LRS+1                     /DIVIDE BY 2
            ISZ RSHIFT   SKP          JMS ERRMES   /COUNT SHIFTS: ERROR
PERYD3=.+1 AC.GT.        XX           JMP HIGH
            CLL
PERYD4=.+1 DIV           XX
            SZL          JMS ERRMES   /OVERFLOW
            LAC (LLS     TAD RSHIFT   DAC SCALEM   /RESTORE FACTORS OF 2
            LACQ         MUL          74
SCALEM,     XX           /SCALE FOR CORRECT HI-ORDER TERM
            JMS DUBOUT   /OUTPUT FOR HIGH RATES

ALLOUT,     TSP          TSP
            ISZ COUNTS   JMP RATOUT   /MORE RATES
            JMP I CNTRAT              /ALL RATES OUTPUT
.+10/

/***** TERMINATE RUN ***** TYPE "TR" ****
TERMRN,     JMS ALLOFF   /CLEAR AND DISABLE, CLEAR PI. FLAG.
            DZM RUNFLG

            TCR          JMS SMPLTT   /OUTPUT DATA FROM LAST EVENT
            LAC(JMP ACSCPT            DAC BPDSUB / DEFAULT = NO MOTOR
            TCR2         JMP REENTR-1
.+20/

/***** HOLD RUN (CLOCK KEEPS COUNTING) ***** ACS5 UP ****
HLDRUN,     0
            JMS DISPL1
            LAS          AND (ACS23   SZA          JMS DISPA
            LAS          AND (ACS5    SZA          JMP HLDRUN+1
            TCR
            STL          JMS CLEAR    /CLEAR ONLY SCALER DATA
            NOP          NOP
            JMP I HLDRUN
PAUSE
```

```
//BEAM STABILITY VS TIME 19.8.70 DP  TAPE 3 OF 4 ......................

/AUTOMATIC BEAM CONTROL
/TYPE "AB" OR "CB" FOLLOWED BY "SR" OR "FR"
/
/***** NON-AVERAGING SETUP (JMS NAVGBC) ** TYPE "CB" ***
CB = 303302
NAVGBC,     JMS BPINIT  /INITIALIZE "ON-LINE" ROUTINES
            LAC (NOP    DAC BPCSYS 4
            LAC (JMP BPCSYS          DAC BPDSUB
            NOP          NOP         NOP
            JMP SAVMOT
/***** AVERAGING SETUP  (JMS AVGBC) *** TYPE "AB" ****
AB = 301302
AVGBC,      JMS BPINIT  /INITIALIZE "ON-LINE" ROUTINES
            LAC (JMS AVERAG          DAC BPCSYS+4
            LAC (JMP BPCSYS          DAC BPDSUB
            NOP          NOP         NOP
/SAVE MOTOR STEP INFORMATION IN LOW ORDER BITS OF DATA WORDS
SAVMOT,     LAC (JMP NOMOV           DAC RLEFT-1 /INSIDE LIMITS
            LAC (JMP MOVL            DAC RLEFT+1 /LEFT
            LAC (JMP MOVR            DAC RRIGHT+1 /RIGHT
            LAC (JMP OFFBAD          DAC KBDBEL+2           /BAD RATIO
            JMP REENTR

/TRANSFER LEFT/RIGHT DATA FROM "B.S" TO "ON-LINE"
BPCSYS,     LAS          AND (ACS4
            SNA          JMP OFFBAD  /ACS4 DOWN = NO CONTROL
            LAC I ADDRL DAC BPDL
            LAC I ADDRR DAC BPDR
            JMS ERRMES  /"NOP" OR "JMS AVERAG"
            JMS BPCRAT  /TAKE (L/R) RATIO
            JMS BMPOS   /1 MOTOR STEP IF RATIO OUTSIDE LIMITS
            JMP NOMOV
/
NMOV,       0            /CLEAR LOW ORDER BITS
            LAC I ADDRL AND (777776 DAC I ADDRL
            LAC I ADDRR AND (777776 DAC I ADDRR
            JMP I NMOV
/
NOMOV,      JMS NMOV     JMP ACSOPT  /NO MOVE
MOVL,       JMS NMOV     ISZ I ADDRL JMP ACSOPT  /LEFT
MOVR,       JMS NMOV     ISZ I ADDRR JMP ACSOPT  /RIGHT
OFFBAD,     JMS NMOV
            ISZ I ADDRL ISZ I ADDRR
            JMP ACSOPT  /CONTROL OFF OR BAD RATIO
/

/***** MOVE MOTOR SPECIFIED # OF STEPS L OR R ***** TYPE "MM" ***
/CALL BY "JMS NMOT" OR "JMP NMOT+1"
MM = 315315
/
RNMOT,      JMS NMOT     JMP .-1     /REPEATED MOVE MOTOR CALLS
/
STEPS,      0            /# OF STEPS TO TAKE
NMOT,       0
            TCR          DECNMB      /# STEPS
            CMA          TAD (1      DAC STEPS
            TSP          GIC         /DIRECTION L OR R
            SAD (314     SKP         JMP . 3
            LAC (IOT 5406            JMP . 5     /L
            SAD (322     SKP         JMP NMOT 6
            LAC (IOT 5405            /R

            DAC . 1
            JMS ERRMES  /MOTOR STEP
            LAC (23420  /10000(DEC) = 100 STEPS/SEC
            JMS MICSEC
            ISZ STEPS    JMP .-4     JMP I NMOT

/***** SMOOTH DATA TAKEN PREVIOUSLY WITHOUT AVERAGING ** TYPE "SD" ***
SD = 323304
LX,         0            /LEFT INDEX
RX,         0
LRNUM,      0            /SAMPLE INDEX

AVGOLD,     0
            JMS BPINIT
            LAC (LEFTD  DAC LX       LAC (RIGHTD DAC RX
            LAM-3400 1  DAC LRNUM

            LAC I LX     DAC BPDL    LAC I RX    DAC BPDR

            JMS AVERAG
            NOP          /"JMS BPCRAT" TO TAKE RATIO
            NOP          /"JMP . 4" TO STORE AVG RATIO IN 14000-17777
            LAC BPDL     DAC I LX
            LAC BPDR     DAC I RX
            ISZ LX       ISZ RX
            ISZ LRNUM    JMP AVGOLD 10
            JMP I AVGOLD
```

```
/***** #1 AND #2 VS. #3  ***** TYPE "VS" ***

/1 NC = 50 COUNTS FROM BROOKHAVEN INSTR CO INTEGRATOR (2 NA SCALE)
/TO USE, CALL "VS" ... DESTRUCTIVE MODIFICATION OF
/           'SLOW RUN' PORTION OF "BEAM STABILITY VS TIME"

/USES 'SLOW RUN'.  SET CLOCK COUNTS/SAMPLE ABOUT 60
/           GIVING ABOUT 10 NC AT 1 NA
CHGTOT,     0             /TEMP. STORE #3 COUNTS

/CHECK FOR OPTIONS
YES,        331           /Y
NO,         316           /N
VS = 326323
VERSUS,     TYT
            LAC (JMP RLOAD              /MODIFY SLOW RUN AND FAST RUN
            DAC CODEAC 1                DAC CODEAC 3
            LAC (BELLM-1                TTEXT       /"BELL (Y,N)  "
            GIC
            SAD YES       JMP .+6
            SAD NO        SKP
            JMP VERSUS
            LAC (SKP      SKP
            LAW 207       DAC BELL
            LAC (ORDM-1 TTEXT           /"  ORDINATES (Y,N)  "
            GIC
            SAD YES       JMP .+6
            SAD NO        SKP
            JMP .-7
            LAC (JMP I SMPLTT           SKP
            LAC (NOP      DAC CNTSDN    /MODIFY SMPLTT
            LAM-100+1     DAC REGSIZ    /DISPLAY = 64 (DEC) LOCATIONS
            JMS SET123
            JMP SLORUN    /BEGIN A 'SLOW RUN'

/"BELL (Y,N) "
BELLM,      302305        314314        277250        331254
316251      240000
/"  ORDINATES (Y,N) "
ORDM,       240240        317322        304311        316301
324305      323277        250331        254316        251240
000000

RLOAD,      LAC (RLM-1    TTEXT         JMP REENTR
/"RELOAD PROGRAM"
RLM,        240322        305314        317301        304240
320322      317307        322301        315000

SET123,     0
            LAC (SETM-1 TTEXT           /"  #3 COUNTS/SAMPLE -, "
            DECNMB        SNA           JMP .-4
            TAD (LAM      DAC CPERS
            LAC (JMP ONE23              DAC SAMPLE  /CHARGE, NOT TIME
            LAC (LAM-4 1                /OUTPUT TIME + 3 SCALERS
            DAC SMPLTT 3                DAC CNTRAT 3
            LAC (LAC CHGTOT             DAC READSC+10
                                        /MODIFY SCALER READ
            LAC (DZM CHGTOT             DAC READSC+12
            DZM CHGTOT
            JMP I SET123

/"  #3 COUNTS/SAMPLE = "
SETM,       215212        243263        240303        317325
316324      323257        323301        315320        314305
240275      240000

ONE23,      IOT 5313      /READ (CLEARS LOW ORDER BITS)
            OPR
            TAD CHGTOT    DAC CHGTOT    /ACCUMULATE #3
            IOT 5304      IOT 5302      /RESET AND RESTART
            LAC CHGTOT
            AC.GT.
CPERS,      62-1          /#3 COUNTS PER SAMPLE (DEFAULT = 50)
            JMP EOFSAM
            LAC (1750     JMS MICSEC    /1000TIMES PER SECOND
            JMP ONE23

EOFSAM,     ISZ SMPLNO
            LAC SMPLNO    JMP NEWSAM 1

/***** PRINT MOTOR STEP DATA ***** TYPE "MS" ****
MS = 315323
STPHST,     LAC (NOP      DAC WRITTT+3
            LAC (DECPNT DAC PRMOD
            LAC (CLL      DAC DECPNT-JMS+1
            LAC (LSTEP1 DAC DUMPA
            LAC (NODATT DAC DUMPB
            TCR
            JMP TTYDMP+4


