MEASUREMENTS IN A MODEL LUNG BIFURCATION USING AN AUTOMATED LASER DOPPLER ANEMOMETER

by

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ABSTRACT

Aspects of flow in a human lung can be modeled by a series of simple bifurcations. A scaled-up which preserves dynamical similarity can be accomplished by using a fluid of higher viscosity and reducing the flow speed so that the Reynolds number is constant.

The experiment carried out here uses a Laser Doppler Anemometer System to measure velocity field in a three-quarter inch diameter tube which is a scaled-up typical bronchial bifurcation. Tap water seeded with alumina trihydrate is used as the working media. An ad-hoc calibration program is introduced to take care of the reflection problem caused by different reflective indice between water and the bifurcation which is constructed of plexiglas.

Measurement of tubewise velocity component is made with a He-Ne LDA system moved by a three dimensional traversing system which is controlled by an SDK-85 microprocessor. Signals processed through tracker are analyzed by a PDP-11 minicomputer. Serial interface between the minicomputer and the microprocessor is established so that the positioning of the laser system can be automated.

Evolution of the primary profiles thruogh the bifurcation is investigated in detail at Reynolds number 320. The flow was found to have 'head-shoulder', second hump', and 'wing-like'features, etc. Plausible reasons are

given to interpret these features. A comparison of the flow pattern in major direction with Olson's hot-wire-measured data is made. The differenct situations between the two measurements are noted.

INTRODUCTION

1.1 GENERAL STATEMENT OF THE WORK

The mechanics of breathing in human trachea and bronchia from the viewpoint of an engineer is just a flow going through various bifurcations. It is therefore believed that aspects of flow in a human lung can be modeled by a series of simple bifurcations. Because of the small sizes associated with the real lung ,it is highly desirable in the laboratory to work with scale models which are larger. Dynamical simulation of the flow in the lung can be accomplished in these models using the principle of dynamic similarity, which requires that the Reynolds number of the model be the same as that in the lungs.

This study is an attempt to measure the flow field in a lung bifurcation using a computerized Laser Doppler Anenometer system. The scope of this work is two-fold:

(1) The investigation on the flow field

Care is taken to avoid possible errors due to the inherent characteristics of the laser system.

(2) The automation process

Efforts were made to have both the probe positioning and data acquisition/analysis process

Altough the application of this investigation is to flow in the human lung, the methods developed and the results obtained are also applicable to piping systems where bifurcations occur.

1.2 RESEARCH BACKGROUND

Studies of flow patterns within the branching systems which attempt to mimic flow conditions within the body have been conducted for years. Leonado Da Vinci, in about 1500, conducted experiments on branched channel flow for biological application. He sketched the flow patterns in his experiments which clearly show the division of the fluid stream into the two branches, an eddy formation on the surface of the flow divider, gradual disappearance of the large eddy as it moves downstream, and separation at the sharp inner wall of curvature, along with reattachment at a downstream position.

Naumann and Zeller (1970) conducted experimental studies on large scale model bifurcations with laminar flow for a range of Reynolds number from 400 to 1100 under steady and pulsatile conditions. They used colored dye streams to describe the basic patterns of flow and found secondary velocity components developing just downstream from the flow

Several researchers have used hot wires to measure velocity profile in model bifurcations. Schroter & Sudlow (1969) used a single hot wire to determine the velocity profile in the plane of the bifurcation and normal to the plane for a symmetrical bifurcation with a sharp flow divider, a total branching angle of 70 degrees, and a sharp curvature. They also used a smoke stream to visualize the secondary currentsμ showing a secondary flow pattern downstream from the flow divider. At the inner wall of curvature they also showed separartion occurring.

Schreck & Mockros (1970) also used single hot wire to measure the velocity profiles at each π/4 position in a series of bifurcations. The two symmetrical models used have total branching angles of 42 and 80 degrees. The velocity distribution obtained by Schreck β Mockros were in general similar to the measurements of Schroter β Sudlow.

Olson ( ) conducted more extensive hot wire measurements. He used a pulsed and a sensor wire together to measure all three components of the velocity field within a set of bifurcations. He used six bifurcations of which one is asymmetric and the branching angles were 50, 70, and 90 degrees. Olson recorded results at various Reynolds numbers between 300 and 1700. He found no separation from the outside wall since the wall in his model is gradually curved and the Reynolds numbers were kept low.

All previous investigators used hot wires which we believe could have some disturbance on the flow fields. The experiment carried out here used Laser Doppler Anemometer to measure the flow fields. The major advantages for the laser system over hot-wires are:

(1) It creates essentially no disturbance to the flow.

(2) The relation between Doppler frequency and flow velocity is linear

(3) It is Sensitive to only velocities in the measured direction.

Another advantage of the LDA over hot wires in measurement accuracy is its Gaussian intensity distribution which weights more on the center-point velocity than on the pheripheral area in the 'control volume'.

Although the effectiveness of the LDA technique has been widely recognized, some of the problems associated with LDA have been noted in taking the measurement. (See Chapter 5.)

1.3 BASIC PRINCIPLES OF THE LDA SYSTEMS

As shown in Fig. 1.1, for the differential mode LDA system which we use here there is a well known Doppler effect so that:

$$f_{s1} = f_{i1} + \frac{\bar{V} \cdot (\hat{e}_{s1} - \hat{e}_{i1})}{\lambda_1} \quad \text{------(Eq. 1.1.a)}$$

$$f_{s2} = f_{i2} + \frac{\bar{V} \cdot (\hat{e}_{s2} - \hat{e}_{i2})}{\lambda_2} \quad \text{------(Eq. 1.1.b)}$$

Where:

$f_{i1}, \lambda_1, \hat{e}_{i1}$ =frequency,wavelength,and unit vector of the first incident light

$f_{i2}, \lambda_2, \hat{e}_{i2}$ =frequency,wavelength, and unit vector of the second incident light

$f_{s1}, \hat{e}_{s1}$ =frequency and unit vector of the scattered light due to the first incident light

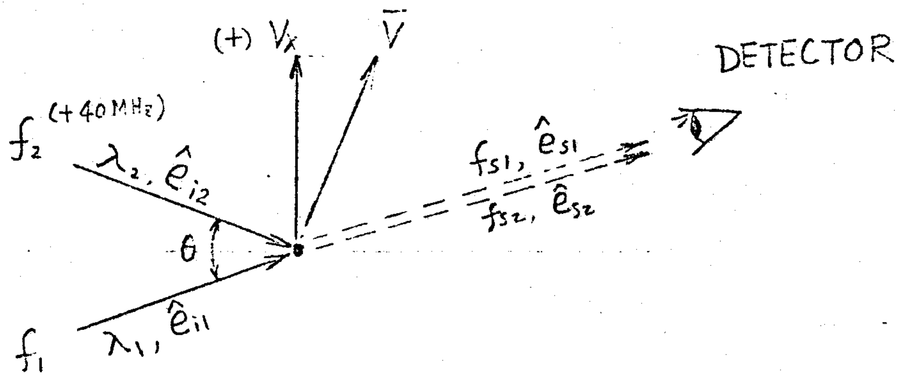
$f_{s2}, \hat{e}_{s2}$ =frequency and unit vector of the scattered light due to the second incidentlight

$\bar{V}$ =velocity vector of the scattering center

θ =scattering angle

V_x =projection of the velocity vector V on the measuring direction , in the plane of the two incident beams and normal to the bisector of the angle between the two incident beams

FIG. 1.1 Doppler Signal Formation



Therefore we can detect a beating frequency:

$$f_d = f_{s2} - f_{s1}$$
$$= \left[\frac{\bar{V}\cdot(\hat{e}_{s2}-\hat{e}_{i2})}{\lambda_2} - \frac{\bar{V}\cdot(\hat{e}_{s1}-\hat{e}_{i1})}{\lambda_1}\right] + \left[f_{i2} - f_{i1}\right] \qquad \text{------(Eq. 1.2)}$$

This is a general case either with or without a frequency shift. In practice we have the 'optical frequency shift, ($f_o = f_{i2} - f_{i1}$) much much smaller than the incident frequency($f_o \sim 40$ MHz, $f_i \sim 10^{14}$ MHz) so that Eq. 1.2 is then reduced to :

$$f_d = \frac{V_x \cdot 2\sin(\theta/2)}{\lambda} + f_0$$

$$= f_D + f_0 \qquad \text{------(Eq. 1.3)}$$

where:

$\lambda = \lambda_1 = \lambda_2 = 632.8$ nm the wave length of the incident light for the Helium-Neon system

f_D = the Doppler frequency

and: $V_x = C \cdot f_D$ -----(Eq. 1.4)

$$C = \frac{2\sin\theta/2}{\lambda} \qquad \text{-----(Eq. 1.5)}$$

Note that based on Snell's law, different reflective indices of the fluids will not affect the calibration factor C because of the self-compensation between λ and $\sin\frac{\theta}{2}$.

The detected frequency is encoded in the photocurrent by a photodector in the following form:

$$i_d \propto E_{s1}^2 + E_{s2}^2 + 2E_{s1}E_{s2}\cos(2\pi \cdot f_d \cdot t) \qquad \text{------(Eq. 1.6)}$$

where:

i_d =photodector current

E_{s1} =amplitude of the light scattered from the first beam

E_{s2} =amplitude of the light scattered from the second beam

t = time variable

Knowing f_D, θ, and λ we can thus obtain the velocity component by processing the photocurrent.

CHAPTER 2

EXPERIMENTAL DESCRIPTION

2.1 GENERAL DESCRIPTION

This chapter describes the experimental setup and how the facilities are working together. A schematic system configuration is shown in Fig. 2.1. The whole system is divided into the following sub-systems:

(1) The Flow System

(2) The Laser and Optics System

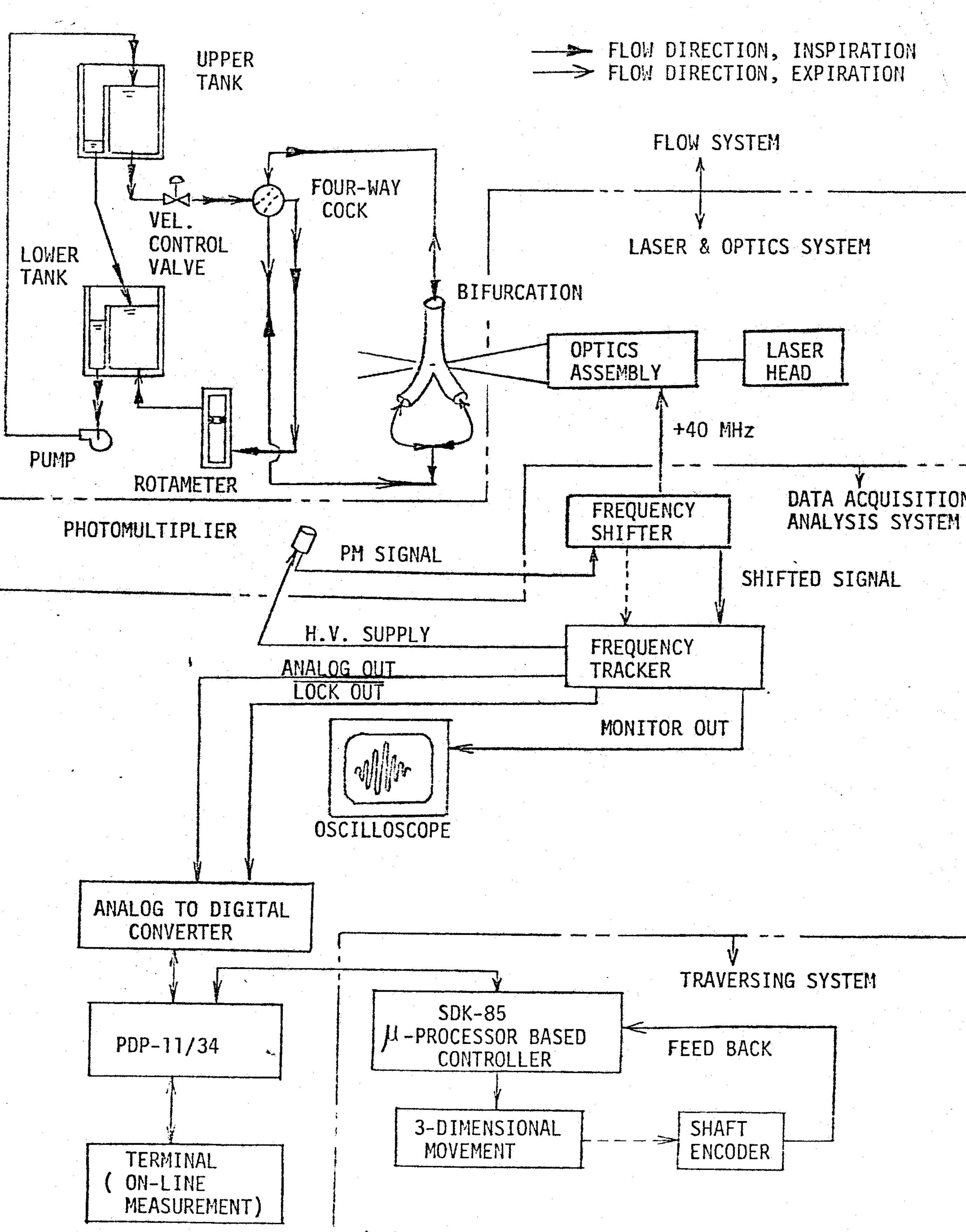
(3) The Data Acquisition/Analysis System

(4) The Traversing System

2.2 THE FLOW SYSTEM

As can be seen on Fig. 2.1, the working fluid is flowing in closed loop manner with constant head reservoirs to maintain a steady flow pressure across the bifurcation.

SYSTEM CONFIGURATION



To maintain a slow and steady flow, the driving force of the liquid is the elevational difference between the upper and the lower tanks. The two tanks are situated on angle-iron racks which are bolted to a vertical steel frame. The relative elevation of the two tanks is adjustible from approximately -35 inches to +35 inches, but is set at +29 inches all through the experiment. Flow velocity is controlled by a velocity control valve right downstream the upper tank. A pump is used to provide the make-up water for the upper tank so that constant water levels on both upper and lower tanks can be maintained. The function of the four-way cock is to easily reverse the flow direction at any time without reassemble any portion of the flow system.

The bifurcation portion is constructed of two opposite and symmetric pieces of plexiglas in which the semi-circular grooves are carved.(See section 5.1 for more detail geometry of the bifurcation area.) Note that the long straight tubing is deliberately introduced right upstream and downstream of the interesting area to ensure a fully developed steady-state incoming flow. A calibrated rotameter is installed on the returning line to measure the volume flow rate.

All the piping is consisted of three quarters inch inside diameter tygon tubes. The diameter on the bifurcation area is also three quarters inch.

2.3 THE LASER & OPTICS SYSTEM

The laser system used is Helium-Neon laser, Model 124B, made by Spectral-Physics. Some specifications are included in Table 2.1. The transmitting optics is a DISA 55x modular system and is schematically shown on Fig.2.2.

The laser light enters the quarter wavelength retarders, of which one is connected on the laser head to convert the linearly (and vertically) polarized beam into circularly polarized beam, and the other, mounted onto the initial optical end, reverses the polarization back to vertical direction. This allows free rotation of the entire optics assembly without altering the polarization within the optics unit.

The entering beam is then split into two equal intensity beams in the beam splitter. When the two beams go through the Bragg cell section, one of them passes through the Bragg cell which up-shifts the beam by 40 MHz. The unshifted beam passes through a glass rod in order to maintain optically equal paths with the shifted beam. The next module, the beam displacer, displaces the shifted beam so that both beams can collimate into the ensuing backscatter section.

Pinhole section is situated next to the backscatter section to eliminate undesirable reflections or scattered light from front lens. The two beams pass through pinhole section and then enter the beam translater where the beam separation is drawn closer to enter beam expander.

The function of the beam expander is to intensify the light at the latter focal point by a factor of approximately 14, resulting in an improvement of signal to noise ratio(SNR) by approximate 1/7 times. Lastly, the beams are brought to a focal point via a front lens.