PAUSE
```

```
//BEAM STABILITY VS TIME 19.8.70 DP TAPE 4 OF 4 .....................
/
/USES DATA TO FORM A LEFT/RIGHT RATIO SUITABLE FOR CALCOMP OUTPUT
/ALSO MODIFIES DATA TO FIT PLOT RANGE AND CAN DUMP SUBSETS
/OF THE DATA ON THE TELETYPE

/*******
/FORM RATIO OF (LEFT/RIGHT*10000) AND STORE IN PLACE OF 'RIGHT'
LR=314322

LBYR,       LAC (LEFTD
            DAC L        /LEFT START ADDRESS
            LAC (RIGHTD
            DAC R

            NOP          NOP

LOVERR,     CLL
            LAC I R      DAC . 5      /DENOMINATOR
            LAC I L      MUL          23420      /TIMES 10000(DEC)
            DIV          XX           /FORM RATIO
            LACQ
            SZL          CLA          /L=1=OVERFLOW
            DAC I R
            ISZ L        ISZ R
            LAC L        SAD (RIGHTD JMP REENTR
            JMP LOVERR

L,          0
R,          0
/
/***** EXTRACT MOTOR STEP INFORMATION *** TYPE "XT" ****
/
XT = 330324
STPREC,     0            /MOTOR STEP DISPLACEMENT
DATLEN,     3400         /EACH DATA REGION IS 3400(OCT)
/
/LOW-ORDER BITS L,R = 1,1   CONTROL OFF OR BAD RATIO
/                   = 0,0   CONTROL ON; NO MOVE
/                   = 1,0   CONTROL ON; MOVE LEFT
/                   = 0,1   CONTROL ON; MOVE RIGHT
/
XSINST,     LAC (144     /NO MOTION
            LAC (143     /MOVE RIGHT
            LAC (145     /MOVE LEFT
            CLA          /CONTROL OFF OR BAD RATIO
            CLA
            LAM          /MOVE RIGHT
            LAC (1       /MOVE LEFT
            CLA
/
/
XTRACT,     LAC (LEFTD
            DAC L        TAD DATLEN   DAC R        /ADDRESSES
            LAC (310     DAC STPREC   /INITIAL DISPLACEMENT 200 STEPS
/
XTLOOP,     LAC I L      RCL          DAC I L      /LEFT
            LAC I R      RAR          CLA!HAL      /RIGHT
            TAD I L      AND (3       /CODE IN BITS 16,17
            TAD (XCT XSINST           DAC .+3
            TAD (4       DAC .+3
/
            XX           DAC I L      /INDIVIDUAL STEPS IN LEFT REGION
            XX           TAD STPREC   /STEP DISPLACEMENT IN RIGHT REGION
/
            DAC I R      DAC STPREC
            ISZ L        ISZ R
            LAC L        SAD (RIGHTD JMP REENTR   /DONE
                                      JMP XTLOOP   /MORE
/
```

```
/
/***** ADJUST RATIOS TO LET PROGRAM "CC" PLOT A SEGMENT OF THE GRAPH

PS=320323

PLTSEG,     TCR
            JMS FROMTO  /REGION START AND END
            DAC R       LACQ        DAC L
            LAC (MINM-1 TTEXT       DECNMB      DAC MIN
            CMA         TAD (1      DAC CMPMIN
            LAC (MAXM-1 TTEXT
            DECNMB      TAD MIN     DAC MAX

/CHECK FOR VALUES ABOVE THE REQUESTED MAXIMUM

            LAC I R
            AC.GT.      /IS AC>MAX
MAX,        XX          LAC MAX     /YES
                        /NO
            AC.LT.      /IS AC<MIN
MIN,        XX          LAC MIN     /YES
            TAD CMPMIN              /NO; SUBTRACT MIN FROM ALL CHANNELS
            DAC I R
            LAC R       SAD L       JMP REENTR
            ISZ R       JMP MAX-2

            NOP         NOP

CMPMIN,     0
MINM,       240240      315311      316256      240275      000
MAXM,       240240      315301      330256      240275      000

/***** TELETYPE DUMP OF RATIOS (OR OTHER DATA) **** TYPE "RT" ****

TSP = JMS 1042
RT = 322324

TTYRAT,     LAM-60 1    DAC LINES
            LAM-5 1     DAC COLS

            JMS FROMTO  DAC R       /START
            LACQ        DAC SSRAT+6 /END
            LAC (CHANM-1            TTEXT       /"  CHANNEL INCREMENTS="
            DECNMB      DAC DCHAN
            LAC (CLL    DAC DECPNT-JMS+1        /ALL OUTPUT POSITIVE
            DZM CHAN    TCR2

            TCR         LAC CHAN    DECPNT      /TYPE CHANNEL NUMBER
SSRAT,      TSP         TSP
            LAC I R     DECPNT
            LAC R       AC.GT.      XX          /END OF OUTPUT YET
            JMP RSTMON  /END.  RESTORE MONITOR FORMATS
            TAD DCHAN   DAC R
            LAC CHAN    TAD DCHAN   DAC CHAN
            ISZ COLS    JMP SSRAT   /END OF LINE YET
            LAM-5 1     DAC COLS    /YES
            ISZ LINES   JMP SSRAT-3 /END OF PAGE YET
            LAM-70 1    DAC LINES   /YES
            JMP SSRAT-4

LINES,      0
COLS,       0
CHAN,       0
DCHAN,      1           /CHANNEL NUMBER INCREMENTS
/"  CHANNEL INCREMENTS="
CHANM,      240240      303310      301316
316305      314240      311316      303322
305315      305316      324323      275000

PAUSE
```

```
//ARITHMETIC COMPARISONS  07.8.70 DP....................
/
/ROUTINES TO TEST IF THE NUMBER IN THE ACCUMULATOR IS > OR <
/ A SPECIFIED CRITERION (FOR 18-BIT POSITIVE NUMBERS ONLY)
/THE NUMBER IN THE AC AFTER CALLING THESE ROUTINES IS THE SAME AS
/           THE NUMBER IN THE AC BEFORE THE CALL

/***** AC GREATER THAN CRITERION - CALLING SEQUENCE
/           LAC NUMBER
/           AC.GT.       CRITERION    JMP YES
/           JMP NO


GTSTOR,     0
AC.GT. = JMS .
ACGT,       0
            DAC GTSTOR
            CMAICLL     TAD (1        TAD I ACGT
            ISZ ACGT    OPR
            SZL          ISZ ACGT     OPR
            LAC GTSTOR
            JMP I ACGT


/***** AC LESS THAN CRITERION - CALLING SEQUENCE
/           LAC NUMBER
/           AC.LT.       CRITERION    JMP YES
/           JMP NO


LTSTOR,     0
AC.LT. = JMS .
ACLT,       0
            DAC LTSTOR
            DAC . 5
            LAC I ACLT
            ISZ ACLT    OPR
            AC.GT.      XX            SKP
            ISZ ACLT    OPR
            LAC LTSTOR
            JMP I ACLT
PAUSE
```

```
//LIGHTPEN SERVICE, "DUBOUT" 07.8.70 DP....................
/ADAPTION OF EARLIER ROUTINES WRITTEN BY B. KING
        XADR1,      0           /ADDRESS OF LAST POINT SELECTED
        YADR1,      0           /CONTENTS OF LAST POINT SELECTED
        XADR2,      0           /ADDRESS OF FIRST POINT SELECTED
        YADR2,      0           /CONTENTS OF FIRST POINT SELECTED
        HIGHNO,     0           /HIGH-ORDER PART OF SUMMATION
        LOWNO,      0           /LOW-ORDER PART OF SUMMATION
        SAVAC2,     0           /TEMP. SAVE AC
        SAVMQ2,     0           /TEMP. SAVE MQ
        FLAG1,      0           /ISZ THIS LOC. FOR 3/4 SECOND
                                /           DELAY IN PENSER

/***** TYPE LOC. AND CONTENTS OF LAST TWO POINTS SELECTED BY LIGHTPEN
LGPEN,      TCR
            LAC PARMDS 1
            CMA
            TAD XADR1
            DECPNT      /OUTPUT CH. NO. OF LAST POINT SELECTED
            LAW 254
            JMS OTY
            LAC YADR1
            DECPNT      /OUTPUT CONTENTS OF LAST POINT SELECTED
            TCR
            LAC PARMDS 1
            CMA
            TAD XADR2
            DECPNT      /OUTPUT CH. NO. OF FIRST POINT SELECTED
            LAW 254
            JMS OTY
            LAC YADR2
            DECPNT      /OUTPUT CONTENTS OF FIRST POINT SELECTED
            JMP REENTR  /RETURN TO MONITOR FOR NEXT COMMAND

/***** INTEGRATE BETWEEN LAST TWO POINTS SELECTED BY LIGHTPEN
/  SELECT RIGHT-HAND POINT, THEN LEFT-HAND POINT
INTEG,      DZM HIGHNO
            LAC XADR1
            TAD (-1 1
            DAC 14      /SUMMATION BEGINS AT XADR1
            CLA
            CLL
            TAD I 14
            SZL
            ISZ HIGHNO
            DAC LOWNO#
            LAC 14
            SAD XADR2   /SUMMATION ENDS AT XADR2
            JMP . 3
            LAC LOWNO
            JMP .-11
            TCR
            LAC LOWNO#
            LMQ
            LAC HIGHNO
            JMS DUBOUT
            JMP REENTR-1          /RETURN TO MONITOR
```

```
/***** DOUBLE PRECISION DECIMAL TELETYPE OUTPUT
/CALLING SEQUENCE
/           LAC LOWORDER            LMQ
/           LAC HIGHORDER
/           JMS DUBOUT

/THE MAXIMUM NUMBER WHICH THIS ROUTINE CAN OUTPUT IS ABOUT 25 BILLION
DUBA,       LAC DUBB
DUBB,       JMP 1331
DUBC,       LAC 2401    /CONTAINS "SZA"
DUBSAV,     0
DUBOUT,     0
            CLL
            DIV
            303240      /100000 IN DECIMAL
            DAC DUBSAV
            LACQ
            DECPNT      /OUTPUT HIGH-ORDER PORTION
            LAC DUBA    DAC 1276    /MODIFICATION TO DECPNT
            LAC DUBSAV
            DECPNT      /OUTPUT LOW-ORDER PORTION
            LAC DUBC
            DAC 1276
            JMP I DUBOUT            /RETURN TO CALLING PROGRAM

/***** SERVICE ROUTINE FOR A.P.I. INTERRUPTS FROM THE LIGHTPEN
/PROGRAM INITIALIZATION MUST INCLUDE
/           LAC (PENSER
/           DAC 54
PENSER=JMS .
            0
            703702
            DAC SAVAC2  /TEMP. STORE AC
            LACQ
            DAC SAVMQ2  /TEMP. STORE MQ
            LAC XADR1#
            DAC XADR2#  /REPLACE XADR2 BY XADR1
            LAC YADR1#
            DAC YADR2#  /REPLACE YADR2 BY YADR1
            LAC 14
            DAC XADR1   /ADDRESS OF LOC. BEING DISPLAYED AT TIME
                        /           OF INTERRUPT
            LAC I XADR1
            DAC YADR1   /CONTENTS OF LOC. BEING DISPLAYED AT TIME
                        /           OF INTERRUPT
            LAC SAVMQ2#
            LMQ         /RESTORE MQ
            LAC SAVAC2# /RESTORE AC
            ISZ FLAG1#
            JMP .-1     /WAIT 3/4 SECOND
            DBR
            JMP I PENSER-JMS        /CONTINUE INTERRUPTED PROGRAM

            PAUSE
```

```
//SINGLE HIST DISPLAY  07.8.70 DP....................
/
/ADAPTION OF EARLIER ROUTINE WRITTEN BY D. REIMER
/TO BE ASSEMBLED WITH USER'S SYMBOLIC TAPES AS NEEDED.
/3 INSTN. CALLING SEQUENCE FOR DISPLAY PARAMETER INITIALIZATION -
/"JMS" TO USER REGION SELECTION
/"LAC" 'TOTAL VALUE' OF AC SWITCHES USED TO SELECT DISPLAY REGION
        /"CLA" IF NO SWITCHES USED
/"JMS DISPLS" TO CHANGE DISPLAY ROUTINE PARAMETERS
/
/ACS0 AND ACS9-17 USED FOR SCALING DISPLAY
/ACS1-8 AVAILABLE FOR OTHER USES

AUTO14=14

DMK,        400777
PARMDS,     1               /DEVICE DONE -- ALWAYS
            0               /STARTING ADDRESS-1
            0               /WORD COUNT 2'S COMP

ACSMOD,     0               /AC SWITCHES TO BE CHECKED TO SEE IF DISPLAY
                            /REGION IS TO BE CHANGED
ACSTMP,     0               /TEMP. STORE OF ACS CODE SWITCHES
CALLDS,     0               /ADDRESS-2 OF CALL TO DISPLS
DISPLS,     0               /CALLED BY EXTERNAL PROGRAMS ONLY
            JMS DSPLS       /CHANGED PARAMETERS
            JMP I DISPLS

/***** CALL TO SET UP PROGRAM PARAMETERS
DSPLS,      0               /CALLED FROM THIS ROUTINE ONLY
            DAC ACSMOD      /ACS TO BE CHECKED TO CAUSE REGION MODIFICATION
            LAC AUTENT
            SZA             JMP . 3
            LAC (PARMDS
            INITAL          LAC PARMDS+1
            DAC A14SV#      /START ADDRESS
            LAC PARMDS+2
            DAC WC14SV# /OCTAL WORD COUNT
            CLL!CMA         DAC .+3
            LAC (2000                   /MAX SCOPE SIZE
            IDIV            XX
            LACQ            SNA
            TAD (1                      /X STEP > 0
            DAC XSTEPZ# /DISTANCE BETWEEN POINTS DISPLAYED
            LAC (JMS DISPL1
            DAC SYSMOD
            JMP I DSPLS


/***** CALL TO MAKE ONE DISPLAY SWEEP OF THE DATA
DISPL1,     0               LAC WC14SV
            DAC WC14#       LAC A14SV
            DAC AUTO14      /SETUP ADDRESS & WORD COUNT OF DATA
            DZM XDIRCZ#
            LAS
            AND ACSMOD      /TEST FOR REGION MODIFICATION FROM ACS
            SAD ACSTMP      JMP SAMEDI   /SAME DISPLAY
            DAC ACSTMP      /NEW DISPLAY
            LAM-3+1         TAD DISPLS
            DAC CALLDS      /ADDRESS OF LAST CALL BY USER TO DISPLS
            LAC ACSTMP      /GIVE ACS CODE TO USER PROGRAM
            XCT I CALLDS                /"JMS" TO CHANGE DISPLAY REGION
            ISZ CALLDS
            XCT I CALLDS                /"LAC" AC SWITCH DISPLAY CODE
            JMS DSPLS       /CHANGE DISPLAY ROUTINE PARAMETERS

SAMEDI,     LAS             AND DMK     /SCALING USES ONLY ACS0 AND ACS9-17
            SNA             JMP DISPL2  /AC SWITCHES = 0
            SMA             JMP DISPL3  /AC SWITCHES > 0
            XOR (XCT        SNA
            JMP DISPL2      DAC DISPL5+1
            LAC (IDIV       JMP DISPL4

DISPL2,     LAC (JMP DISPL5+2
            JMP DISPL4

DISPL3,     DAC DISPL5+1
            LAC (MUL
DISPL4,     DAC DISPL5
            LAC XDIRCZ      TAD XSTEPZ
            DAC XDIRCZ      DXL
            CLL             LAC I AUTO14            LMQ
DISPL5,     XX                          /MUL,IDIV,JMP .+3
            XX                          /DIVISOR OR MULTIPLIER
            LAW 3           DLB         /INTENSITY DISPLAY
            LACQ            DYS
            ISZ WC14        JMP DISPL4+1
            JMP I DISPL1

PAUSE
```

```
//LOG. SCALE OF DATA REGION  07.8.70 DP....................
/***** CONVERT 0-18 BIT DATA WORDS TO BASE-10 LOGS
/
LG = 314307
ABEGIN,      0              /START ADDRESS
AEND,        0              /END ADDRESS
/
LOGSCL,      JMS FROMTO
             DAC ABEGIN     /START ADDRESS
             LACQ           DAC AEND      /END ADDRESS
/
LOGLOP,      LAC I ABEGIN
             JMS LOGCAL     /10-BIT BASE-2 LOG
             NOP
             JMS BETTER     /BASE-10 LOG( X 10000)
             DAC I ABEGIN
             LAC ABEGIN     SAD AEND      JMP REENTR   /DONE
             ISZ ABEGIN     JMP LOGLOP    /MORE TO DO
/
/
/"FAST LOGARITHMIC CONVERSION - DECUSCOPE VOL 7, NO 3, PAGE 13
/
/'GENERATES A CHARACTERISTIC BY FINDING THE MOST SIGNIFICANT
/BIT AND TACKING ON THE SIX NEXT MOST SIGNIFICANT BITS FOR USE
/IN LIEU OF A TRUE MANTISSA.  THE ROUTINE PLOTS NUMBERS 2↑2 OR
/LESS ON THE BASE LINE AND PLOTS 2↑18-1 AT FULL SCALE ON A TEN
/BIT DISPLAY....THE SUBROUTINE IS ENTERED WITH THE NUMBER TO BE
/CONVERTED IN THE ACCUMULATOR AND RETURNS WITH THE LOGARITHM
/PROPERLY SCALED (FOR DISPLAY)....'
/
LOGCAL,      0
             SPA!CLL      JMP . 11      /JMP FOR AC > 131,072
             CLQ!NORM-25
             RTL            LMQ           /SAVE ALL BITS < HIGH-ORDER
             LACS
             SNA!CMA
             SKP!CLA
             LLS 6
             JMP I LOGCAL
             LRS 13         TAD (1600     JMP I LOGCAL
/
/
BETS,        0              /TEMP STORAGE
BETTER,      0              /IMPROVE MANTISSA BY TABLE LOOK-UP
             AND (1777
             SZA            TAD (200      /RESTORE FACTOR OF 4 REMOVED BY
                                          /"LOGCAL" FOR DISPLAY
             DAC BETS       /STORE BASE-2 TRUNCATED LOG
             LACQ           SPA           ISZ BETS
             LAC BETS       /ROUNDED BASE-2 LOG
             CLL            LRS+6         /MANTISSA IN MQ
             RTL
             RTL
             RTL
             DAC BETS       /STORE CHARACTERISTICS
/
             CLA            LLS+6         TAD (LAC CORMAN
             DAC .+1
             XX             /BRING CORRECTED MANTISSA INTO AC
             TAD BETS
             CLL            MUL           57
             LACQ           /AC CONTAINS BASE-10 LOG( X 10000)
/
             JMP I BETTER
/
/TABLE OF ACCURATE MANTISSAE
CORMAN,      0              1             3             4
6            7              10            12
13           14             15            17
20           21             22            23
25           26             27            30
31           32             33            34
35           36             37            40
42           43             43            44
45           46             47            50
51           52             53            54
55           56             57            57
60           61             62            63
64           64             65            66
67           70             70            71
72           73             74            74
75           76             77            77
PAUSE
```