In the backscatter mode, signal from the scattering center at the focal point penetrates back through front lens, beam expander,beam translater, pinhole section and then is reflected by the backscatter section into the photomultiplier. This mode was orginally designed but later abandoned because of the extremely low signal to noise ratio resulting from the reflected light from the plexiglas surface which is much higher than the backscattered Doppler signal.

In the forward scatter mode used, the photomultiplier(PM) tube is attached to a long bar which, in turn, fixed to the traversing system to compensate the movement of the beam intersection. (See Figure 2.5.)

The shifted Doppler signal is detected by the PM optics, transformed into current signal by the PM section, and then fed to the shifter for further processing.

A list of optical parameters is shown on Table 2.1.

55X MODULAR LDA OPTICS.

One-Component Forward Scatter and Backscatter Mode with Frequenc

1 FRONT LENS, Achromatic (310 mm)
1 PM SECTION
1 BEAM EXPANDER
1 COVER and RETARDER
2 SUPPORT
1 BEAM SPLITTER, Pol. 633
1 BEAM DISPLACER
1 BACKSCATTER SECTION
1 PINHOLE SECTION
1 BEAM TRANSLATOR
1 LENS MOUNTING RING
1 PM OPTICS
1 INTERFERENCE FILTER
1 MOUNTING BENCH
1 TRIPOD
1 BRAGG CELL SECTION

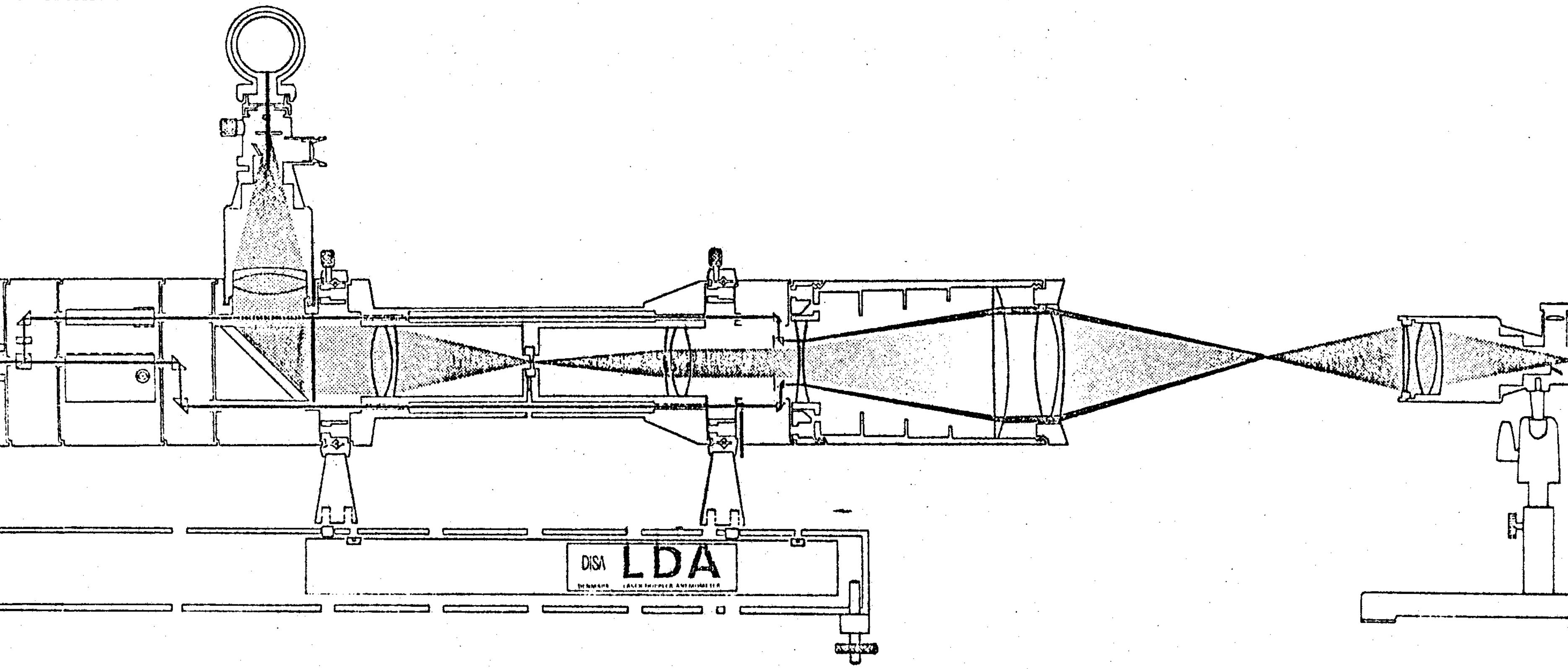


TABLE 2.1 PARAMETERS FOR THE LASER AND OPTICS SYSTEM

Laser type: He-Ne 15~35 mW, polarized

Laser make: Spectral-physics, Model 124B

Wavelength, : 632.8 nm

Front lens type: DISA X57, Achromatic

Focal length, f : 310 mm

Focal length apurature, D : 79 mm

Beam diameter, d :1.1 mm

Beam separation, D (after beam expander): 25 mm

Expansion ratio, E : 1.9375

Half intersection angle, $\theta/2$ (in the air): 4.56 Deg.

Focused beam waist diameter, d_f: 0.1172 mm

Detector optics: imaging type with pinhole

Photodetector :Photomultiplier RCA 4526

Dector pinhole diameter, r : 0.1 mm

Probe volume diameters:

2a=1.475mm (Convention as in Fig. 5.2)

2b=0.117mm

2c=0.117mm

Fringe space, δ_f : 3.983 m

Fringe number, N_f : 15

Calibration factor, $C=\dfrac{\lambda}{2\sin(\theta/2)}$: 3.983 ms^{-1}/MHz

2.4 DATA ACQUISITION AND ANALYSIS SYSTEM

2.4.1 Signal Nomenclature

The following symbols are used:

f_D :Doppler frequency, directly proportional to particle velocity in the direction of measurement

f_o :Optical frequency shift, introduced by Bragg cell (f_o =+40 MHz)

f_d :The detected frequency by PM tube

f_{LO} :Electronic frequency shift, due to the local oscillator in the 55N10 DISA frequency shifter is consisted of two parts: (f_{LO} =40 MHz + , f_s). The 40 MHz is to cancel out the optical shift f_o , f_s is the net frequency shift.

f_T : The tracker input frequency, also the shifter output frequency

2.4.2 Signal Processing Before Tracker

The frequency detected by PM is:

$$f_d = | f_D + f_o | \text{-------}(Eq.\ 2.1)$$

This signal is then fed to the frequency shifter where the electronic frequency shift is imposed.

Since f_o=40 MHz and f_D>-40 MHz all through the experiment, we have output from the shifter:

$$f_T = |f_d - f_{Lo}| = |f_0 - f_s| \quad \text{-----(Eq. 2.2)}$$

This signal is then fed into a DISA 55N20 frequency tracker.

2.4.3 Signal Processing In Tracker

Fig. 2.3 shows how signal is 'tracked' by a voltage controlled oscillator (VCO), and the various outputs of the tracker.

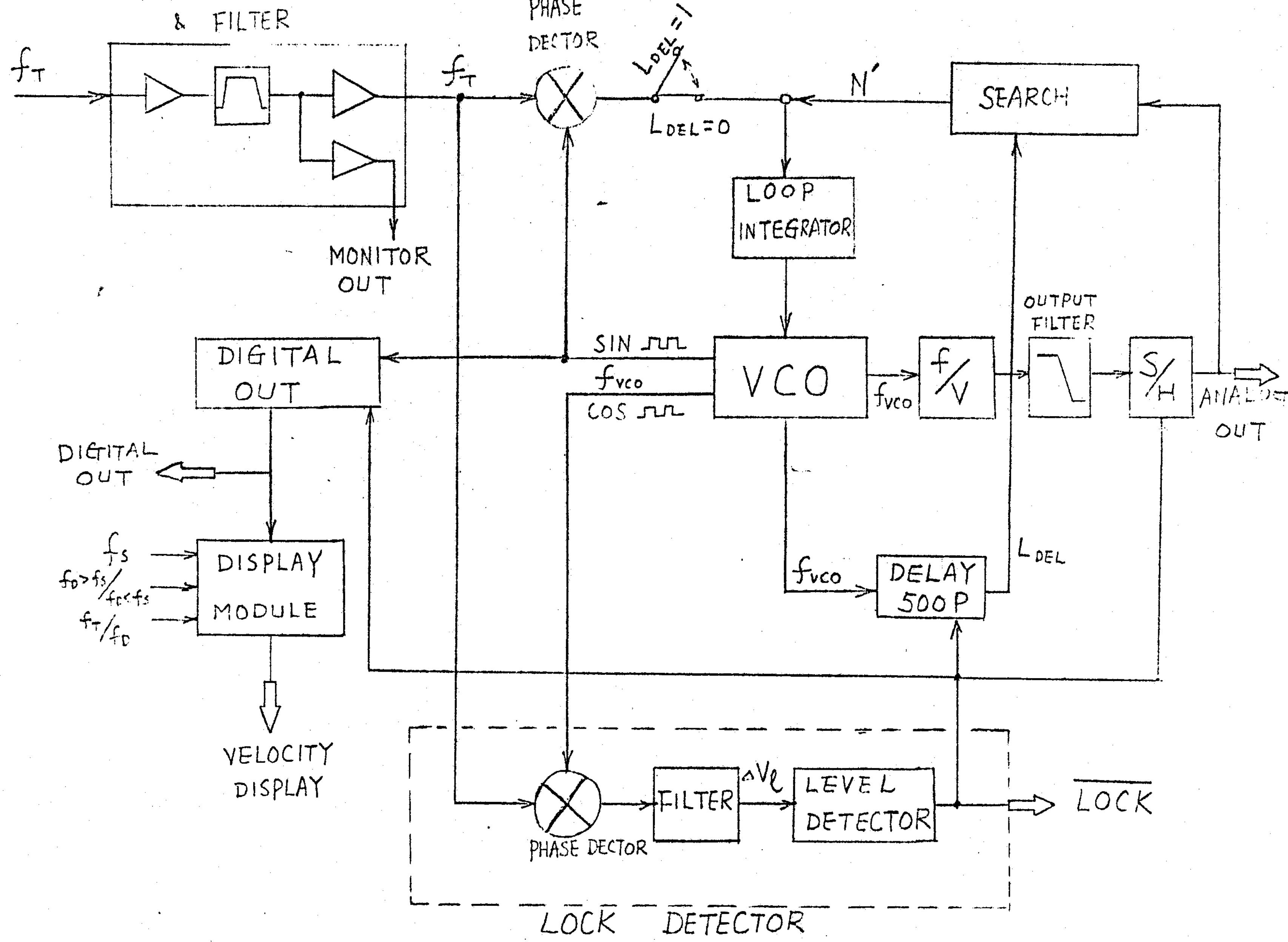
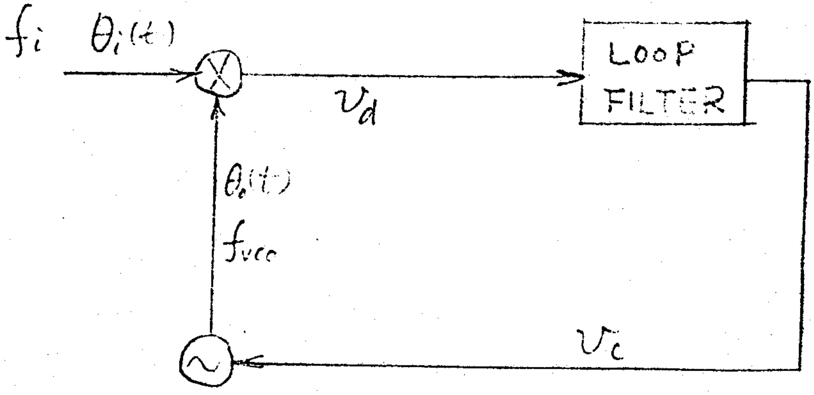


FIG. 2.3 FUNCTIONAL BLOCK DIAGRAM OF A TRACKER

FIG. 2.4 PHASELOCK LOOP



The core potion of a tracker is a phaselock loop whose task is to reproduce the original input signal while removing as much of the noise as possible.

A simplified phaselook loop is shown in Fig. 2.4. The input signal has a phase θ_i (t) and the VCO output has a phase θ_o(t). The two signals are compared in the phase detector and the 'error' signal, V_d is produced proportional to the difference in phase between its inputs, i.e.:

$$V_d = K_d \cdot (\theta_i - \theta_o - \phi) \quad \text{-----(Eq. 2.3)}$$

Where :

K_d =phase-dector gain factor (volt/radian)

ϕ =the designed phase lag between θ_i and θ_o

Phase error voltage, V_d is filtered by a loop filter where noise and high frequency signal components are suppressed and the control voltage, V_c is produced.

The frequency of the VCO is controlled by V_c . We have:

$$\omega = K_0 \cdot V_c$$ -----(Eq. 2.4) where:

K_0 is the VCO gain factor (rad./sec. volt)

ω is VCO frequency (rad./sec.)

Eq. 2.4 can be rewritten as:

$$\frac{d\theta_0}{dt} = K V_c$$ -----(Eq. 2.5) Thus, by tracking the phase of input using output signal θ_i , the VCO frequency is essentially the average frequency of the input signal when the loop is locked. Note that the time constant of the loop is so small that VCO frequency is actually an instant reflection of the input signal.

As shown in Fig. 2.3, the input signal is amplified and filtered leaving only frequencies in the set range before being fed into the phaselock loop. The 'SIN' output from the VCO is kept 90 degrees behind the input(i.e. ϕ =90 Deg.) when signal is locked,

thus : $$f_{VCO} = f_T$$ -----(Eq. 2.6)

is further processed in three ways:

(1) ANALOG OUTPUT

One branch goes through frequency-to-voltage(f/v) converter, output filter, sample & hold, and then output so that

$$V_{analog\ out} = \frac{10\,V}{RANGE} \cdot f_T \qquad \text{----(Eq. 2.7)}$$

Where RANGE is the maximum frequency in the selected range.

(2) DIGITAL OUTPUT & DISPLAY MODULE

The second branch goes to the DIGITAL OUT Block (Fig. 2.3), where counting of the 'SINE' output of the VCO takes place at regular intervals.

The digital output is expressed as:

$$D = 256 \cdot \frac{f_T}{RANGE} \qquad \text{----(Eq. 2.8)}$$

and is represented by an 8-bit word.

This signal was orginal used as a digital input to a PDP-11/34 minicomputer for data analysis but was substituted for by the analog output because of the non-functional serial buffer interface between the digital output and the computer.

The display module gets signal from the digital out. The following parameters are used to calculate either the Doppler frequency or flow velocity:

a) net frequency shift f_s, from shifter

b) frequency range R, from front pannel setting

c) calibration factor C, from front pannel setting

C=1 Display Doppler frequency

$C = \frac{\lambda}{2 \sin \theta/2}$ Display velocity

d) f_T / f_D seting, from front pannel

When in f_T mode , f_S will be forced to be 0 in calculation.

e) $f_D - f_S > 0 / f_D - f_S < 0$ setting, from front pannel

$f_D = f_S + f_T$ when $f_D - f_S > 0$

$f_D = f_S - f_T$ when $f_D - f_S < 0$

(3) LOCK DETECTOR

The third branch from VCO is presented in the 'COSINE' form. (i.e. ϕ =0 no phase lag to the input signal) This signal, together with a branch of the amplified input are first multiplied in a phase detector and then low-passed by a filter. The low-passed signal, ΔV_ℓ is compared with a preset reference level $\Delta V_{\ell r}$ in the level detector. The result is:

(a) When $\Delta V_\ell > \Delta V_{\ell r}$ the locked situation is determined.

The LOCK output will show a TTL logic 0

(b) When $\Delta V_{\ell} < \Delta V_{\ell r}$ the unlocked situation is determined and the LOCK output will show a TTL logic 1. If the lock detector indicates out of lock, the analog as well as the digit outputs will immediately be frozen .

When signal is out of lock, a search circuit, which is triggered by a delay circuit 500 VCO periods after the initial unlock, will assume.(i.e. =1) The phaselock loop will be interrupted by an electronic contact at the input of the loop integrator. The 'search' block will send an N' signal of alternately -0.22 V and +0.22 V to the loop integrator thus forcing the VCO frequency going up and down in the selected range until an agreement between tracker input and the search frequency is reached. AT this time the lock detector will resume locked and the phaselock loop will lock in again.

2.4.4 Signal processing After Tracker

The ANALOG OUT and the LOCK signals are drawn from tracker and fed into a Phoenix analog to digital converter whereby the 'data' enter computer. These data are analized by a FORTRAN subroutine, ANA.FTN and the mean velocity, root mean square fluctuation, turbulence intensity for the locked, unlocked, and combined situations are calculated.

2.5 THE TRAVERSING SYSTEM

2.5.1 GENERAL DESCRIPTION

The function of the traversing system is to:

(1) carry the bifurcation and move it in Z-direction

(2) carry the laser and optics system, including receiving PM, and have two-dimensional maneuverbility on the system (X & Y directions)

(3) perform automatic as well as manual positioning of the LDA system

(4) display current position of LDA in XYZ system.

By combining (1) and (2), the laser 'probe' has actually three dimensional maneuverbility.

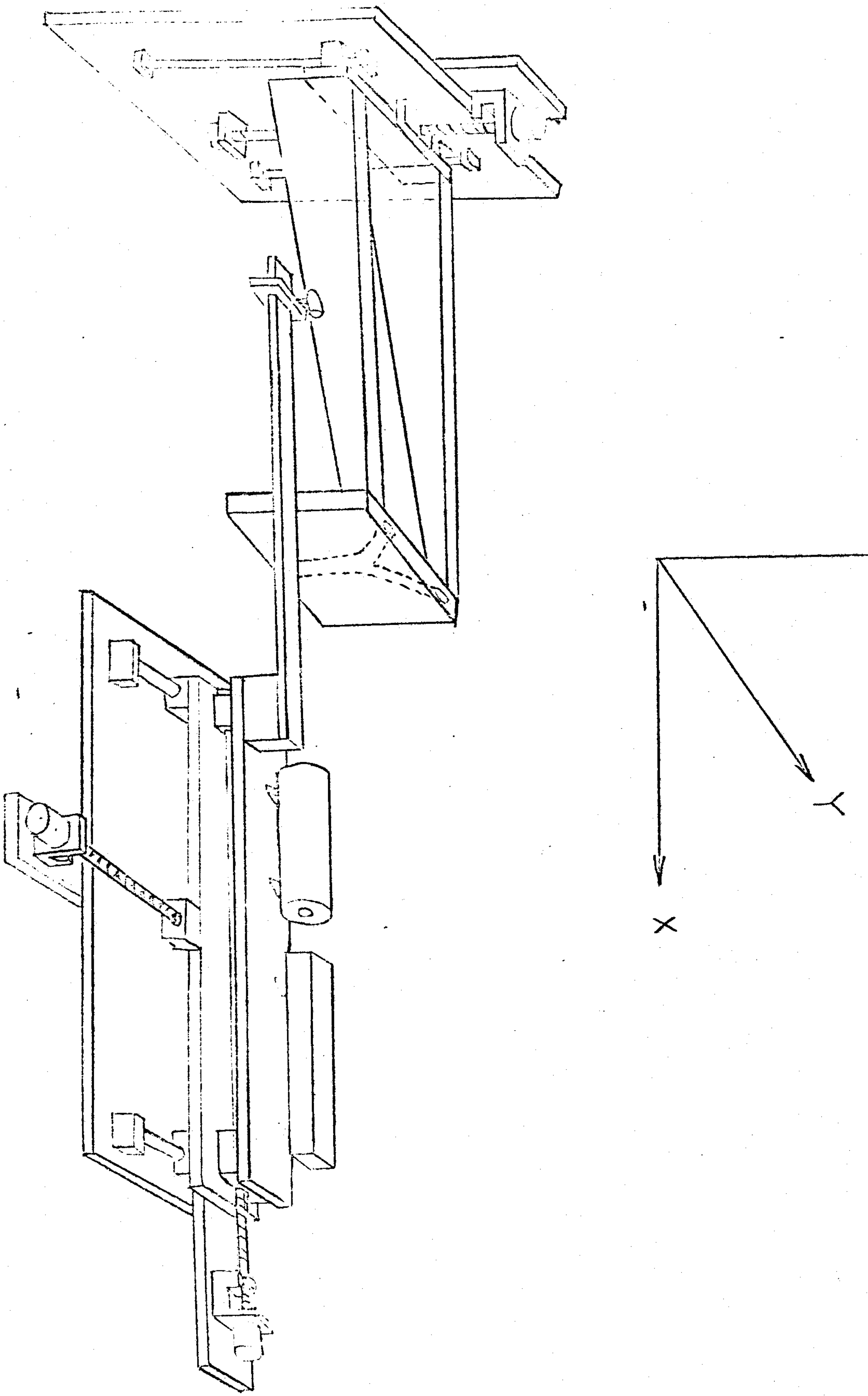
The traversing system can be divided into three portions:

a) The mechanical portion & its power drive

b) The translater and the translater interface

c) The SDK-85 microprocessor controller and position display

FIG. 2.5 MECHANICAL PARTS OF THE TRAVERSER



2.5.2 THE MECHANICAL PORTION

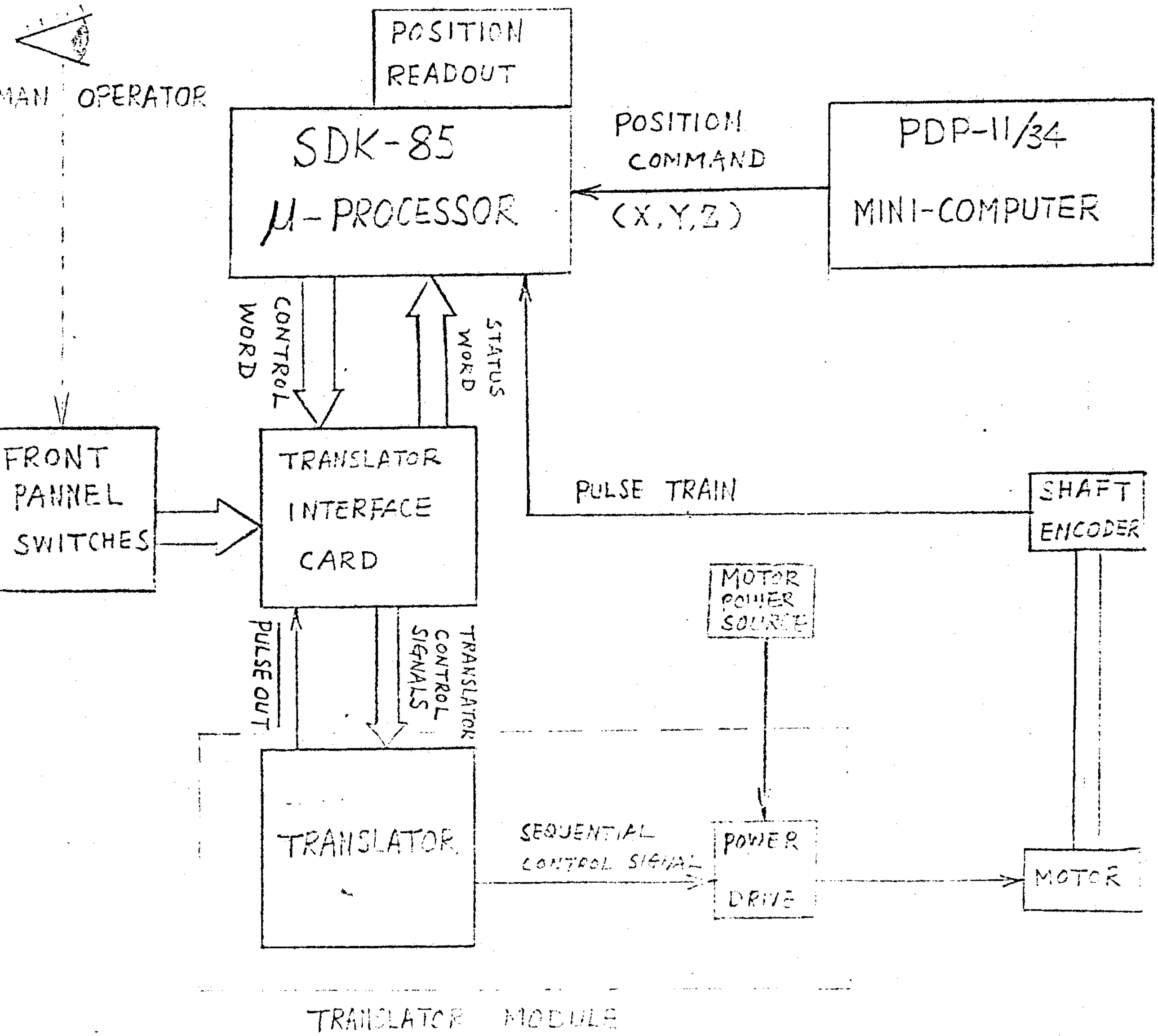
Fig. 2.5 shows a pictorial sketch of the mechanical parts. Note the position of the bifurcation and laser optics.

The vital parts of the mechanical portion are the three sets of stepper motors and shaft encoders which are distributed to the three axes. Each axis is moved by a stepper motor of which the internal windings are sequentially energized by its power drive. Each axis has also a shaft encoder assembly which is an optical-incremental type and provides a digital pulse train to the SDK-85 controller.

The encoder consists of an encoder plate attaching to the shaft and the body of the encoder is mounted to a fixed location. A matched photodiode and LED is mounted on the body. With a 5-pitch-per-inch lead screw and the 200-slot encoder plate, the system accuracy is approximately within 0.002 inch.

The stepper motor type is M062-FD09 made by Superior Electric and the encoder is made by Vernitech for robotics industry.

FIG. 2.6 TRAVERSING SYSTEM BLOCK DIAGRAM



2.5.3 THE TRANSLATER AND THE TRANSLATER INTERFACE

A functional block diagram of the traversing system is given in Fig. 2.6 .

The function of the translater is to provide a sequential control signal in order to energize the motor sequentially. There are a variety of selections for the sequential control. (See Appendix 3.) However, due to the software and hardware arrangement, only the following control mode is being used:

a) For manual control: Base speed & Run speed (High speed)

b) For automatic control: Base speed only

The translater interface is at the system site where the switching of signals from the SDK-85 or the manual switch array from front pannel switches and the gating of proper combination of these signals onto the translator card occur.

Refer to Fig. 2.6. The PULSE OUT signal, a pulse train generated by the internal oscillator in the translator, is 'gated', in the translator interface card. according to the control switch on the front panel or a control word from SDK-85, in the translator interface card. This pulse train, included in the translator control signals, is then fed back to either CW PULSE or CCW PULSE on the translator board to determine the motor direction.

A list of control bits is given in Table 2.2. Note all signals are TTL compatible. (Also refer to Appendix 2, TRANSLATOR & TRANSLATOR INTERFACE CONNECTION DIAGRAM for better understanding.)

TABLE 2.2 MNEMONICS OF THE CONTROL BITS

BIT NAME	DESCRIPTION
AUTO/MANUAL	Switch on front pannel determining auto or manual mode
A0,A1	Address codes for translators and their corresponding motors A1,A0= 0,0 axis 1 i.e. Z axis 0,1 axis 2 Y axis 1,0 axis 3 x axis
NC BASE	Base speed for auto mode
NC RUN	High speed for auto mode
NC CW	Clockwise rotation of motor, auto mode
NC CCW	Counterclockwise rotation, auto mode
MAN BASE	Base speed, manual mode
MAN RUN	High speed, manual mode
MAN CW	Clockwise rotation, manual mode
MAN CCW	Counterclockwise rotation, manual mode
$\overline{\text{RUN}}$	Run speed, active low
$\overline{\text{BASE}}$	Base speed, active low
$\overline{\text{CCW PULSE}}$	Triggering pulses for counterclockwise rotation, gated from $\overline{\text{PULSE OUT}}$
$\overline{\text{CW PULSE}}$	same as CCW PULSE but for clockwise rotation
$\overline{\text{PULSE OUT}}$	Triggering pulse train from built-in oscillator in translator

2.5.4 THE SDK-85 CONTROLLER AND POSITION READOUT

Except for the expansion area and the readout portion, the micro-processor is, in general, the same as a standard SDK-85 micro-processor. (Refer to SDK-85 system design kit, Users manual.)

The functions of the controller are to:

(1) Determine mode of operation (auto/manual) by reading front pannel switch settings.

(2) Accept manual move command from front pannel switchs when in manual mode.

(3) Accept position command (in XYZ format) from a PDP-11/34 executive computer when in auto mode.

(4) Decode the position information and activate the translator control word to drive the motors accordingly.

(5) Monitor position via a feedback loop closed by shaft encoders during motor operation.

(6) Update current position to the front pannel LED position readouts.

(7) Stop drives by resetting the translator control word when the system reaches the disired position.

The translator status word is hardware wired but is not used by the software program.

An analysis of the execution time shows that at a feedback loop execution time of 90 seconds, the software counter can track both base speed pulse train (600 step/sec) and high speed pulse train (3000 step/sec) without a loss of data pulse.