```
//SOFTWARE DIAGNOSTICS AND UTILITIES  07.8.70 DP....................
/FOR USE WITH THE D. REIMER PDP-9 MONITOR "SALMON"
/
/CALLING SEQUENCES
/           SAD (JM        JMP SUBEX    /EXEC SUBR.; RETURN TO SALMON
/           SAD (BP        JMP BRKPNT   /INSERT BREAKPOINT
/           SAD (BC        JMP BRKCNT   /INSERT 'BREAK-AND-CONTINUE'
/           SAD (RG        JMP RMPGEN   /GENERATE RAMP HISTOGRAMS
/           SAD (ZM        JMP ZERMEM   /ZERO MEMORY REGION
/           SAD (FW        JMP FNDWRD   /FIND WORD IN MEMORY
/           SAD (TD        JMP TTYDEC   /DECIMAL TELETYPE DUMP
/           SAD (TO        JMP TTYOCT   /OCTAL TELETYPE DUMP
/           SAD (RM        JMP RSTMON   /RESTORE MONITOR OUTPUT FORMAT
/           SAD (MO        JMP MOVEDA   /MOVE A DATA REGION IN MEMORY
/           SAD (OD        JMP OCTDEC   /OCT-TO-DEC (READ.CONVERT.PRINT)
/           SAD (DO        JMP DECOCT   /DEC-TO-OCT (READ.CONVERT.PRINT)
/           SAD (CO        JMP COMMNT   /PUT COMMENT ONTO PAGE
/
/           LAC DELAY      JMS MICSEC   /WAIT FOR "DELAY" MICROSECONDS
/           SNA            JMS ERRMES   /(EXAMPLE) AC=0 == ERROR MESSAGE
/           JMS FROMTO                  /REQUEST INITIAL AND FINAL ADDRESS
/           JMP RSTMON    /RESTORE "SALMON" MONITOR OUTPUT FORMATS
/
/***** OR THIS SUBROUTINE MAY BE CALLED TO CHECK MNEMONIC CODES
/
SOFBUG,     0
            SAD (JM        JMP SUBEX
            SAD (BP        JMP BRKPNT
            SAD (BC        JMP BRKCNT
            SAD (RG        JMP RMPGEN
            SAD (ZM        JMP ZERMEM
            SAD (FW        JMP FNDWRD
            SAD (TD        JMP TTYDEC
            SAD (TO        JMP TTYOCT
            SAD (RM        JMP RSTMON
            SAD (MO        JMP MOVEDA
            SAD (OD        JMP OCTDEC
            SAD (DO        JMP DECOCT
            SAD (CO        JMP COMMNT
            NOP            NOP
            NOP            NOP
            JMP I SOFBUG
/
/
/***** EXECUTE SUBROUTINE AND RETURN TO MONITOR ***** TYPE "JM" *****
JM = 312315
/
SUBAC,      0
SUBMQ,      0
SUBEX,      LAC (JMSM-1 TTEXT
            OCTNMB      TAD (JMS     DAC . 5
            LAC SUBMQ   LMQ          /COULD BE "LAS" TO LOAD MQ
            OPR         /COULD BE "HLT" TO CHANGE AC SWITCHES
            LAC SUBAC   /COULD BE "LAS"
            XX          JMP REENTR
/"S TO "
JMSM,       323240      324317       240000
/
/
/***** BREAKPOINT INSERT ***** TYPE "BP" *****
BP=302320
BPJMS,      JMS BPSER
BPADDR,     0
BRKPNT,     LAC (BPIN-1 TTEXT
            OCTNMB      DAC BPADDR  /BP WHERE
            LAC (REPL-1 TTEXT
            LAC I BPADDR
            OCTPNT      /CONTENTS OF LOC. WHERE BP INSERTED
            LAC BPJMS   DAC I BPADDR            /AT BP, JMS BP SERVICE
            JMP REENTR
/
/***** 'BREAK-AND-CONTINUE' INSERT ***** TYPE "BC" *****
BC=302303
BCJMS,      JMS BCSER
BCFLAG,     0           /0=NO BREAK IN USE; LAM = BREAK IN USE
BCADDR,     0           /ADDRESS AT WHICH TO INSERT 'BREAK-AND-CONTINUE'
BCINST,     0           / INSTRUCTION REPLACED BY "JMS BCSER"
/
BRKCNT,     LAC BCFLAG  SNA         /SKIP IF BREAK IN USE
            JMP BCIN    / BREAK NOT IN USE ALREADY
            LAC BCINST
            DAC I BCADDR            /REPLACE OLD "BC" BY ORIG. INSTN.
/
BCIN,       LAC (BPIN-1 TTEXT       /"BC IN"
            OCTNMB      DAC BCADDR  /LOCATION OF BC
            LAC (REPL-1 TTEXT       /" REPLACES"
            LAC I BCADDR            DAC BCINST  /INSTRUCTION
            OCTPNT
            LAC BCJMS   DAC I BCADDR
            LAM         DAC BCFLAG  /AT BREAK, "JMS BCSER"
            JMP REENTR
/
```

```
/
/***** BREAKPOINT SERVICE ROUTINE *****
BPLINK,     0           /CONTENTS OF LINK AT BREAK
BPAC,       0           /CONTENTS OF AC AT BREAK
BPMQ,       0           /CONTENTS OF MQ AT BREAK
/
BPSER,      0           DAC BPAC
            GLK         DAC BPLINK
            LACQ        DAC BPMQ
/
            NOP         /SET = "ION" FOR USE OF P.I.
            LAM         TAD BPSER   AND (17777  DAC BPADDR
            LAC (302320 DAC BFROM   DAC REPLAC 1          /"BP FROM"
            JMS BLACMQ  /OUTPUT BP ADDRESS, LINK, AC, MQ
            JMS BRKRST  /CHECK WHAT TO DO WITH BREAKPOINT
            SZA         /LEAVE BREAKPOINT IN
            DAC I BPADDR            /REPLACE BREAKPOINT FROM TELY
            JMP REENTR
/
/***** BREAK-AND-CONTINUE SERVICE *****
TSP = JMS 1042
/
BCSER,      0           DAC BPAC
            GLK         DAC BPLINK
            LACQ        DAC BPMQ
            NOP         /SET = "ION" FOR USE OF P.I.
            LAM         TAD BCSER   AND (17777  DAC BPADDR
            LAC (302303 DAC BFROM   DAC REPLAC 1          /"BC FROM"
            JMS BLACMQ  /OUTPUT BC ADDRESS, LINK, AC, MQ
            JMS BRKRST  /WHAT TO DO WITH BREAKPOINT
            SZA         JMP BCREPL
REGRST,     LAC BPMQ    LMQ
            LAC BCSER   RAL
            LAC BPAC                /RESTORED MQ, LINK, AC
            XCT BCINST  /EXEC. INSTRUCTION, LEAVE BREAK IN, CONTINUE
            JMP I BCSER
BCREPL,     DAC I BPADDR            /REPLACE BREAK FROM TELY
            DZM BCFLAG  /BREAK NO LONGER IN USE
            JMP REGRST  /BREAK REMOVED, EXECUTE INSTRUCTION, CONTINUE
/
/***** ERROR MESSAGE SERVICE *****
ERRMES,     0
            DAC BPAC
            GLK         DAC BPLINK
            LACQ        DAC BPMQ
            LAC (305303 DAC BFROM   /"EC FROM ..." MESSAGE
            LAM         TAD ERRMES  AND (17777
            DAC BPADDR  /LOCATION OF ERROR
            JMS BLACMQ  /OUTPUT MESSAGE + LINK, AC, MQ
            LAC BPMQ    LMQ
            LAC ERRMES  RAL         /RESTORE LINK
            LAC BPAC
            LAC (47040  JMS MICSEC  /LET TELETYPE SETTLE
            JMP I ERRMES            /PROCESSING CONTINUES DESPITE ERROR
/
/
/
/** OUTPUT PROGRAM BREAK MESSAGE + L, AC, MQ *****
TDIGIT = JMS 1026
/
BLACMQ,     0
            TCR2
            LAC (BFROM-1            TTEXT
            LAC BPADDR  OCTPNT      /LOC. OF BP
/
            LAC (LACMQM-1           TTEXT
            LAC BPLINK  TDIGIT      TSP         /LINK
            LAC BPAC    OCTPNT      TSP         /AC OUTPUT
            LAC BPMQ    OCTPNT                  /MQ OUTPUT
            JMP I BLACMQ
/
/
/** WHAT TO DO WITH "BP" AND "BC" BREAKPOINTS *****
BRKRST,     0
            LAC (REPLAC-1           TTEXT
            OCTNMB      /RESTORE BREAK IF NON-ZERO
            JMP I BRKRST            /RETURN TO SERVICE ROUTINE
/
/"BP IN " OR "BC IN "
BPIN,       240311      316240      000000
/" REPLACES "
REPL,       240322      305320      314301      303305
            323240      000000
/"BP FROM " OR "BC FROM " OR "EC FROM "
BFROM,      XX          240306      322317      315240
            000000
/"  L, AC, MQ = "
LACMQM,     240240      240314      254240      301303      254240
            315321      240275      240000
/". BP - " OR ". BC - "
REPLAC,     256240      XX          240337      240000
/
```