A schematic block diagram of the SDK-85 is given in Fig. 2.7. For completeness, the following information is included in the Appendices:

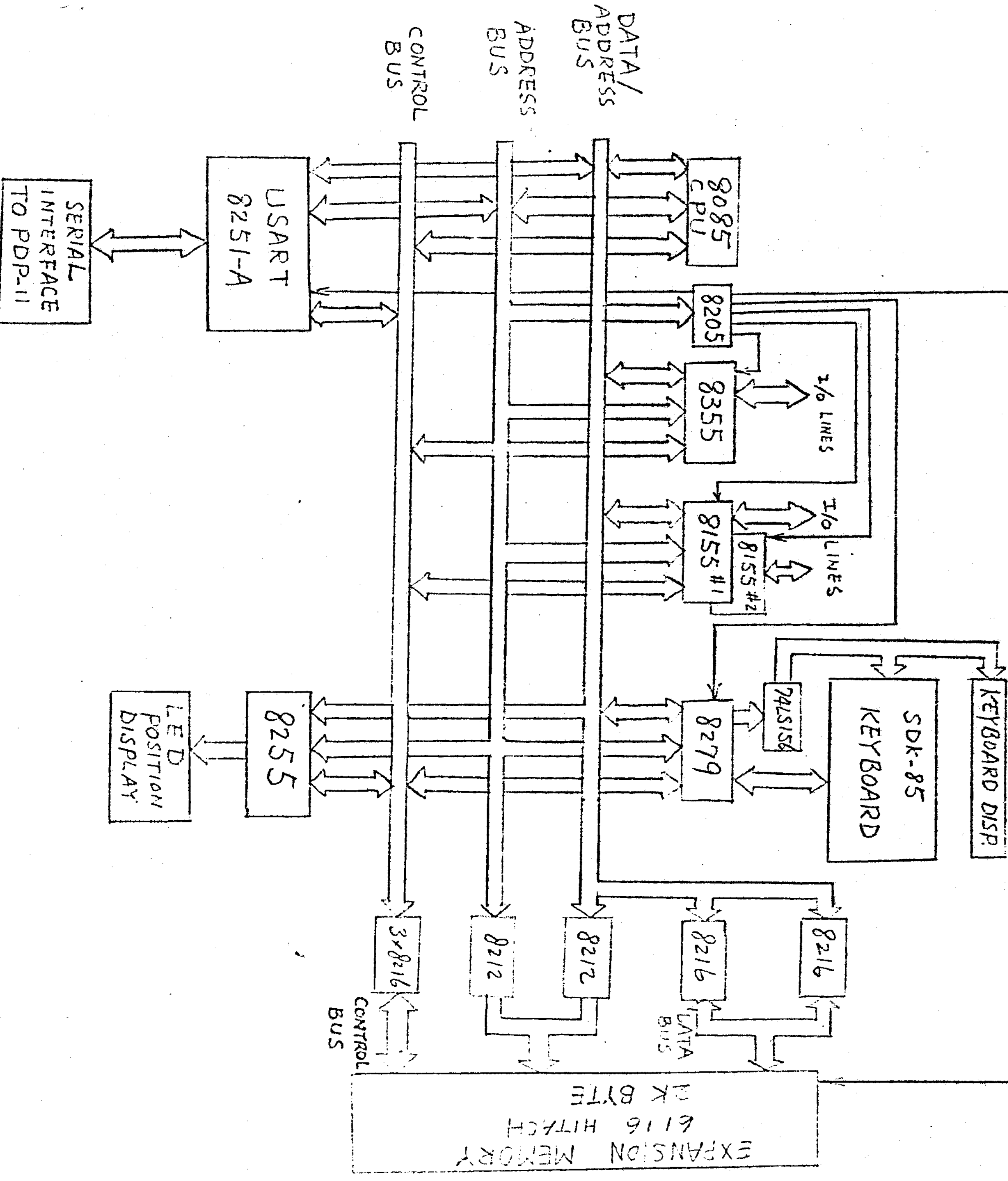
SDK-85 EXPANSION AREA SCHMATIC----Appendix 1

I/O PORT β BIT ASSIGNMENT----Appendix 4

PIN ASSIGNMENT----Appendix 5

LED INTERFACE SCHEMATIC----Appendix 6

FIG. 2.7 SDK-85 CONTROLLER BLOCK DIAGRAM



CHAPTER 3

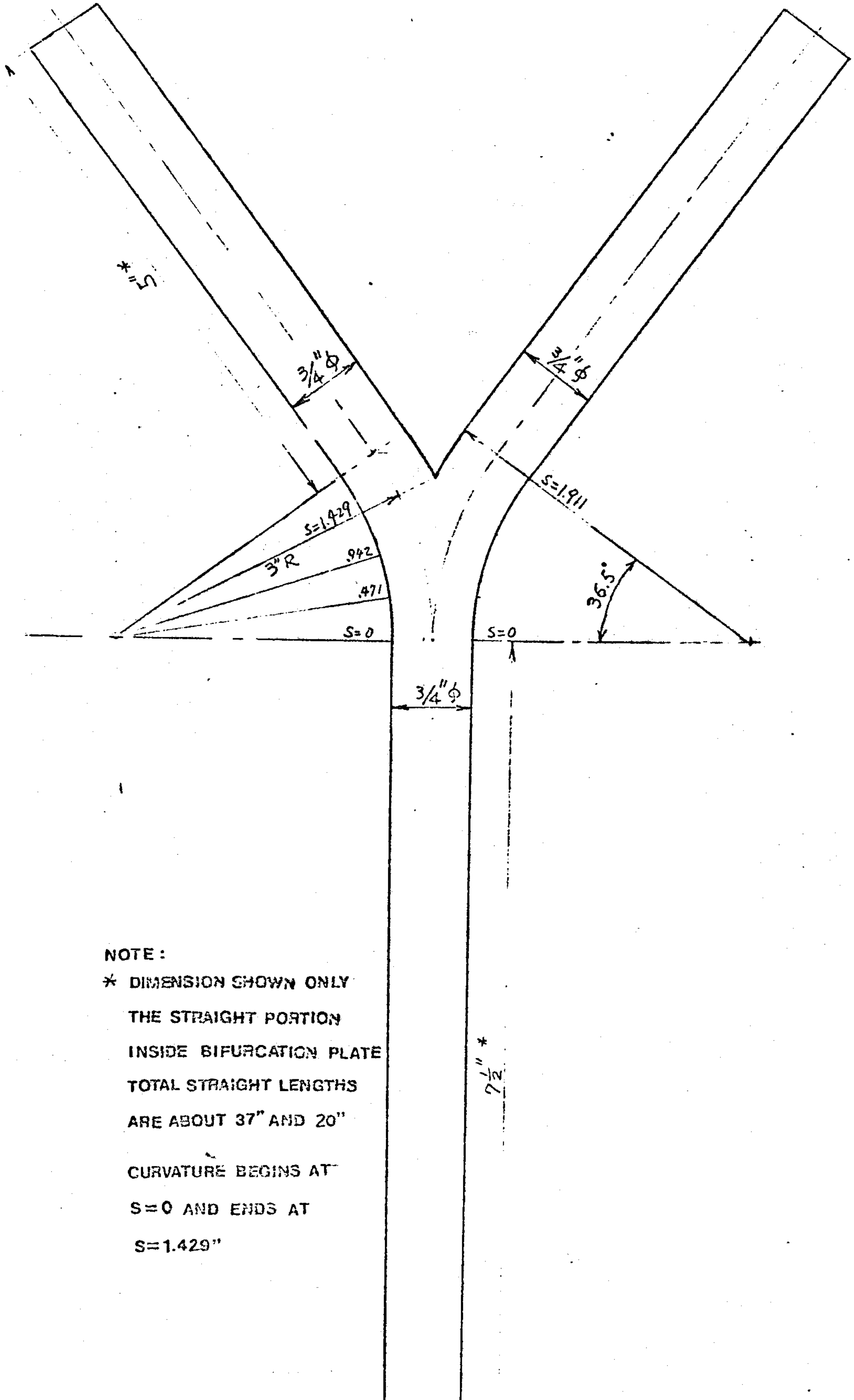
THE COORDINATE SYSTEMS AND THE CALIBRATION

3.1 THE BIFURCATION

Fig. 3.1 shows the detail geometry of the bifurcation under investigation. The bifurcation was milled symmetrically out of two pieces of rectangular plexiglas.

The major axes are defined in the $\pi/2$ or $3\pi/2$ direction on each plane (s=constant). These axes also fall on the plane of bifurcation. The minor axes are defined perpendicular to the corresponding major axis on the same s plane. In other words, it falls on =0 or π position.

The 'lung' is positioned upside down to avoid accumulation of the small air entrainment at low speed running.



NOTE:

* DIMENSION SHOWN ONLY THE STRAIGHT PORTION INSIDE BIFURCATION PLATE TOTAL STRAIGHT LENGTHS ARE ABOUT 37" AND 20"

CURVATURE BEGINS AT S=0 AND ENDS AT S=1.429"

3.2 THE COORDINATE SYSTEMS DEFINITION

Since the traversing system can only travel in the Cartesian coordinates and the probe point in bifurcation is better expressed in a 'cylindrical' coordinates, The two coordinates must be well defined and their relationship be established.

Fig. 3.1 sketches the relation between the 'cylindrical' coordinates (s,r,θ) for beam intersection and the Cartesian coordinates on the LDA (X,Y,Z). The origin of (s,r,θ) system is set right at center line spot where the curvature begins. The +s direction is defined as streamwise (actually tubewise) displacement toward downstream of the lung bifurcation. The straight lines $\theta=0$ are defined normal to the plane of bifurcation and toward LDA system.(i.e. Parallel to and toward +X direction.)

The (X,Y,Z) coordinates on the LDA is defined such that the traversing system is at its origin when the beam intersection is at the origin of the (s,r,θ) system. The +Y direction is parallel to the line, $\theta=\pi/2$ on s=0 plane.

The programmed transformation from (s,r,θ) system to (X,Y,Z) system is established through optical as well as geometrical relationship. Thus accurate and automatic positioning of the probe point becomes possible.

The transformation from (s,r,θ) to (X,Y,Z) is established in the following ways:

(1) Case 1, $s=0$: $Z=0$ and transformation is detailed in section 3.2.

(2) Case 2, $s<0$: Same as case 1 except $z=s$.

(3) Case 3, $s>0$:

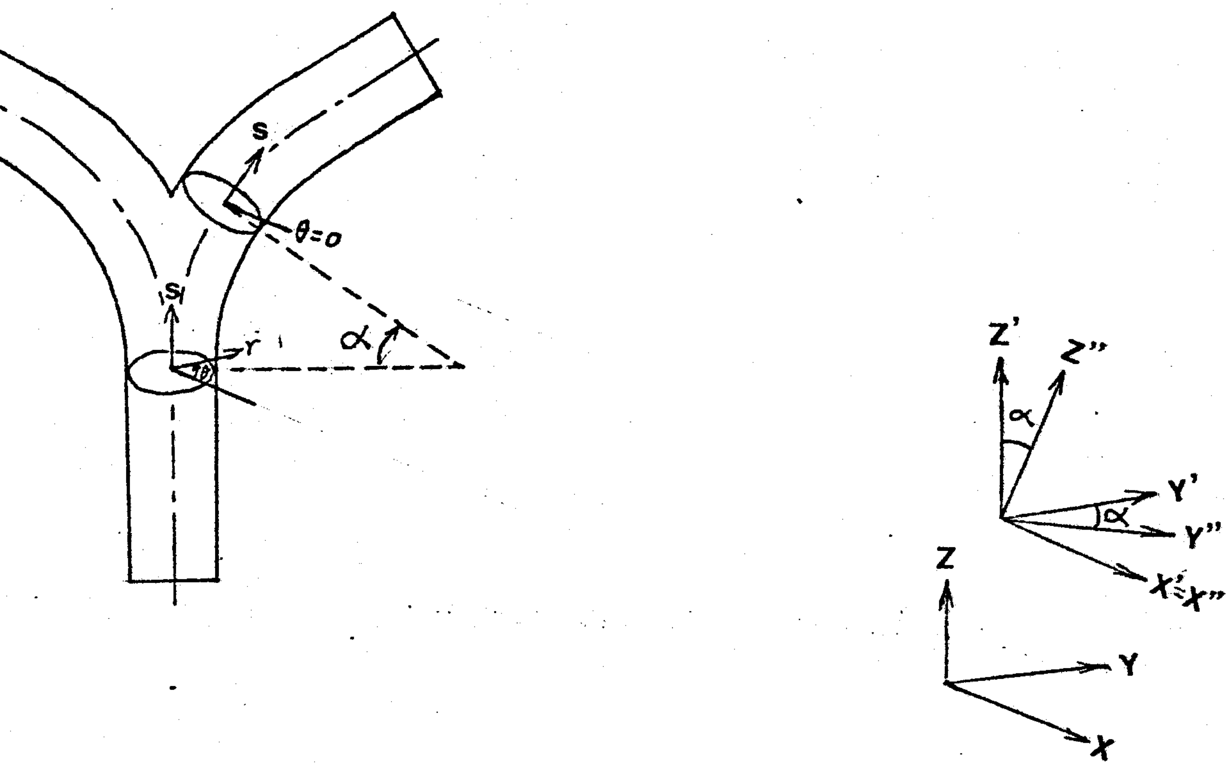
(a) Transformation from (s, r, θ) to (X'', Y'', Z'') is first made in the same way as case 1 by presuming (X'', Y'', Z'') as (X, Y, Z)

(b) Transform (X'', Y'', Z'') into (X', Y', Z') through a rotation angle as shown in Fig. 3.1.

Note $X''=X'=X$ in the case.

(c) Transform (X', Y', Z') into (X, Y, Z) through a pure translation.

FIG 3.2 DEFINITION OF THE COORDINATES



3.3 THE RELATION BETWEEN THE TWO COORDINATES ----WHEN TWO BEAMS ARE IN VERTICAL PLANES

Fig. 3.2 shows how the probe point $P(0,r,\theta)$ and the position of LDA $(X,Y,0)$ are related.

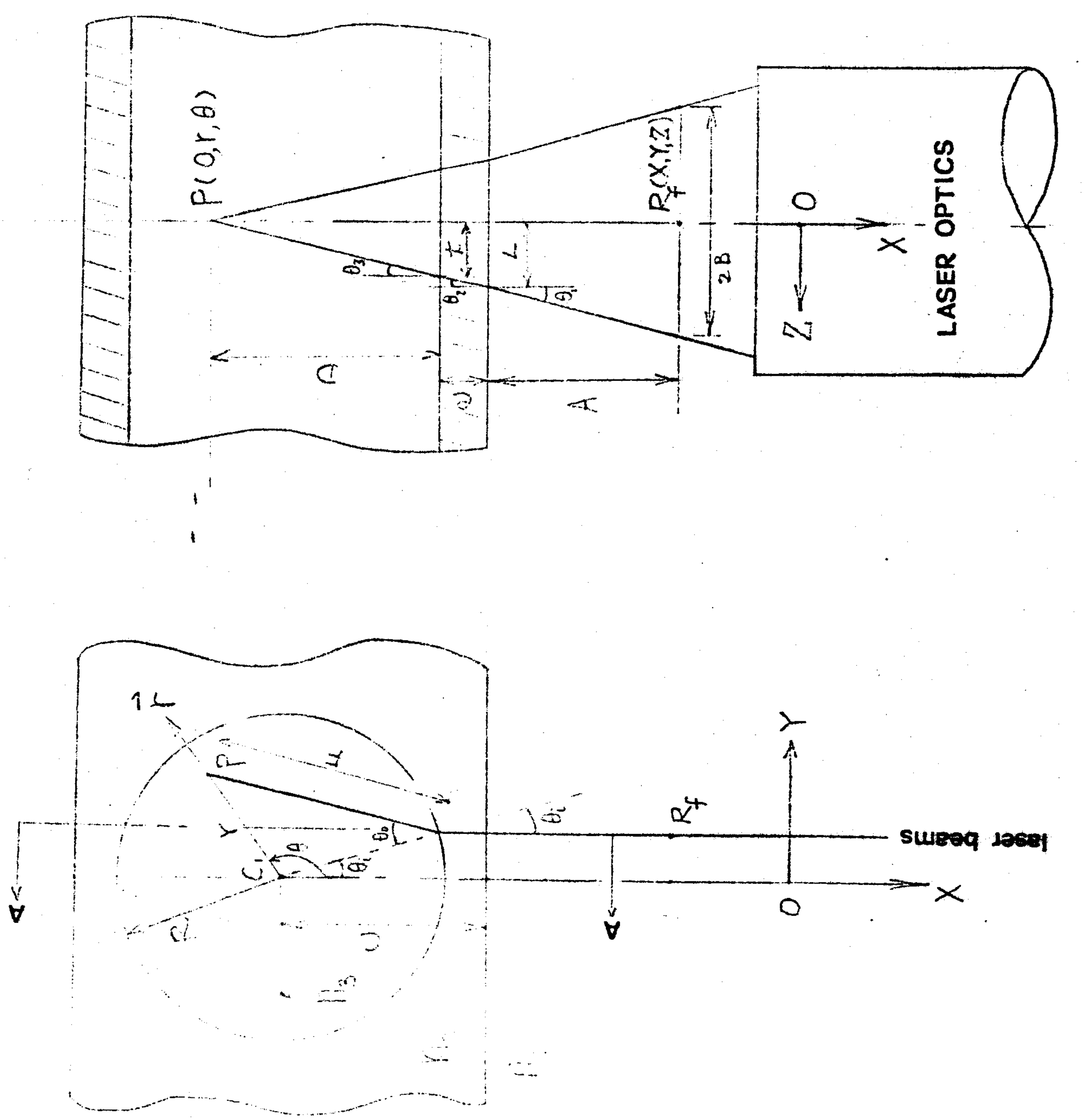
The reference R, imbedded in the LDA, is arbitrarily chosen and thus defines 2b and A which is the distance from the reference point to the plexiglas surface. It is defined that when P goes to C(0,0,0) in (s,r,θ) system, R goes to Cartesian origin and A becomes A_0.