```
/
/
/***** RAMP GENERATOR ***** TYPE "RG" *****
/ I.E. INSERT INTO SPECIFIED LOCATIONS A NUMBER
/EQUAL TO THE OCTAL ADDRESS OF EACH LOCATION
RG = 322307
RMPCON,     0              /CONSTANT ADDEND TO ALL RAMP NUMBERS
RMPADD,     0
RMPEND,     0
RMPGEN,     LAC (LAC RMPADD           DAC DEP
            JMS FROMTO  DAC RMPADD  /INITIAL ADDRESS
            LACQ        DAC RMPEND  /FINAL ADDRESS
DEP,        XX          TAD RMPCON  DAC I RMPADD          /RAMP
             LAC RMPADD  SAD RMPEND  JMP REENTR  /END OF RAMP
            ISZ RMPADD  JMP DEP     /CONTINUE RAMP GENERATION
/
/
/***** ZERO OUT A MEMORY REGION ***** TYPE "ZM" *****
ZM = 332315
ZERMEM,     LAC (CLA    DAC DEP      /"RMPCON" MUST BE 0;
            JMP RMPGEN+2             /OTHERWISE REGION == RMPCON
/
/
/
/*****  ***** TYPE "FW" *****
/SEARCH SPECIFIED MEMORY FOR WHOLE WORDS OR ADDRESSES ONLY
/
SRCHAA,     0
SRCHA,      0
SRCHB,      0
FINDW,      0
FW=306327
/
FNDWRD,     JMS FROMTO
            DAC SRCHAA  /INITIAL ADDRESS
            LACQ
            DAC SRCHB   /FINAL ADDRESS
CRFIND,     TCR2
            LAC SRCHAA  DAC SRCHA
            LAC (FIND-1 TTEXT
            OCTNMB      DAC FINDW    /OCTAL NUMBER SOUGHT
/
/
            AND (760000 SZA          JMP INSTRN
/
/FIND ALL WORDS IN THIS REGION CONTAINING THE SOUGHT ADDRESS
LOCONY,     LAC I SRCHA
            CMA
            XOR FINDW
            AND (17777  SAD (17777  SKP          JMP ENDCHK
            LAC SRCHA   SAD (OCTNMB+23-JMS       JMP ENDCHK
                        SAD (FINDW               JMP ENDCHK
            TCR
            LAC SRCHA
            OCTPNT      /LOCATION CONTAINING SOUGHT ADDRESS
            TYT         LAC I SRCHA
            OCTPNT      /WHOLE WORD
ENDCHK,     LAC SRCHA   SAD SRCHB    /END OF REGION YET
            JMP CRFIND  /YES
            ISZ SRCHA   NOP          /NO MATCH OF ADDRESS
            JMP LOCONY  /NO
            NOP
/
/FIND ALL WORDS IN THE REGION IDENTICAL WITH THE WHOLE WORD SOUGHT
INSTRN,     LAC I SRCHA CMA          XOR FINDW
            SAD (LAM    SKP          JMP ENDCK2
            TCR
            LAC SRCHA   SAD (OCTNMB+23-JMS       JMP ENDCK2
                        SAD (FINDW               JMP ENDCK2
            OCTPNT      /LOCATION OF SOUGHT WORD
ENDCK2,     LAC SRCHA   SAD SRCHB    /END OF REGION YET
            JMP CRFIND  /YES
            ISZ SRCHA   NOP          /NO MATCH OF WHOLE WORD
            JMP INSTRN  /NO
            NOP
/
/" FIND "
FIND,       240306      311316       304240       000000
/
/
```

```
/***** *****
/MICROSECOND DELAY ROUTINE-CALL BY "JMS MICSEC"
/MIN. = 32 MICROSEC.; MAX. = 262 MILLISEC.
/
MICCNT,     0               /4-MICROSECOND-DELAY-LOOP COUNTER
MICLOC,     MICCNT
MICSEC,     0               /DELAY = CONTENTS OF ACCUMULATOR AT TIME
                            /OF CALLING THIS ROUTINE, IN MICROSECONDS
                            /      = TIME TO EXECUTE "JMS MICSEC"
                            /PLUS THE MICSEC ROUTINE INCLUDING "JMP I MICSEC
            CLL             LRS 2           /DIVISION BY 4
            CMA             TAD (1 7        SMA         LAM
            DAC MICCNT                      /NO. OF LOOPS REQUIRED
/
            CLA             LLS 2
            CMA             TAD (1
            TAD (JMP LOOP4                  DAC . 1
            XX
            OPR             OPR             OPR         /1-3 MICROSEC DELAY
/
LOOP4,      ISZ I MICLOC                    JMP .-1     /4 MICROSEC LOOP
            OPR
            JMP I MICSEC                    /RETURN TO CALLING PROGRAM
/
/***** REQUEST INITIAL AND FINAL ADDRESS FROM TELY *****
/RETURN TO CALLING PROGRAM WITH INITIAL ADDRESS IN AC, FINAL IN MQ
/
FFROM,      240306          322317          315240      0           /" FROM "
TTOM,       240240          324317          240000                  /"  TO"
FT,         0
/
FROMTO,     0
            LAC (FFROM-1                    TTEXT       /" FROM "
            OCTNMB          DAC FT          /INITIAL ADDRESS
            LAC (TTOM-1                     TTEXT       /"  TO "
            OCTNMB          LMQ             /FINAL ADDRESS
            LAC FT
            JMP I FROMTO                    /RETURN
/
/***** TELETYPE DUMP ROUTINES *****
/10 SEC PER LINE = 1.25 SECONDS PER WORD DUMPED
/
/***** DECIMAL DUMP ***** TYPE "TD" *****
TD=324304
TTYDEC,     LAC (DECM-1 TTEXT
            LAC (NOP    DAC WRITTT 3                /DEFEAT OCTAL DEFAULT
            LAC (DECPNT DAC PRMOD   /DECIMAL
            LAC (CLL    DAC DECPNT-JMS 1            /POSITIVE NUMBERS ONLY
            JMP TTYDMP
/"EC"
DECM,       305303          000
/
/***** OCTAL DUMP ***** TYPE "TO" *****
TO=324317
TTYOCT,     LAC (OCTM-1 TTEXT
            LAC (OCTPNT DAC PRMOD
            JMP TTYDMP
/"CT"
OCTM,       303324          000
/
/
/FINAL ADDRESS MUST BE >= INITIAL ADDRESS FOR THE DUMP
PRMOD = 2011                /PRINT MODE SPECIFICATION IN"MONITOR 17,MARCH 68"
DUMPA,      0               /INITIAL ADDRESS
DUMPB,      0               /FINAL ADDRESS
/
TTYDMP,     JMS FROMTO      DAC DUMPA   /INITIAL ADDRESS
            LACQ            DAC DUMPB   /FINAL ADDRESS
/
            LAM-10 1        DAC WRITTT 5                /10(OCT) WORDS/LINE
            LAM-2+1         DAC TYT-JMS 1               /2 SPACES BETWEEN WORDS
            LAC (TCR2       DAC WRITTT 7                /DOUBLE SPACE
            LAC DUMPB       CMA             TAD DUMPA
            NOP             DAC PARMWK 2                /DUMP HOW MANY
            LAM             TAD DUMPA       DAC PARMWK+1            /START DUMP
                                                                    /WHERE
            JMS WRITTT      /DUMP
TTYRST,     TCR             JMP RSTMON  /RESTORE MONITOR
/
/
/***** RESTORE MONITOR OUTPUT FORMAT ***** TYPE "RM" ***
RM = 322315
RSTMON,     LAM-4 1         DAC WRITTT 5                /4 WORDS PER LINE
            LAM-6 1         DAC TYT-JMS 1               /6 SPACES PER TAB
            LAC (TCR        DAC WRITTT 7                /SINGLE SPACE LINES
            LAC (CLL!SMA                DAC DECPNT-JMS 1
                            /RESTORE NEG. OUTPUT FEATURE TO DECPNT ROUTINE
            LAC (DAC PRMOD              DAC WRITTT 3
                            /RESTORE OCTAL MODE DEFAULT
            NOP             NOP         NOP
            JMP REENTR                  /RETURN TO MONITOR
```