The following equations can be solved for θ_i and θ_0:

$$n_2 \sin\theta_i = n_3 \sin\theta_0 \quad \text{----(Eq. 3.1)}$$

$$\frac{r}{\sin\theta_0} = \frac{R}{\sin[\pi-(\theta-\theta_i)-\theta_0]} \quad \text{----(Eq. 3.2)}$$

FIG. 3.3 RELATION BETWEEN (0,r,θ) AND (X,Y,0)



where:

n_2 =reflective index of plexiglas (1.489)

n_3 =reflective index of working fluid (water 1.33)

θ_i =incident angle in horizontal plane

θ_o =reflected angle in horizontal plane

R =internal radius of the tube

Introducing $\Delta = \theta - \theta_i$, we have:

$$\theta_i = \sin^{-1}\left(\frac{n_3 \cdot r \sin\Delta}{n_2\sqrt{r^2\sin^2\Delta + (R - r\cos\Delta)^2}}\right) \text{----(Eq. 3.3)}$$

$$\theta_o = \sin^{-1}\left(\frac{r \sin\Delta}{\sqrt{r^2\sin^2\Delta + (R - r\cos\Delta)^2}}\right) \text{---(Eq. 3.4)}$$

An iteration program was made to solve for θ_i and θ_o. From this the cartesion position of the LDA can be calculated:

And:

$$Y = R\ \mathrm{SIN}\ \theta_i = \frac{R \cdot n_3 \cdot r \sin\Delta}{n_2\sqrt{r^2\sin^2\Delta + (R - r\cos\Delta)^2}} \text{----(Eq. 3.5)}$$

Further we have:

$F = r \cdot \cos[\pi - (\theta + \theta_o)] + R\cos\theta_o$ ----(Eq. 3.6)

$D = F \cdot \cos(\theta_o - \theta_i)$ ----(Eq. 3.7)

$t = D\tan\theta_3$ ----(Eq. 3.8)

$e = C - R\cos\theta_i$ ----(Eq. 3.9)

$L = t + e\tan\theta_2$ ----(Eq. 3.10)

$A = (B - L) \cdot \tan\theta_1$ ----(Eq. 3.11)

$X = A - A_c$ ----(Eq. 3.12)

$N_1 \sin\theta_1 = N_2 \sin\theta_2 = N_3 \sin\theta_3$ ----(Eq. 3.13)

Solving for X:

$$X=\left\{B-\left\{\left[R\cos\theta_0-r\cos(\theta+\theta_0)\right]\cos(\theta_0-\theta_i)\cdot\frac{n_1\sin\theta_1}{\sqrt{n_3^2-n_1^2\sin^2\theta_1}}+(C-R\cos\theta_i)\cdot\frac{n_1\sin\theta_1}{\sqrt{n_2^2-n_1^2\cdot\sin^2\theta_1}}\right\}\right\}\tan\theta_1-A_0 \quad \text{----(Eq. 3.14)}$$

Where $\theta_1 \cdot \theta_2 \cdot \theta_3$ are the incident and reflective angles in vertical plane and all symbols are as shown on Fig. 3.3.

3.4 A DISCUSSION FOR PROBE POINT IN THE CURVED PORTION

In the course of transformation from the (s, r, θ) system to the (X,Y,Z) system when s>0, we have added a combination of pure rotation and pure translation to the basic transformation of case 1. This is exactly true when the two beams hit the straight tube portion, assuming the tube is perfectly milled. However, an offset from the 'modeled' position to the true position exists. This section estimates the error and discusses the legitimacy of neglecting this offset in practice.

Different perspectives of the beam hitting on the curved portion of the plexiglas and water interface are shown in Fig. 3.4. Note the exaggerated comparison on the actual beam locus (solid lines) and the model one (double dotted lines). The offset PQ can be decomposed into PQ1 as shown in sideview 1 and PQ2 shown in front view. Fig. 3.5 clarifies the difference between the modeled half-intersection angle, θ_2 and the actual ones, θ_{21} and θ_{22} in two perpendicular planes.

Considering a unit incident beam IK and taking θ_2 =4.56 deg.=0.079587 , we can approximate:

$$\beta \sim \frac{\theta_2 R}{DCC} = 0.57^\circ \qquad \text{----(Eq. 3.14)}$$

~~also we can approximate:~~

~~----(Eq. 3.16)~~

where R=0.375 in. :ID of the tube

DCC=3 in. :Distance from center of the cured portion to centerline of the tube.

All symbols are as shown on the figures.

and,

$$HK = DCC \sin\beta = 0.0298''$$

Also: $AD = \cos\theta_2$ ----(Eq. 3.15)

$KD = \sin\theta_2 * \cos\beta$ ----(Eq. 3.16)

$AK = \sqrt{\cos^2\theta_2 + \sin^2\theta_2 \cos^2\beta}$ ----(Eq. 3.17)

$\cos(\frac{\pi}{2} - \theta_{21}) = \frac{AK^2 + KD^2 - AD^2}{2 \cdot AK \cdot KD}$ ----(Eq. 3.18)

So, θ_{21}=4.5598 deg. by substituting θ_2 & β into (Eq.'s 3.15 to 3.18).

Therefore the offset from sideview 1 is

$$PQ1 = (\cot\theta_{31} - \cot\theta_3) \cdot HK$$
$$= 0.000494''$$

and the offset from front view is

$$PQ2 = HK \tan[\arcsin(\frac{n_3}{n_1} \sin\beta) - \beta]$$
$$= 0.0000354''$$

The conclusion is that the error is of order

FIG. 3.4 POSITION OFFSET IN CURVED PORTION

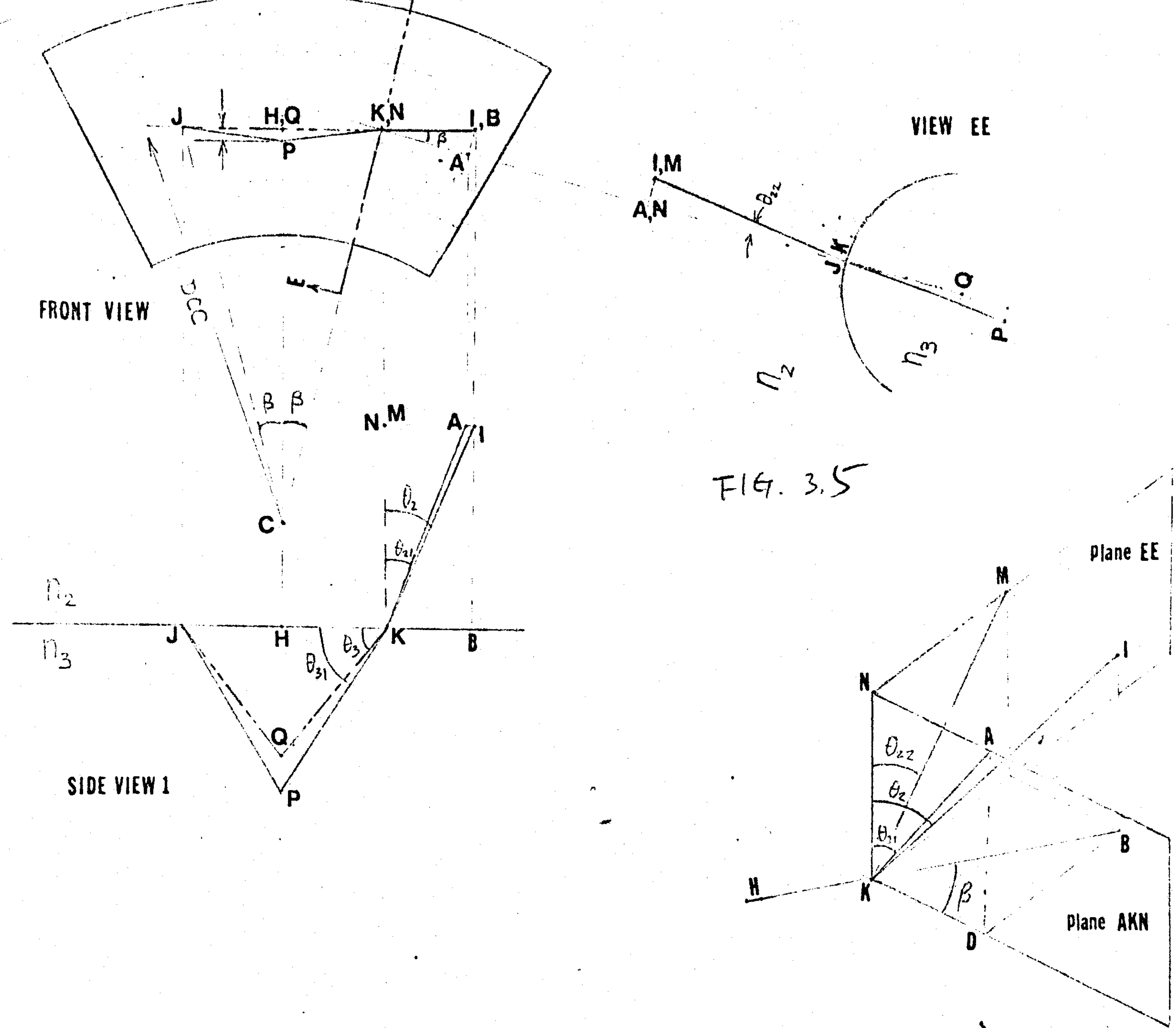


FIG. 3.5

3.5 POSITION CALIBRATION IN PRACTICE

In addition to the analytical analysis, a second bifurcation which has exactly the same geometry but contains only the vicinity of the bifurcation area was made to perform the experimental calibration.

Scale lines on a grid enscribed on a thin film was put in the second (along with the working fluid) tube to see if the beam crossing actually hits the calculated positions. Excellent agreement between the computed transformation and the actual positioning was confirmed.

To assure that centerline of the optics is perpendicular to the bifurcation plane, a thin flat mirror was stuck onto the plexiglas. The spot where the reflected laser beam hits on the focal lens was carefully examined to be in the correct position at all turning angles and all positions of the optics assembly.

The displacement in +X direction on LDA system is measured when their corresponding probe point is translated, in +X direction, from centerline of the miniature to its outer flat surface. This physical displacement, which agrees with the calculated one, is then applied back on the bifurcation to locate its origin. A measured symmetric velocity profile on 2.5 inches upstream the origin further confirms the calibration.

3.6 CALIBRATION ON TRACKER OUTPUTS

The voltage from the analog output was supposed to be:

$$V_{analog\ out} = \frac{10V}{RANGE} \cdot f_T$$ ----(Eq. 2.8) A drift on the output voltage was found: Therefore, calibration was necessary before $V_{analog\ out}$ could be further processed.

Based on the data shown on the tracker display module, which we found to be working correctly, the following listing shows the relation between the $V_{analog\ out}$ and the calibrated analog output $V'_{ana\ out}$:

$$V'_{ana\ out} = b1 \cdot V_{analog\ out} + b0$$ ----(Eq. 3.17)

Where b1, b0 are constants and were determined by linear regression fitting over the ranges.

b1,b0	=0.973459, -0.036448	for Range: 1 ~ 10 MHz
	=0.991966, -0.091971	0.3 ~ 3.3 MHz
	=0.988761, -0.080598	0.1 ~ 1 MHz
	=0.988288, -0.072361	33 ~ 333 KHz
	=0.979682, -0.103719	10 ~ 100 KHz
	=0.979710, -0.068719	3 ~ 33 KHz
	=0.979661, -0.095801	1 ~ 10 KHz

A similar calibration on the LOCK output is also included in the software program ATOD.FTN. The lock percentage is then decided as:

$$\text{Lock } \% = (1.0143 - LV/4.88)\ 100\%$$ ----(Eq. 3.18)

Where LV= voltage measured on LOCK output and we have used 0.07 volt for full lock indication and 4.95 volts for full unlock situation.

CHAPTER 4

THE SUPPORTING SOFTWARE PROGRAMS

There are two big programs performing automatic positioning of LDA, data acqusition, data analysis, coordinate transrormation, and data recording:

(1)MOVE.SRC

This program on SDK-85 was written by Bryan Howe and is modified by the present investigator on the portion which communicates with PDP-11. A simplified flow chart of this program is given in Fig. 4.1.

(2)LUNG.FTN

This main program carries 6 subroutines functions which are delineated below:

PARAM.FTN: * Initialization of tracker parameters

* Select parameters for analog output calibration

CAL.FTN : * Transformation of (s,r,θ) to (X,Y,Z)

ATOD.FTN : * Calls ADPHX.MAC to sample data from analog-to-digit converter

* Transformation of sampled data to velocity & lock percentage

ADPHX.MAC: * Samples data from A/D converter

ANA.FTN : * Calculates mean velocity, RMS fluctuation , and turbulence intensity for the locked, unlocked, and combined signals

TALK.FTN : * Communicates with MOVE.SRC on SDK-85
The (X,Y,Z) were expressed in thousandth of inches when they are sending out.

A flow chart showing the overall algorithm is given in Fig. 4.2.

FIG. 4.1 FLOW CHART FOR MOVE.SRC

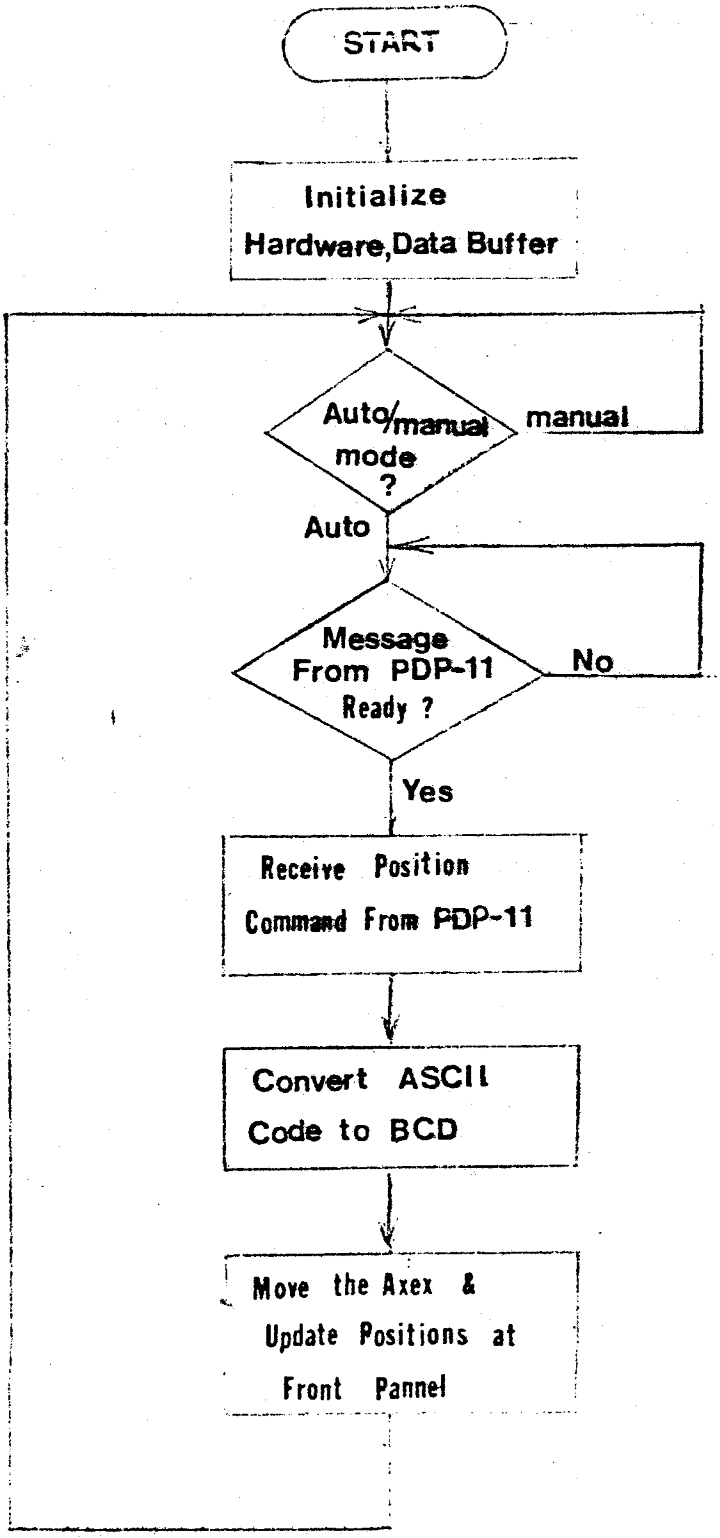


FIG. 4.2 FLOW CHART FOR LUNG.FTN (P 1/2)

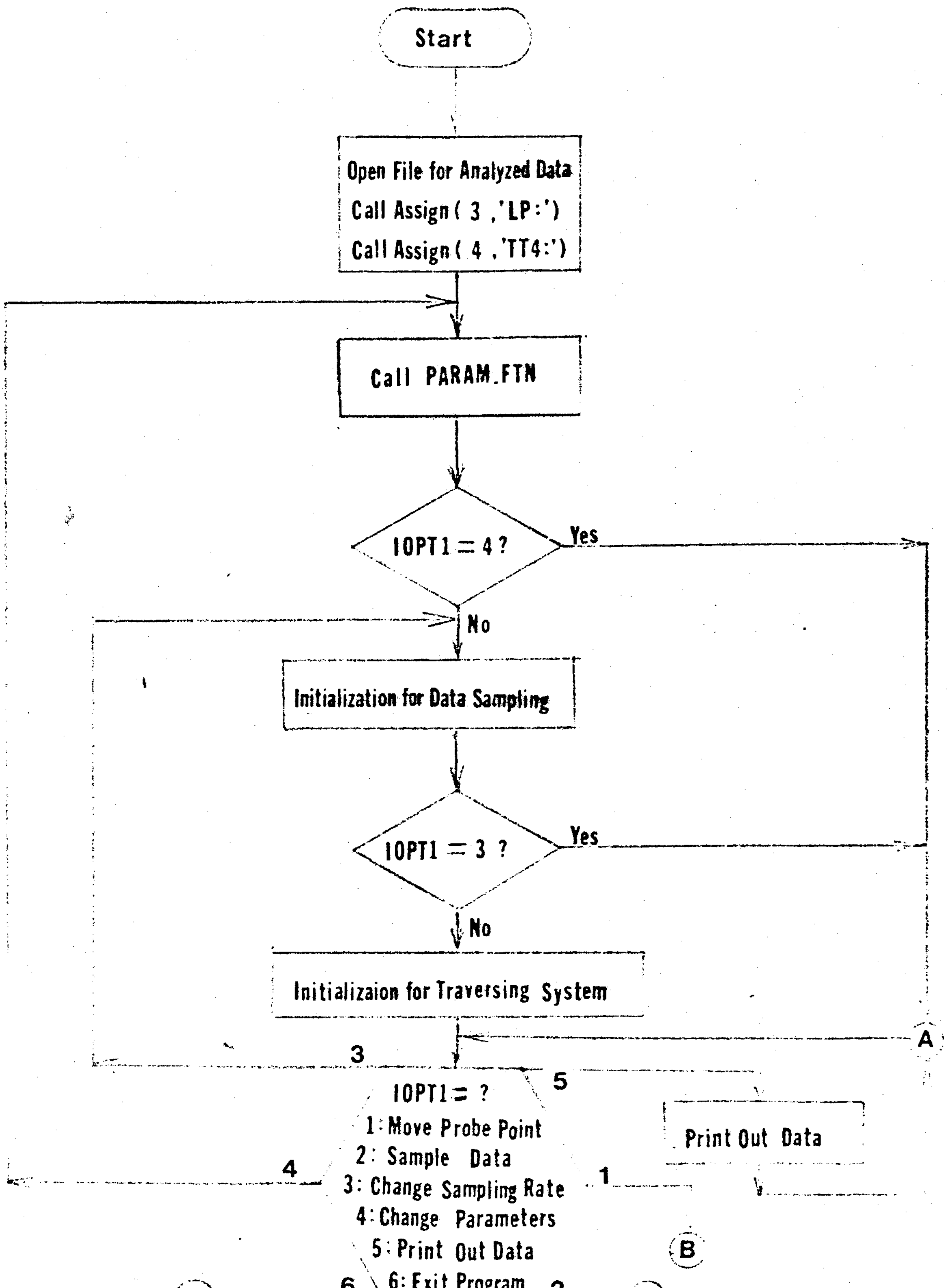
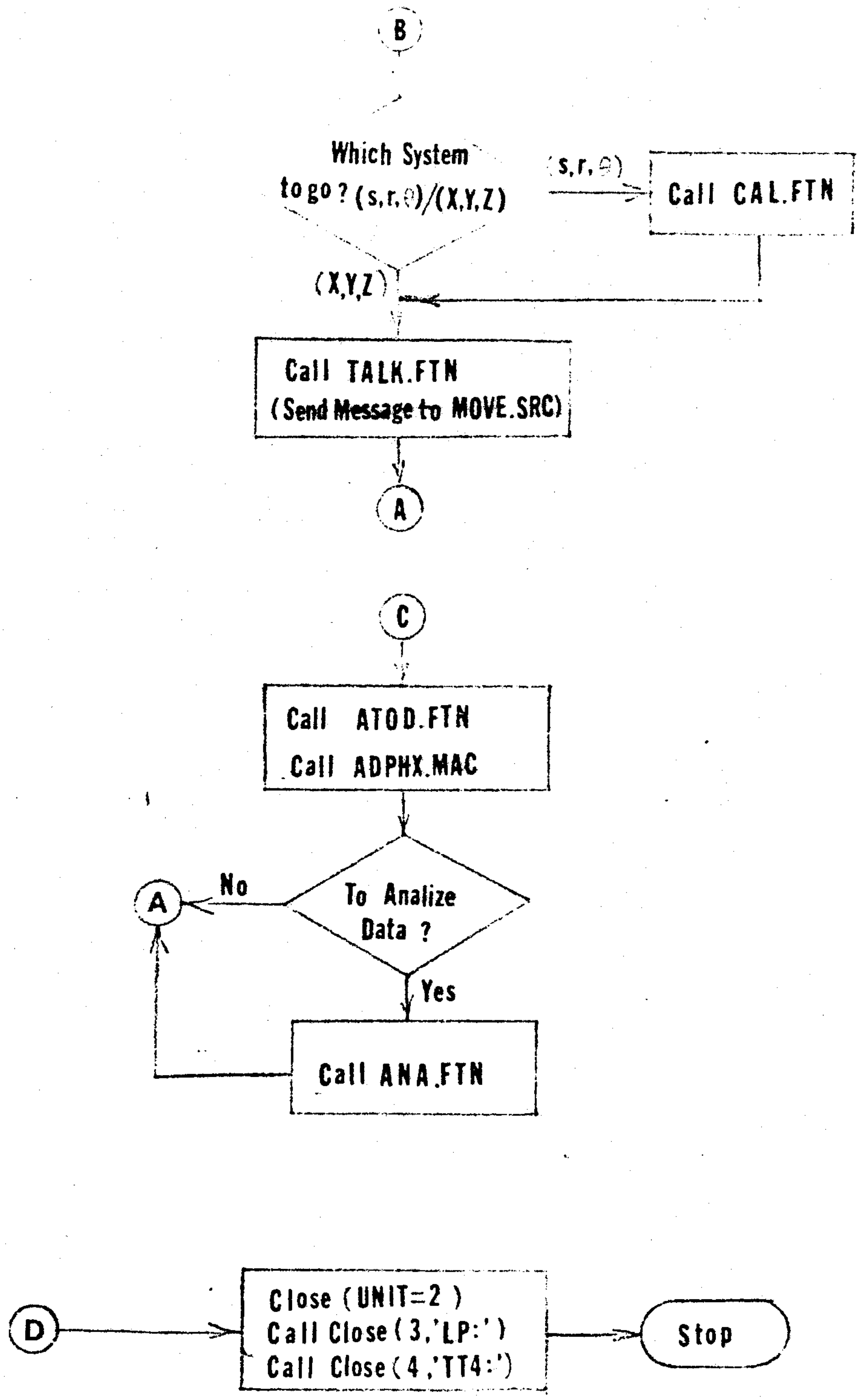


FIG. 4.2 FLOW CHART FOR LUNG.FTN (P2/2)



CHAPTER 5

THE MEASURING TECHANIQUES AND LIMITATIONS

5.1 THE SEEDING PARTICLES

Tap water was used as working medium. There are natural 'seeding' particles in it, however, to enhance the signal receptance, Alumina Trihydrate from Alcoa were added. Approximately one quarter of a teaspoon for 18 gallons of water. Composition of the seeding particles is listed in TABLE 5.1.

TABLE 5.1 COMPOSITION OF THE SEEDING PARTICLES

C333 ALUMINA TRIHYDRATE

Al O	65.0 %
SiO	0.01
Fe O	0.004
Na O	0.15
Na O(soluble)	0.02
moisture(110 C)	0.4

Density: 2.42 g/cc

Average particle size: 6.5 ~ 8.5 μm

5.2 LIMITATIONS ON THE LASER ANEMOMETRY

There are a few factors affecting the performance of the LDA system. This portion is to discuss specifically how much these factors affect our measurement.

(1) Temporal Resolution

The temporal resolution is limited from two sides:

(a) The limited ability of the seeding particles to adapt to flow velocity without significant lag. This becomes more difficult when the flow has very high fluctuation and short cycle time.

(b) The response time of the signal processor, the frequency tracker, in our case. The processor will not be able to detect the signal if the cycle time of the flow or the the residence time of the particle is shorter than the minimum transit time of the processor.

Noel Nee (1982) in his thesis set a criterion for maximum particle size. He assumed that particles act like a linear first order system. Therefore, the particle time constant can be evaluated as:

$$1/\tau_p = \alpha = \frac{\nu K}{a^2} \quad \text{----(Eq. 5.1)}$$

Where $K = \frac{9}{2\frac{\rho'}{\rho}+1} \sim 1.5$

α = a measure of maximun frequency that particle is able to respond without a significant lag.

ρ = density of the working fluid (=1 in our case)

ρ' = density of the particle ($\sim$ 2.5 in our case)

ν =viscosity of the fluid ($\sim$0.95*10 ft /sec)

a =radius of the particle

Since mean particle dimeter is 6.5 $\sim$ 8.5 µm, we can conseratively pick a=5 µm. Then:

$$\alpha = 52950 \ \text{sec}^{-1} \quad \text{or} \quad \tau_p = 1.89 \cdot 10^{-5} \ \text{sec}$$

Considering the bifurcation region which is the only acceleration zone in our problem, We have:

ω =V/R Where ω =angular velocty (sec^{-1})

Since has a dimension of sec^{-1}, we can imagine the flow frequency is of order of ω .

Let $V=V_{max}$ =3.24 m/sec , R=.375 in. , then:

$$\omega \sim 340 \text{ sec}^{-1} \text{ , or } \tau_f \sim 2.94\cdot10^{-3} \text{ sec}$$

Seeing that $\alpha \gg \omega$, we definitely do not have the velocity lag problem. In fact the difference is so great that even reasonably intense secondary flow regions should be 'traded' satisfactorily.

A check on the other side of the problem shows that the tracker time constant is of order 10 μsec. This is also much much smaller than τ_f thus it may be concluded that there is no problem here either.

(2)The Signal Drop Out Problem

Signal dropout is a common problem in the continuous LDA processing. The physical reasons for the dropout are as follows:

(a)The signal amplitude is too low due to:

aa) Particle concentration too low or particle size too small

bb) Poor S/N ratio

cc) Phase cancellation among the particles

(b)The particle transit time is much too short relative to the loop response time of the tracking type processor.

Buchhave etc. (1979), according to their analysis, concluded that if the dropout time is small compared to the turbulence integral scale and the tracker holds the last value, as in our case, all the moments of the velocity will be conserved.

It is desirable that dropout be less than 10 % if we want to conserve higher order moments in the case of high-turbulence measurement. However, if we can assume that the dropout rate is independent of the velocity of the fluid and sufficient averaging time is used, the first moment of the velocity will be conserved even if we have higher dropout time.

Since our major concern is the first moment velocity (the flow is laminar)and seeing that the dropout rate was kept under 20 % throughout our measurement, we concluded no problem in this regard.

(3) Spatial Resolution : Probe Volume

Probe volume is defined as the volume within the $1/e^2$ boundary of the optical fringe modulation. For laser beams which have Gaussian intensity profile, the probe volume is an ellipsoid as shown in Fig. 5.2.

The intensity can be formulated as

$$W(\bar{X}) = \frac{1}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left[-\left(\frac{x^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2}\right)\right] \qquad \text{(Eq. 5.3)}$$

Where : $\bar{X}$ =(x,y,z) is the position vector

and $\sigma_x, \sigma_y, \sigma_z$ are the standard deviations of the corresponding Gaussian distributions

The spatial resolution of the LDA depends on the probe volume. The selected probe volume must be smaller than the shortest wavelength of the velocity to be measured.

In the system we have:

$$2a = 4\sigma_x = \frac{d_f}{\sin \theta/2} \quad \text{(Eq. 5.4)}$$

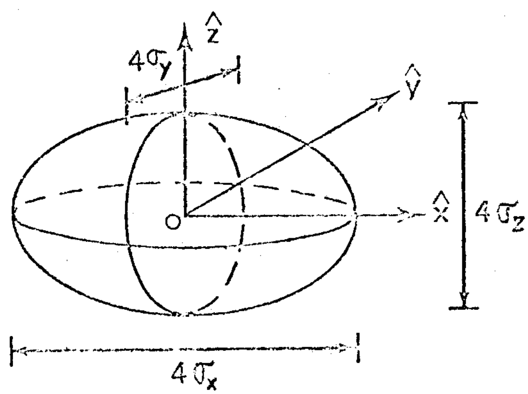
$$2b = 4\sigma_y = d_f \quad \text{(Eq. 5.5)}$$

$$2c = 4\sigma_z = \frac{d_f}{\cos \theta/2} \quad \text{(Eq. 5.6)}$$

$$d_f = \frac{4}{\pi}\,\frac{f\lambda}{E d_1} \quad \text{(Eq. 5.7)}$$

where all symbols are as shown in Table 2.1.

FIG. 5.2 THE PROBE VOLUME



(4) The Curvature Effect

The finite extension of the probe volume resulted in a spatial integration of the flow field. If the flow field is not uniform in the probe volume, the measured data will be different from the velocity at the center point of the volume. This is known as the curvature effect. The following estimates the worst error in our case due to curvature effect.

For multi-particle flows, the continuous Doppler signal relates to the true velocity as follows:

$$Um(t)= \frac{1}{N(t)} \iiint W(\bar{x})\ U(\bar{x},t)\ g(\bar{x})\ d^3\bar{x} \quad \text{----(Eq. 5.8)}$$

Where : W(x) , given in Eq. 5.3, is a weighting function referring to the shape of the measuring volume

N(t) is the instaneous number of particles in the probe volume

Um(t) is the measured velocity

U(x,t) is the velocity at point x

g(x) is a function which accounts for the presence or absence of a particle at a location. (g(x)= 1, presence µ 0, absence)

To simplify the problem, let's consider only U_x direction. Assuming the principal gradient of U_x to be in the z-direction and taking the ensemble average yields we can rewrite

$$\overline{U}_{x,m}(t)=\int I(z)\overline{U}_x(z,t)\ dz \qquad \text{(Eq. 5.9)}$$

where $$I(z)=\frac{1}{\sqrt{2\pi}\,\sigma_z}\exp\left(-\frac{z^2}{2\sigma_z^2}\right) \qquad \text{(Eq. 5.10)}$$

Note that in Eq. 5.10, we have taken the ensemble average so that N(t) and g(t) are no longer present.