```
/
/***** MOVE A DATA REGION IN MEMORY ** TYPE "MO" **
/COPIES THE DATA FROM ONE REGION TO THE NEXT WITHOUT ALTERING THE FIRST
/   REGION
/SECOND REGION MUST NOT OVERLAP FIRST REGION FROM ABOVE!!!
/
MO = 315317
/
MOVEA,      0           /PRESENT INITIAL ADDRESS
MOVEB,      0           /NEW INITIAL ADDRESS
MOVEX,      0           /INDEX
MOVEDA,     LAC (MOVEM-1            TTEXT       /MESSAGE
            DECNMB
            CMA         TAD (1      DAC MOVEX
            TCR
            LAC (CHANGM-1           TTEXT       /GET ADDRESSES
            JMS FROMTO
            DAC MOVEA   /PRESENT INITHAL ADDRESS
            LACQ        DAC MOVEB   /NEW INITIAL ADDRESS
/
            LAC I MOVEA DAC I MOVEB
            ISZ MOVEA   ISZ MOVEB
            ISZ MOVEX   JMP .-5
/
            JMP REENTR
/
/"VE A DATA REGION OF LENGTH(DEC) ="
MOVEM,      326305      240301      240304      301324
301240      322305      307311      317316      240317
306240      314305      316307      324310      250304
305303      251240      275000
/
/"  CHANGE FIRST ADDRESS "
CHANGM,     240240      240303      310301      316307
305240      306311      322323      324240      301304
304322      305323      323000
/
/
/
/***** *****
/OCTAL-TO-DECIMAL AND DECIMAL-TO-OCTAL CONVERSION
/SAVES TABLE LOOK-UP
/
OD = 317304
ODSAVE,     0
OCTDEC,     TCR         OCTNMB      DAC ODSAVE  TYT
            LAC ODSAVE  DECPNT      JMP .-6
/
DO = 304317
DECOCT,     TCR         DECNMB      DAC ODSAVE  TYT
            LAC ODSAVE  OCTPNT      JMP .-6
/
/
/
/
/***** INSERT COMMENTS ONTO PRINTOUT ***** TYPE "CO" *****
/ SAVES GOING INTO 'LOCAL' MODE OF TELYTYPE
/ IDENTIFIES COMMENTS DISTINCTLY ON THE PRINTOUT
/
CO = 303317
COMMNT,     LAC (COMM-1 TTEXT       TSP         TSP         SKP
            TCR
            LAC (STARM-1            TTEXT       /"***  "
            DIC         /PICK UP ONE CHARACTER FROM TELY
            NOP
            SAD (RETURN JMP COMMNT 5            /NEXT LINE
            SAD (SEMCOL SKP         /SEMICOLON IS TERMINATOR OF COMMENT
            JMP COMMNT 10           /CONTINUE FOR NEXT CHARACTER
            TCR2        JMP REENTR
/
RETURN = 215
SEMCOL = 273
/
/"MMENT:-"
COMM,       315315      305316      324272      255000
/
/"***  "
STARM,      252252      252240      240000
/
/
PAUSE
```

APPENDIX G

ON-LINE BEAM POSITION CONTROL ROUTINES

These routines were written to accept data from the PDP-9 scalers, to interpret the asymmetry in scaler counts as an indication of the lateral position of the proton beam, and to change the current through the steering magnet as necessary. A description of the uses of these routines was given in Chapter 3.5c.

These routines are used in the Beam Observation Program (Appendix F) and in the on-line programs that analyze data from the wire chamber spectrometer.[2] The functional relationship between these routines and the wire chamber spectrometer programs are shown in Figure G.1. In the program listing which follows the descriptions given below, the begining of each routine is marked by a comment whose first 6 characters are "/xxxxx".

Functional Description of Control Routines:

Set up the constants in the beam position control routines - subroutine "BPINIT" - called before a data run to set all parameters and control data to their initial values. Does not establish any linkage to the scaler Program Interrupt (P.I.) service routine.

Turn beam position control ON - "BPCON" - resets and enables the scalers. Sets up linkage from SALMON Monitor to the scaler P.I. service routine.

Turn beam position control OFF - "BPCOFF" - resets and disables scalers. Removes linkage from SALMON Monitor to P.I. service routine for the scalers.

Service program interrupts from the scalers - "BPCPI" - when a scaler overflow is detected, both scalers are reset and a software flag set to prevent any position control based on the current sample.

Read the scalers (after each spectrometer event) - "BPCSRD" - if the scalers overflowed during this sample, resets them but does not read them. Otherwise reads and stores the data from the left (#1) and right (#2) scalers before resetting them.

Average the data from the last 2, 4, 8 or 16 samples - "AVERAG" - the arithmetic mean of the data from the last 2, 4, 8 or 16 samples replaces the most recent data from the scalers. Also used by the Beam Observation Program to smooth stored data from 1792 successive samples.

Take the ratio left counts/right counts - "BPCRAT" - for good data, forms the ratio of the counts from the left and right scalers (normalized to 1:1 = 1000). No ratio is formed if either scaler counted less than 100 counts or counted more than 262,143 counts during the sample time.

Compares the measured ratio to the allowed upper and lower limits - "BMPOS" - if the measured ratio is above/within/or below the limits, the motor on the steering magnet power supply is stepped to the right/ not at all/ or to the left. No action is taken if the scalers had too many or too few counts (see routine above). If the ratio is extremely large or small the teletype bell is sounded. If the motor makes more than 200 steps (net displacement) away from its initial position, a teletype message is printed and the program enters a "wait loop". Normal execution resumes after any accumulator switch is changed.

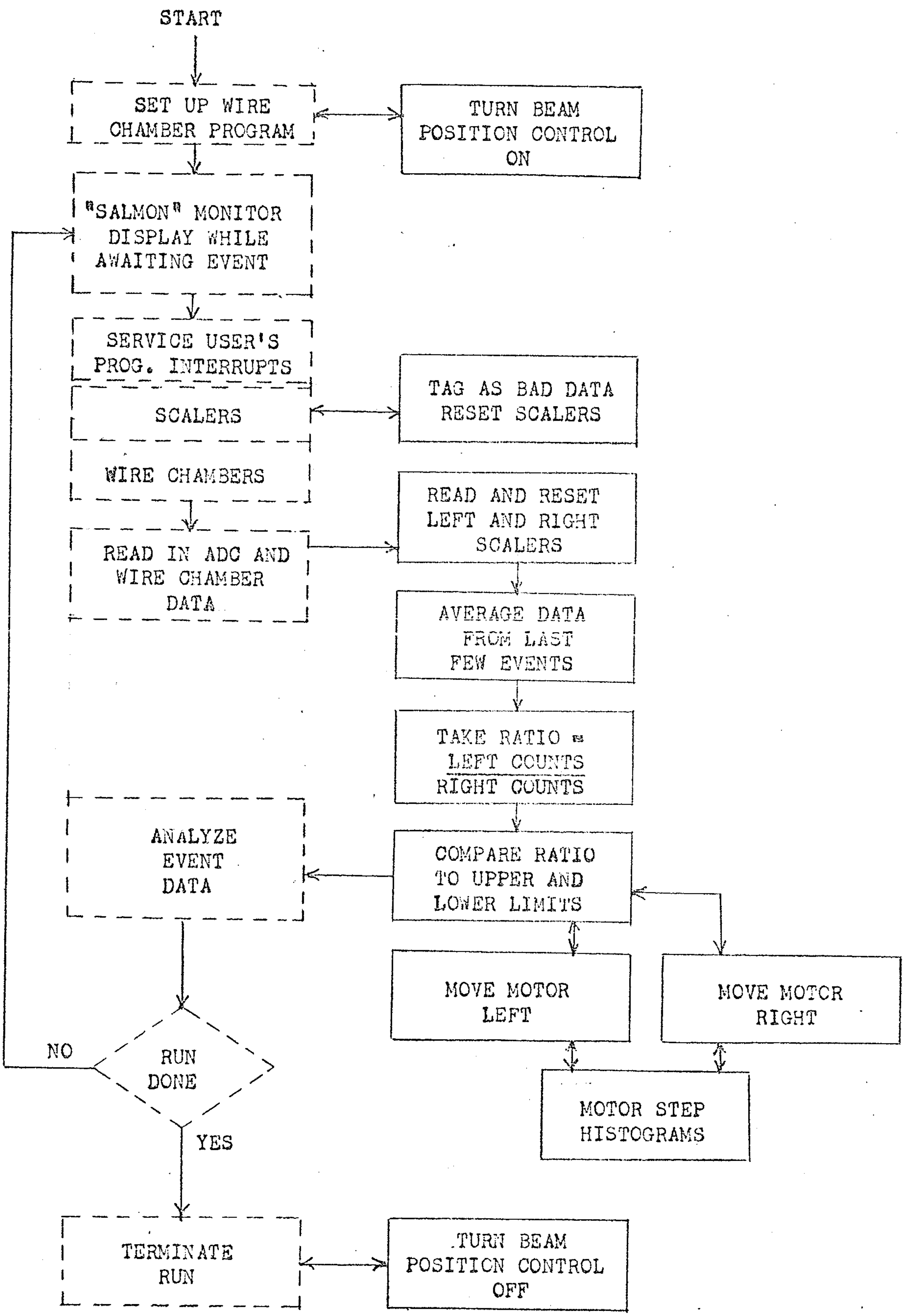
Move the motor one step to the left - "MLEFT" - called by BMPOS to move the motor and to update the current motor direction variable, the net number of motor steps and the total number of steps to the left. A single parameter can easily be modified such that the motor moves only once for every n consecutive calls (n = 1, 2, ...; default = 1).

Move the motor one step to the right - "MRIGHT" - similar to the routine above.

Store information on the behaviour of the control system - "REVCHK" - forms 2 histograms of (the number of occurrences during a run) as a function of (the number of consecutive motor steps taken toward the left (right) before the motor changed direction). Useful in evaluating system performance.

Figure G.1

The linkage of the beam position control routines with the wire chamber spectrometer programs. The double-ended arrows indicate that, upon completion, each of the beam position control routines returns to the part of the main program (dashed lines) which called it.


START
SET UP WIRE CHAMBER PROGRAM
TURN BEAM POSITION CONTROL ON
"SALMON" MONITOR DISPLAY WHILE AWAITING EVENT
SERVICE USER'S PROG. INTERRUPTS
SCALERS
WIRE CHAMBERS
TAG AS BAD DATA RESET SCALERS
READ IN ADC AND WIRE CHAMBER DATA
READ AND RESET LEFT AND RIGHT SCALERS
AVERAGE DATA FROM LAST FEW EVENTS
TAKE RATIO = LEFT COUNTS / RIGHT COUNTS
ANALYZE EVENT DATA
COMPARE RATIO TO UPPER AND LOWER LIMITS
MOVE MOTOR LEFT
MOVE MOTOR RIGHT
NO
RUN DONE
YES
MOTOR STEP HISTOGRAMS
TERMINATE RUN
TURN BEAM POSITION CONTROL OFF

```
//ON-LINE BEAM POSITION CONTROL ROUTINES 19.8.70 DP .....................
/
/SINGLE PRECISION SUBROUTINES TO READ AND COMPARE SCALERS
/           AFTER READING MAGNETIC CORES OF WIRE CHAMBERS
/           AND TO INITIATE CORRECTIVE ACTION IF NECESSARY
/
/USES SUBROUTINES "ARITHMETIC COMPARISONS 07.8.70 DP" AND
/"SOFTWARE DIAGNOSTICS AND UTILITIES 07.8.70 DP"
/
/
/THIS PROGRAM TAPE CONTAINS THE FOLLOWING SUBROUTINES;
/           JMS BPINIT  /INITIALIZE THE BEAM POSITION CONTROL
                        /ROUTINES PRIOR TO A DATA RUN
/           JMS BPCON   /TURN BEAM POSITION CONTROL SYSTEM "ON"
/           JMS BPCOFF  /TURN BEAM POSITION CONTROL SYSTEM "OFF"
/           JMS BPCPI   /CHECK FOR P.I. FROM SCALERS; RESET SCALERS
/           JMS BPCSRD  /READ SCALER #1 (LEFT) AND #2 (RIGHT)
/           JMS AVERAG  /SMOOTH OUT DATA BY AVERAGING 2,4,8 OR 16 SAMPE
/           JMS BPCRAT  /TAKE RATIO BPDL/BPDR; TTY BELL IF RATIO TOO BG
/           JMS BMPOS   /COMPARE RATIO TO CRITERIA; MOVE MOTOR AS NEC.
/           JMS MLEFT   /MOTOR 1 STEP LEFT; KEEP TRACK OF NET STEPS,
/                       CURRENT STEP, CHANGE OF DIRECTION
/           JMS MRIGHT  /AS ABOVE, RIGHT
/           JMS REVCHK  /HIST. "STEPS BEFORE DIRECTION REVERSAL"