In the bifurcation coordinates, let center point of the probe be at $r=r_0$. Then, Eq. 5.10 becomes:

$$U_{s,m}(r_0,t)=\int_{r_0-\infty}^{r_0+\infty}\frac{1}{\sqrt{2\pi}\,\sigma_z}\exp\left[-\frac{(r-r_0)^2}{2\sigma_z^2}\right]U_s(r,t)\,dr \quad \text{----(Eq. 5.11)}$$

By substituting Um for U_s, using a Tailor series expansion of Um, and neglecting higher order terms, we have

$$Um(r_0,t)=U(r_0,t)+\frac{\sigma_z^2\,U''(r_0,t)}{2} \quad \text{----(Eq. 5.12)}$$

where double prime denotes twice differentiation over the r direction.

Thus the error due to the curvature effect is

$$Err(r_0,t)=\frac{\sigma_z^2\,U''(r_0,t)}{2} \quad \text{(Eq. 5.13)}$$

$$=0.1844\,U'' \quad \text{(U in mm/sec)}$$

To have an idea of how big the error is, consider the entrance flow which is Hagen-Poiseuille profile:

$$U(r)=U_{\mathcal{C}}\,[1-(r/R)^2] \quad \text{(Eq. 5.14)}$$

Substituting into Eq. 5.13 and putting the numbers in yields

$$Err(r_0)=-\frac{\sigma_z^2}{R^2}\,U_{\mathcal{C}}=-0.0016\,U_{\mathcal{C}} \quad \text{everywhere}$$

We therefore conclude that, unless very close to the wall, the curvature effect is insignificant.

(5)Measuring Point Effect On Photodector

The measuring volume is defined as the region in the space from which Doppler signals are received and detected by the system. The following are the important factors affecting the measuring volume:

(a)wavelength and the geometry of the receiving optics such as F-number,f/D.

(b)photomultiplier gain

(c)the position and the focusd point of the PM optics

We now focus on the last item since it has certain effect on the measured data.

The detector, placed at a definite angle to the optical axis of LDA, cut out a section of the probe volume given by the intersection of the probe volume and the cone defined by the view field of the detector. Theoretically, the best signal is obtained when the center of the measuring volume coincides with the center of the probe volume. However, in practice, it is not easy to assure this point, especially when lock percentage is lower. We found, instead of a point, there is a small region around centerline of the probe volume in which, when the measuring point is located, the best signal can be obtained. This error,due to the offset of the measuring point, which is often neglected, may become significant with high velocity gradient. Sometimes, this may account to approximately 3 % of the centerline velocity. Some detail as to how this number was achieved may not be appropriate The adopted data is then the mean value of the data taken at several spots inside the small region.

(6)Doppler Ambiguity

LDA measurement with continuous Doppler signals is always affected by the random dispersion of particles in the fluid and the resulting random phase fluctuations of the scattered light. This phenomenom creates an ambiguity in the velocity measurement. It also has a bandwidth broading effect in the spectral analysis.

Fortunately, Doppler ambiguity does not significantly affect the measurement of the first moment which concerns us.

CHAPTER 6

DATA AND RESULTS

6.1 GENERAL DESCRIPTIONS

The flow was measured in detail at a Reynolds number of 320. It was found that flow pattern of 650 Reynolds number is very close to that of 320 Reynolds number based on measurement over several planes.

Measurement were taken on each 30° as well as 45° intervals. The interval in the radial directions is either 0.05 or 0.1 inch depending on local situations. Data points are up to r=0.35 inch and sometimes less because of the inavailability of signals. A list of measured plane is given in Table 6.1.

Because of the symmetrical geometry, the ensuing paragraphs refer only to the right-hand branch of the bifurcation.

6.2 EVOLUTION OF THE FLOW PATTERN

Fig. 6.1 shows that the entrance flow is pretty close to a fully developed Hagen-Poiseuille flow with peak velocity of 2.43 mm/s.

Because of the divider ahead, the profile is gradually suppressed around the centerline area thus making it flatter. (This suppression becomes farther-reaching with higher velocity.)

At S/D=0, Fig. 6.2, a 'shoulder' in minor axis (0-180) is being brewing. As the expansion space lies ahead in major direction (90-270), the pattern is flatter around centerline in this direction than in either 0-180 or 45-225 directions.

Patterns for plane S/D=0.628 are drawn on Fig. 6.4. Note that the centerline of the tube direction deviates from the centerline of the bifurcation by 0.04 inch at this location, and makes little velocity difference.

Flow patterns for S/D=1.256 and 1.565 are given in Fig. 6.5, 6.6, and 6.7. Note: (1)the 'shoulder' is becoming apparent in 180-0 direction, (2)offset of the centerline of the tube is significant and velocity shown is tubewise direction everywhere. (3)a second hump is brewing on the right end of the 90-270, 45-225, and 30-210 curves.(Compare to next few planes.)

Flow patterns right on the plane of the divider are given in Fig. 6.8, 6.9. Note the 'head' is further suppressed on 0-180 line. Because of the inertia, the high velocity is toward the inner wall of bifurcation and the 'head' on minor direction becomes lower. This inertia seems to be a suorce of secondary flow, measured by Olson(1971), which comes from center vincinity toward 270 direction, i.e. inner wall of bifurcation, and bounds back along either side of the tube.The auther believes that it is this secondary flow which makes (1)the 'shoulder' become stronger thus overcome the 'head', and (2)the existence of the second hump near the outer wall of bifurcation on the planes of S/D=2.548 and 3.635. (Fig. 6.10 to 6.12)

Figures 6.13 and 6.14 show profiles of S/D=4.135. Note that double humps are apparent in all directions and the flow peaks are going closer.

On the planes of S/D=5.333, 6.905 (Fig. 6.15, 6.16), the flow is gradually getting used to its new direction and is on its way toward a fully developed flow.

The flow patterns for the major and minor directions are given in Fig. 6.17, 6.18. Note the abrupt closing up as well as speeding up of the 90-270 peak to the inner wall and then gradually slowing down and returning to the centerline of the tube. Also note the boundary layer developing on the inner wall right after the flow divider.

A comparison of equal velocity lines showing the evolution of the wing-like contours is given in Fig. 6.19.

The results are summarized as follows:

(1) Inlet parabolic flow pattern at s=-3 in. (S/D=-4)

(2)Flow gradually retarded down near the center areas. This effect is less apparent in major direction than in the minor direction when it is in the expansion zone.

(3)Because of inertia, the high velocity is toward inner wall of bifurcation and a secondary flow is developed righ after the divider. This secondary flow is going from center portion to the inner wall and bounds back along both banks of the tube. (4)The head-down-shoulder-up pattern in 0-180 direction is because of retardation around center area and of the strong secondary flow mentioned in (3). (5)Instead of the usual slowing down, the peak velocity is first speeding up and moving toward the inner wall very fast right after the divider, and then gradually slowing down as well as moving toward the tube center.

(6)A second hump is gradually formed after divider in all but minor direction. This is due to the secondary flow mentioned in (3) above.

6.3 A COMPARISON WITH OLSON'S DATA

Using a hot wire anemometer, Olson conducted an extensive measurement on several model lung bifurcations. Velocity profiles of the major direction for the condition closest to ours is given in Fig. 6.20. Note that Olson used mean velocity and radius in the parent and daughter branches to nondimensionize velocities and radial lengths in the parent and daughter tubes respectively.

The differences between Olson's experiment and this work is noted in Table 6.2. As geometries of the two bifurcation is not totally comparable, similar nondimensionalization is not drawn to compare with Olson's figure.

Although there are quite a few differences, the results bear the following similar trends:

(1) High velocity is toward inner wall of bifurcation and gradually moving toward center. (2) Second hump appearance and wing-like velocity profile exist after the flow divider.

The conclusion is: The difference in inlet pattern seems to matter little downstream of the divider, althrough it does dominate upstream the divider.

TABLE 6.1

LIST OF MEASURED PLANES

S(in.)	S/D	(S/D)o*
-3	-4	-5.905
0	0	-1.905
.471	.628	-1.277
.942	1.256	-0.649
1.174	1.565	-0.34
1.429	1.905	0
1.911	2.548	0.643
2.726	3.635	1.73
3.101	4.135	2.23
4	5.33	3.425
5.179	6.905	5

* OLSON'S EQUIVALENT (S/D), SEE NOTES ON TABLE 6.2.

TABLE 6.2

COMPARISON OF PARAMETERS FOR OLSON'S AND SHEU'S DATA

	OLSON'S	SHEU'S
Appratus type	hot-wire	LDA
Mother tube size	2π I.D.	0.75π I.D.
Daughter tube size	1.5π	0.75π
Total branch angle	70 deg.	73 deg.
Curvature ratio*	1/7	1/8
Reynolas No.(mother)	468	∼320
Reynolds No.(daughter)	311	∼160
Position of origin**	0 at divider	0 at beginning of curvature

NOTE: * Curvature Ratio= (radius of mother tube)/(radius of centerline curve)

** So+1.429=S

(S/D)o+1.905=(S/D)

where So, S=tubewise displacement for Olson's and Sheu's system (in.)

(S/D)o,(S/D)=nondimensionalized tubewise displacement for the two systems

= -3

/b = -4

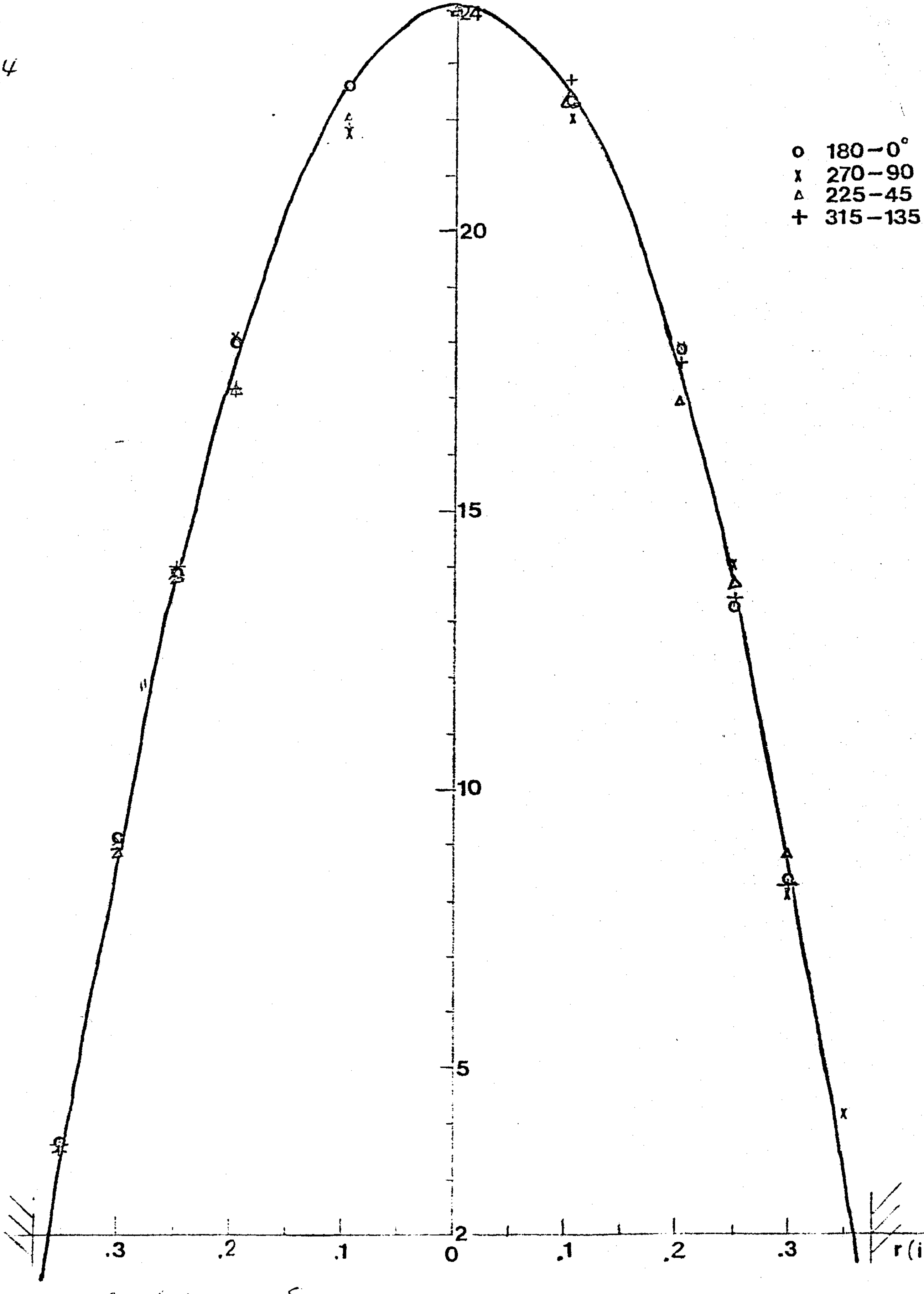
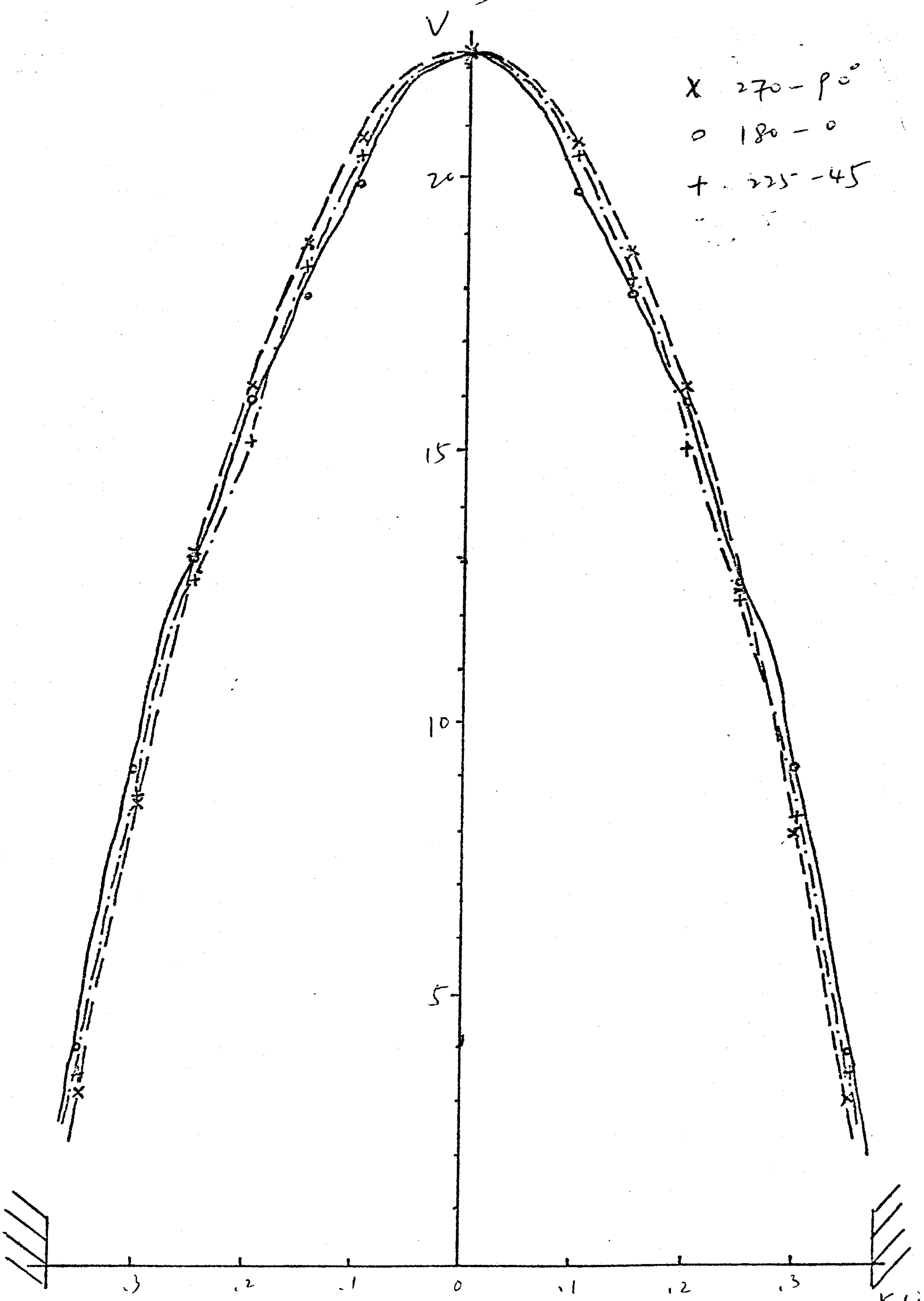
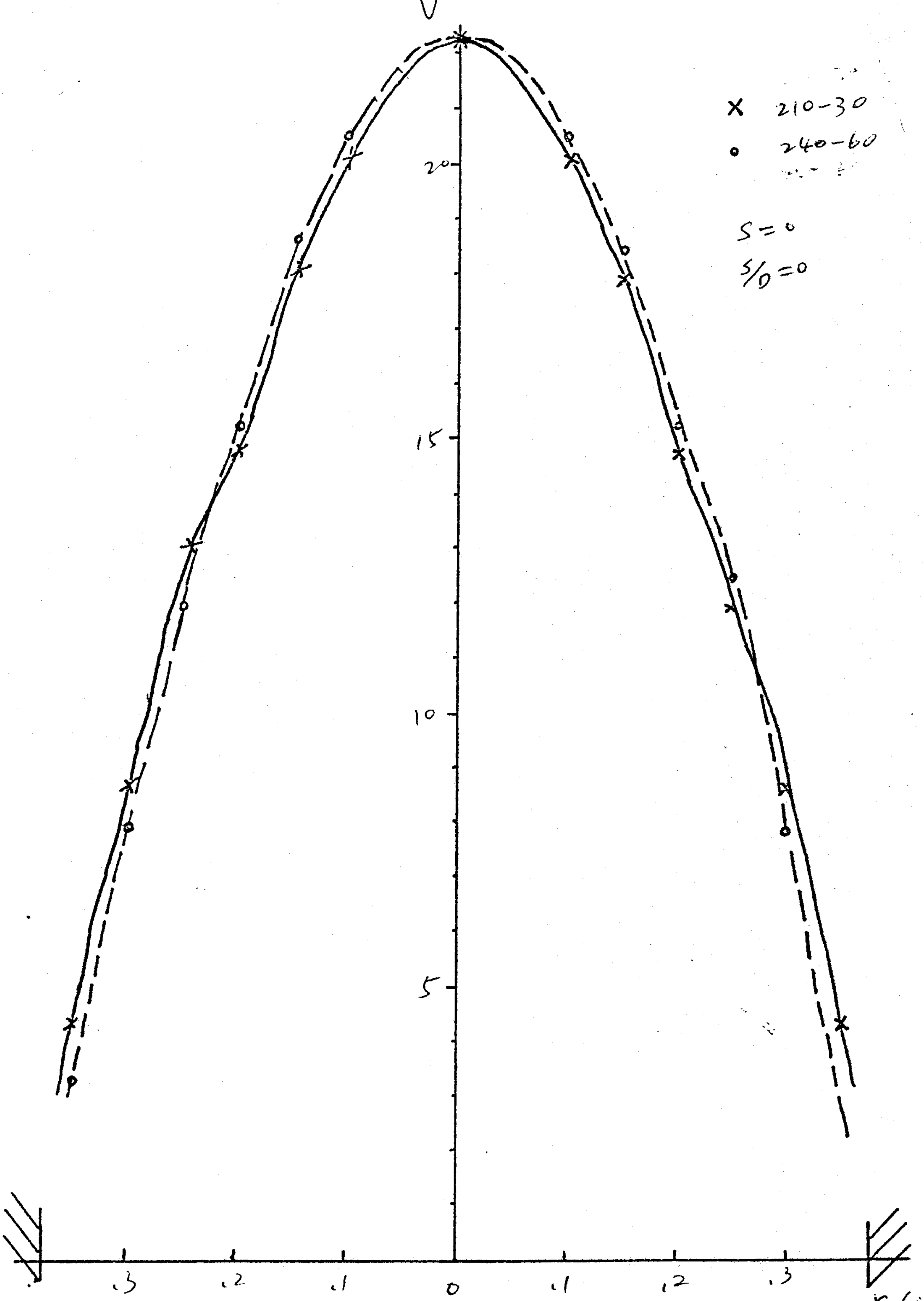