/           JMS BPCSRD  JMS BPCRAT  JMS BMPOS   /NO AVERAGING SEQUENCE
/           JMS BPCSRD  JMS AVERAG  JMS BPCRAT  JMS BMPOS   /AVERAGING
/
/
/
/***** BEAM POSITION CONTROL INITIALIZATION *****
/
TEMP17,     0           /TEMPORARY STORAGE
ZINDEX,     0           /SCRATCH INDEX
/
BPINIT,     0           /INITIALIZATION ROUTINE
            LAC RATNORM DAC NORMC   /NORMALIZATION CONSTANT
            DZM CURSTP  ISZ CURSTP  /# OF MOTOR STEPS IN CURRENT DIR.
            DZM LSTEP   DZM LSTEP1  /TOTAL STEPS LEFT (LO,HI)
            DZM RSTEP   DZM RSTEP1  /TOTAL STEPS RIGHT
            DZM NETSTP  /NET # OF MOTOR STEPS FROM START OF RUN
            DZM BADPI   /RESET SCALER-OVERFLOW CHECK FLAG
/
            LAC 17      DAC TEMP17  /SAVE 17
            LAC (STOREV-1           DAC 17
            LAM-60+1    DAC ZINDEX
            DZM I 17    /ZERO "STEPS-TO-REVERSAL" HISTOGRAM
            ISZ ZINDEX  JMP .-2
            DZM REVBY2  /# OF TIMES REVERSAL HIST SCALED DOWN BY X(2)
/
            LAC (DATAVG-1           DAC 17
            LAM-40 1    DAC ZINDEX
            DZM I 17    /ZERO LEFT AND RIGHT DATA FOR AVERAGING
            ISZ ZINDEX  JMP .-2
/
            DZM ELMENT  /ITEM # OF L,R DATA FOR AVERAGING
            DZM TOTL    DZM TOTL1   /L DATA SUM
            DZM TOTR    DZM TOTR1   /R DATA SUM
            LAC NUMELM  CMA         TAD (1
            DAC ELMX    ISZ ELMX    /ELEMENTS IN FIRST AVERAGE
            LAC NRSHFT  TAD (LRS    /SET-UP AVERAGE-BY-SHIFTING
            DAC AVGDAT 5            DAC AVGDAT 14
            LAM         DAC FULELM  /INITIALLY NOT ENOUGH DATA TO AVG.
/
            DZM CALLL   DZM CALLR   /RESET CALLS-LEFT AND CALLS-RIGHT
            DZM NCALL1  DZM NCALL   /# OF TIMES NO MOVE-MOTOR CALLS NEC
            DZM BADAT1  /# OF TIMES DATA IGNORED BECAUSE OF
            DZM BADDAT  /PI INTERRUPT FROM SCALER OVERFLOW
            DZM NODAT1  /# OF TIMES DATA IGNORED BECAUSE
            DZM NODAT   /BPDL OR BPDR < 100 (DEC)
/
            LAC TEMP17  DAC 17      /RESTORE 17
/
            NOP         NOP         NOP
            NOP         NOP         NOP
/
            JMP I BPINIT
/
/
/
/
```

```
/
/
/
/***** TURN BEAM POSITION CONTROL SYSTEM "ON" *****
/DONE IN IOT-PAIRS TO PREVENT PDP-9 FROM SEEING THE P.I. FLAG
/THAT MAY HAVE BEEN SET BY THE SCALER CLEAR IOT
BPCON,          0
                IOT 5104    IOT 5102    /CLEAR SCALERS+ PI; ENABLE SCALERS
                IOT 5204    IOT 5202
                LAC (JMS BPCPI          /SET-UP PI SERVICE IN MONITOR
                DAC PISER2
                NOP         NOP
                JMP I BPCON
/
/
/
/***** TURN BEAM POSITION CONTROL SYSTEM "OFF"
/
BPCOFF,         0
                IOT 5104    IOT 5106
                IOT 5204    IOT 5206
                LAC (NOP    DAC PISER2  /RESTORE MONITOR
                NOP         NOP
                JMP I BPCOFF
/
/
/
/***** ROUTINE TO CALL TO CHECK FOR P.I. FROM B.P.C. SCALERS
/
BPCPI,          0
                IOT 5101    SKP         JMP RSTSCL   /RESET SCALERS
                IOT 5201    SKP         JMP RSTSCL   /RESET SCALERS
                JMP I BPCPI
RSTSCL,         JMS BPCON
                ISZ BADPI   OPR         /INHIBIT POSITION CONTROL FOR
                                        /CURRENT SAMPLE
                NOP         NOP
                JMP DISMIS
/
/
/
/***** ROUTINE TO READ SCALERS *****
/
/
BPCSRD,         0
                CLA         SAD BADPI   JMP GOODRD
                ISZ BADDAT  SKP         ISZ BADAT1
                JMS BPCON   /RESET SCALERS
                JMP I BPCSRD            /IGNORE THIS DATA
GOODRD,         IOT 5113    DAC BPDL    IOT 5104    IOT 5102
                IOT 5213    DAC BPDR    IOT 5204    IOT 5202
                NOP         NOP
                JMP I BPCSRD
/
PAT2,           0           /ROOM FOR PATCHES
.10/
/
```

```
/
/***** TAKE AVERAGE OF DATA FROM LAST 2,4,8 OR 16 SAMPLES
/
/
TOTL1,      0           /TOTAL COUNTS ON LEFT IN SAMPLE POPULATION
TOTL,       0
TOTR1,      0           /TOTAL ON RIGHT (HI, LO)
TOTR,       0
/
ELMENT,     0           /DATA POPULATION INDEX
ELMADL,     0           /ABSOLUTE DATA POP. ADDRESS ON LEFT
ELMADR,     0
/
/
FULELM,     LAM         /"LAM" == NOT ENOUGH DATA YET; "0" == ENOUGH
ELMX,       0           /INDEX
/
DATAVG,     0           /UP TO 32 (DEC) SAMPLES IN POPULATION
. 37/
/
/
/
/
AVERAG,     0           /TAKE AVERAGE OF DATA
            LAM         TAD NUMELM  AND ELMENT  /RELATIVE L,R ADDRESS
                        /MODULO 2,4,8 OR 16
            TAD (DATAVG             DAC ELMADL  /ABSOLUTE LEFT ADDRESS
            TAD (20                 DAC ELMADR  /ABSOLUTE RIGHT ADDRESS
            ISZ ELMENT  OPR
/
            CLA         SAD FULELM  JMP FULL
            JMS ADDDAT  /ADD THIS DATA TO POPULATION; NOT ENOUGH TO AVG.
            ISZ ELMX
            JMP I AVERAG            /NEXT SAMPLE WON'T BE ENOUGH TO AVG
            DZM FULELM
            JMP I AVERAG            /NEXT SAMPLE WILL BE ENOUGH
/
FULL,       JMS SUBDAT  /REMOVE OLDEST DATA SAMPLES FROM TOTALS
            JMS ADDDAT  /ADD NEWEST DATA SAMPLES TO TOTALS
            JMS AVGDAT  /TAKE THE AVERAGES; STORE IN BPDL AND BPDR
            JMP I AVERAG            /AVERAGEING COMPLETE
/
/
SUBDAT,     0           /REMOVE OLDEST DATA FROM TOTALS
            LAC TOTL1
            SZA         JMP LDUBL   /DOUBLE PRECISION
            LAC I ELMADL            CMA         TAD (1      /SINGLE
            TAD TOTL    DAC TOTL
            JMP RSING
LDUBL,      LAC I ELMADL            SNA         JMP RSING
            CMA         TAD (1      /2'S COMP. OF ELEMENT
            STL         /SET LINK FOR LATER OVERFLOW TEST
            TAD TOTL    DAC TOTL
            SNL         /LINK = 1 IF TOTL WAS < OLD DATA
            JMP RSING   /LINK = 0 IF TOTL WAS > OLD DATA
                        /SUBTRACTION COMPLETE
            TAD (LAM    TAD (1      /TOTL NOW NEG.; BORROW 2**18
                        /AND ADD TO MAKE LOW-ORDER POSITIVE
            DAC TOTL    /STORE CORRECT "POSITIVE" TOTL
            LAM         TAD TOTL1   DAC TOTL1   /LOAN 2**18 FROM HI-ORB
RSING,      LAC TOTR1
            SZA         JMP RDUBL   /DOUBLE PRECISION
            LAC I ELMADR            CMA         TAD (1
            TAD TOTR    DAC TOTR
            JMP I SUBDAT
RDUBL,      LAC I ELMADR            SNA         JMP I SUBDAT
            CMA         TAD (1
            STL
            TAD TOTR    DAC TOTR
            SNL         JMP I SUBDAT
            TAD (LAM    TAD (1      DAC TOTR
            LAM         TAD TOTR1   DAC TOTR1
            JMP I SUBDAT
/
ADDDAT,     0           /ADD NEWEST DATA TO TOTALS
            LAC BPDL    DAC I ELMADL
            CLL         TAD TOTL    SZL         ISZ TOTL1
            DAC TOTL
            LAC BPDR    DAC I ELMADR
            CLL         TAD TOTR    SZL         ISZ TOTR1
            DAC TOTR
            JMP I ADDDAT
/
AVGDAT,     0           /TAKE THE AVERAGES
            CLL         LAC TOTL    LMQ         LAC TOTL1
            XX          /DIVIDE BY 2,4,8,16
            LACQ        DAC BPDL
/
            CLL         LAC TOTR    LMQ         LAC TOTR1
            XX
            SZA         JMS ERRMES  /ERROR MESSAGE
            LACQ        DAC BPDR
/
            JMP I AVGDAT
/
```

```
/
/***** ROUTINE TO TAKE (LEFT/RIGHT) RATIO *****
TSP = 101042
BPCRAT,     0
            LAC BADPI
            SZA
            JMP I BPCRAT                    /RETURN; SCALERS OVERFLOWED
            LAC BPDR    DAC NORMC+2
/
            AC.LT.      144         ISZ NODATT  /< 100(DEC) COUNTS
            LAC BPDL
            AC.LT.      144         ISZ NODATT
            CLA         SAD NODATT  JMP . 5
            ISZ NODAT   SKP         ISZ NODATI
            JMP I BPCRAT            /RETURN; NOT ENOUGH DATA
/
            CLL         LAC BPDL    /MULTIPLICAND = COUNTS ON LEFT
            MUL
NORMC,      XX          /RATIO NORMALIZATION (DEFAULT = 1,000 DEC.)
            DIV         / (L/R)
            XX          /DIVISOR = COUNTS ON RIGHT
            LACQ        /RATIO IN AC
            DAC RATIO
            NOP         NOP         NOP
            JMP I BPCRAT
/
/***** COMPARE RATIO TO CRITERIA; MOVE MOTOR AS REQUIRED *****
/IF MOTOR MOVES MORE THAN 200 STEPS FROM ITS INITIAL POSITION, A TELY
/MESSAGE IS GIVEN AND THE PROGRAM "WAITS" UNTIL ANY AC SWITCH IS
/CHANGED
/
BMPOS,      0
/
            LAC BADPI
            SNA         JMP .+3
            DZM BADPI
            JMP KBDBEL+2            /RETURN; PI O'FLO
/
            LAC NODATT
            SNA         JMP .+3
            DZM NODATT
            JMP KBDBEL+2            /RETURN; NOT ENOUGH COUNTS
            SZL         JMP KBDBEL  /(RATIO>262) = BELL
            LAC RATIO
            AC.LT.      5           JMP KBDBEL  /(RATIO<1/250)=BELL
/
            NOP
/
            LAC NETSTP  AND (377777 /MESSAGE IF NETSTP > 200 (DEC)
            AC.GT.      307         JMS STPFAR
            LAC RATIO
/
BPCUL=, 1   AC.GT.      1767        JMP RRIGHT  /1.5% HIGH
BPCLL=, 1   AC.LT.      1731        JMP RLEFT   /1.5% LOW
            ISZ NCALL   SKP         ISZ NCALLI
            NOP         NOP         NOP
            JMP I BMPOS /RATIO WITHIN THE 1.5% LIMITS
/
RLEFT,      JMS MLEFT   JMP I BMPOS /MOVE MOTOR ONE STEP LEFT
RRIGHT,     JMS MRIGHT  JMP I BMPOS
KBDBEL,     LAW 207     JMS OTY     JMP I BMPOS /RATIO ERROR == BELL
/
/
STPFAR,     0           /STEP OVER 200 FROM START
            TCR2        LAC NETSTP  DECPNT
            LAC (FARM-1 TTEXT       TCR2
            OPR         NOP         /JMS BPCOFF
            LAS         DAC SALAC   /SAVE AC SWITCHES
            LAS         XOR SALAC   /COMPARE PRESENT ACS TO OLD
            SNA         JMP .-3     /STAY TILL ANY ACS CHANGED
            DZM NETSTP  JMP I STPFAR
/"* MOTOR STEPS!!"
FARM,       207240      315317      324317      322240
            323324      305320      323241      241000
SALAC,      0           /STORE AC SWITCHES
/
```

```
/***** ROUTINE TO MOVE MOTOR LEFT *****
LL=314
RR=322
/
/UPDATE NET-STEP COUNTER
MLEFT,      0
            DZM CALLR   ISZ CALLL    LAC CALLL    SAD CALLM    SKP
            JMP I MLEFT
            LAM         TAD CALLL    DAC CALLL
            ISZ LSTEP   SKP          ISZ LSTEP1   /TOTAL # STEPS LEFT
            LAC NETSTP
            SNA         SKP          JMP . 4
            TAD (XCT 1  DAC NETSTP   JMP MOTL     /FIRST STEP LEFT
            SMA         SKP          JMP . 4
            TAD (-1 1   DAC NETSTP   JMP MOTL     /NET STEP IS RIGHT
            ISZ NETSTP  /NET STEP IS LEFT
MOTL,       IOT 5406    /MOVE MOTOR ONE STEP LEFT
            LAC (LL     JMS REVCHK   /IS THIS REVERSE OF PREVIOUS MOTION
            NOP         NOP
MLRET,      JMP I MLEFT
/
/
/***** ROUTINE TO MOVE MOTOR RIGHT *****
MRIGHT,     0
            DZM CALLL   ISZ CALLR
            LAC CALLR   SAD CALLM    SKP          JMP I MRIGHT
            LAM         TAD CALLR    DAC CALLR
/
/UPDATE NET-STEP COUNTER
            ISZ RSTEP   SKP          ISZ RSTEP1   /TOTAL STEPS RIGHT
            LAC NETSTP
            SNA         JMP .+5
            SAD (XCT    SKP
            JMP .+4     DZM NETSTP
            ISZ NETSTP  JMP MOTR     /FIRST STEP RIGHT
            SMA         JMP .-3      /POS = NET STEP RIGHT
            TAD (-1 1   DAC NETSTP   /NET STEP LEFT
MOTR,       IOT 5405    /ONE STEP RIGHT
            LAC (RR     JMS REVCHK   /IS THIS REVERSE OF PREVIOUS MOTION
            NOP         NOP
MRRET,      JMP I MRIGHT
/
/
/
/
/***** HISTOGRAM OF "MOTOR STEPS BEFORE DIRECTION REVERSAL" *****
/
/IF THIS DIRECTION NOT A REVERSAL, INCREMENT 'CURSTP'
/IF THIS DIRECTION IS A REVERSAL, ADD TO REVERSAL HIST; ZERO CURSTP
/
TADL,       TAD (STOREV-1 30          /LEFT STEP AFTER REVERSE MEANS
                                      /ADD TO RIGHT HIST.
TADR,       TAD (STOREV-1
/
REVCHK,     0
            SAD DIRMOT  SKP          JMP . 4
            ISZ CURSTP  OPR          JMP I REVCHK
            DAC DIRMOT  /STORE NEW DIRECTION
            SAD (LL     LAC TADL
            SAD (RR     LAC TADR
            DAC REVHST  /SETUP BASE ADDRESS ADDITION
/
            LAC CURSTP
            AC.GT.      30           LAC (30
REVHST,     XX          DAC CURSTP
            ISZ I CURSTP             SKP          JMS REVSCL
            DZM CURSTP  ISZ CURSTP
            JMP I REVCHK
/
/WHEN AN ELEMENT OF THE HIST EXCEEDS 18 BITS, SCALE HIST DOWN BY FACT.2
REVSCL,     0
            LAC (STOREV DAC TEMP17
            LAM-60 1    DAC ZINDEX
            LAC I TEMP17
            RCR         DAC I TEMP17
            ISZ TEMP17
            ISZ ZINDEX  JMP .-5
            ISZ REVBY2  OPR          /# OF TIMES SCALING APPLIED
            JMP I REVSCL
/
/
```

```
. 6/
/
DIRMOT,     314      /314 = LEFT; 322 = RIGHT MOTOR DIRECTION
LSTEP1,     0        /TOTAL LEFT AND RIGHT STEPS (HI, LO)
LSTEP,      0
RSTEP1,     0
RSTEP,      0
NCALL1,     0        /# OF TIMES NO MOVE-MOTOR CALL MADE
NCALL,      0
BADAT1,     0        /# OF TIMES DATA IGNORED BECAUSE OF
BADDAT,     0        /PI INTERRUPT FROM SCALER OVERFLOW
NODAT1,     0        /# OF TIMES DATA IGNORED BECAUSE
NODAT,      0        /BPDL OR BPDR < 100 (DEC) COUNTS
/
NETSTP,     0        /NET # OF MOTOR STEPS; INITIALLY 0
                     /SIGN AND MAGNITUDE (- = L; + = R)
CURSTP,     0        /# OF MOTOR STEPS SINCE LAST DIRECTION REVERSAL
/
CALLM,      1        /# OF UNIDIRECTIONAL CALLS TO A MOVE-MOTOR
                     /ROUTINE BEFORE SUCH ACTION TAKES PLACE
CALLL,      0        /INDEX FOR CALLM OF STEPS TO LEFT
CALLR,      0        /INDEX FOR CALLM OF STEPS TO RIGHT
/
REVBY2,     0        /# OF TIMES REVERSAL HIST SCALED DOWN BY X(2)
STOREV,     0        /TWO HISTOGRAMS, 24 (DEC) WORDS EACH
                     /:STEPS LEFT BEFORE REVERSING DIRECTION
                     /:STEPS RIGHT  "        "        "
. 57/
NUMELM,     10       /DEFAULT = 8 (DEC) SAMPLES IN EACH AVERAGE
NRSHFT,     3        /== DIVISION BY 8
BPDL,       0        /COUNTS IN LEFT SCALER
BPDR,       0        /COUNTS IN RIGHT SCALER
RATIO,      0        /(COUNTS LEFT/COUNTS RIGHT)
RATNORM,    1750     /NORMALIZATION CONSTANT; DEFAULT = 1000(DEC)
BADPI,      0        /0 == GOOD DATA; >0 == TOO MANY COUNTS
NODATT,     0        /0 == GOOD DATA; >0 == NOT ENOUGH COUNTS
/
/
PAUSE
```