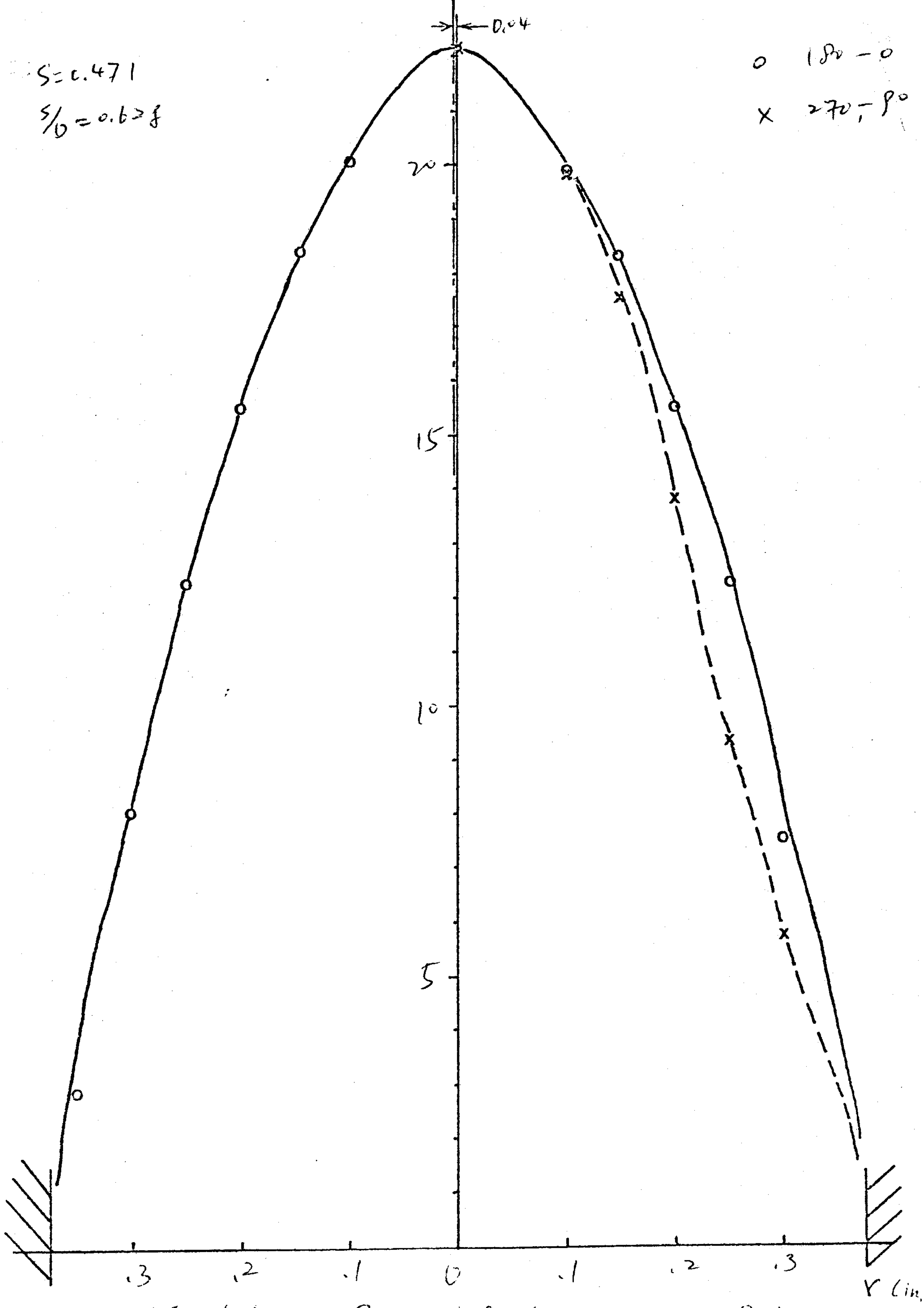
FIG 6.1 S/b = -4



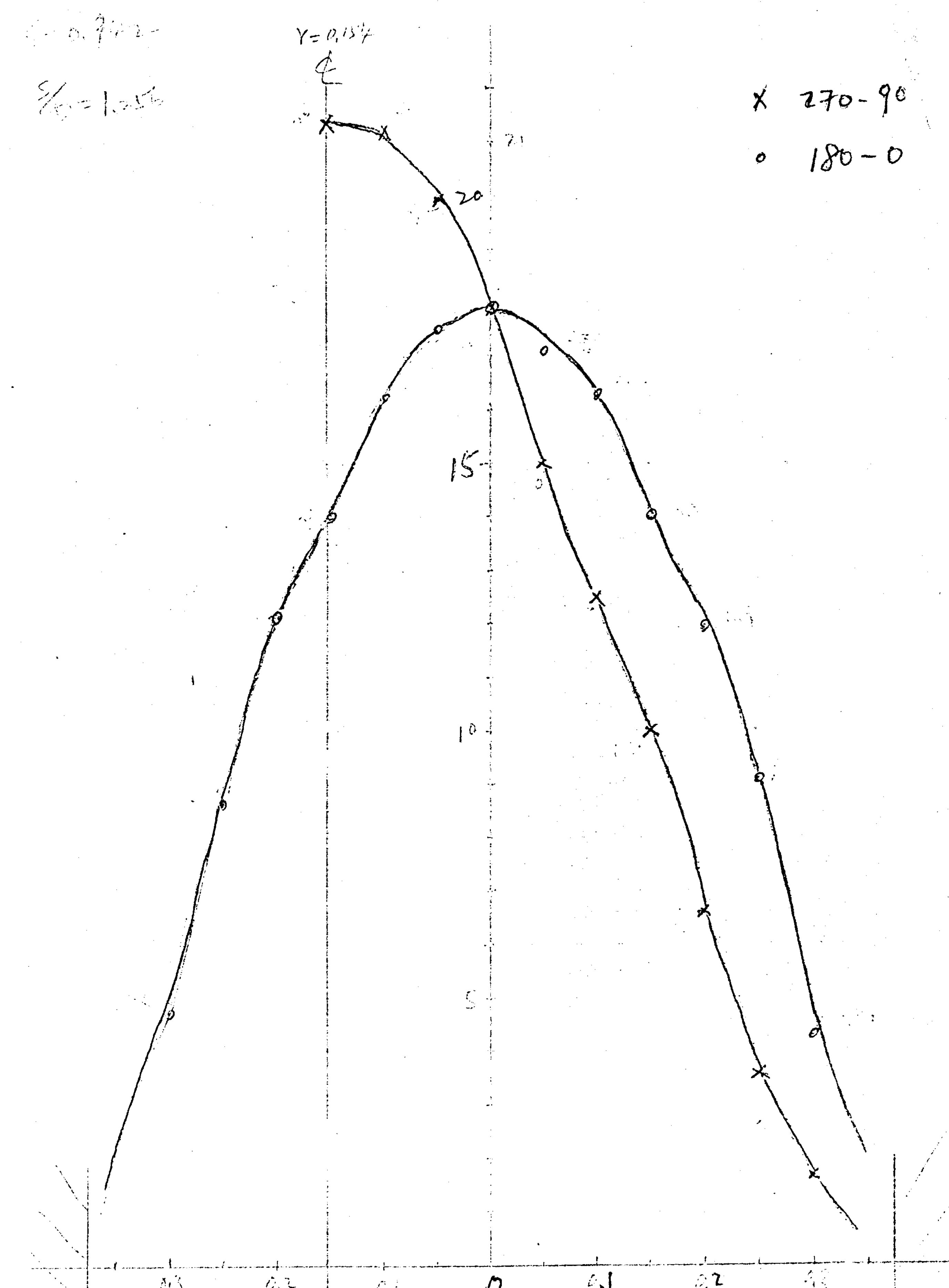
V
x 270 - 90°
o 180 - 0
+ 225 - 45
20
15
10
5
.3
.2
.1
0
.1
.2
.3



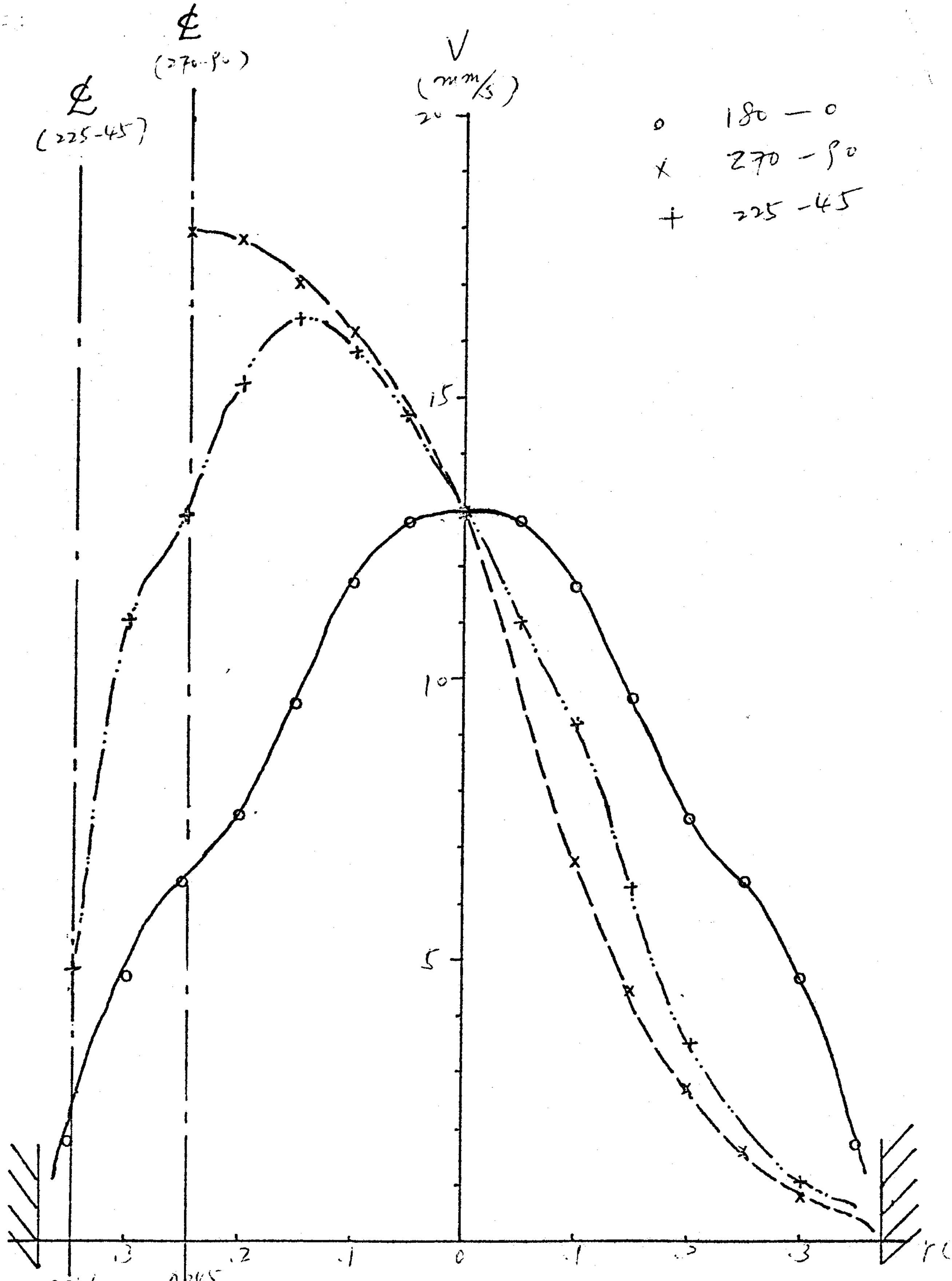
× 210-30
∘ 240-60
S = 0
S/D = 0
20
15
10
5
.3
.2
.1
0
.1
.2
.3

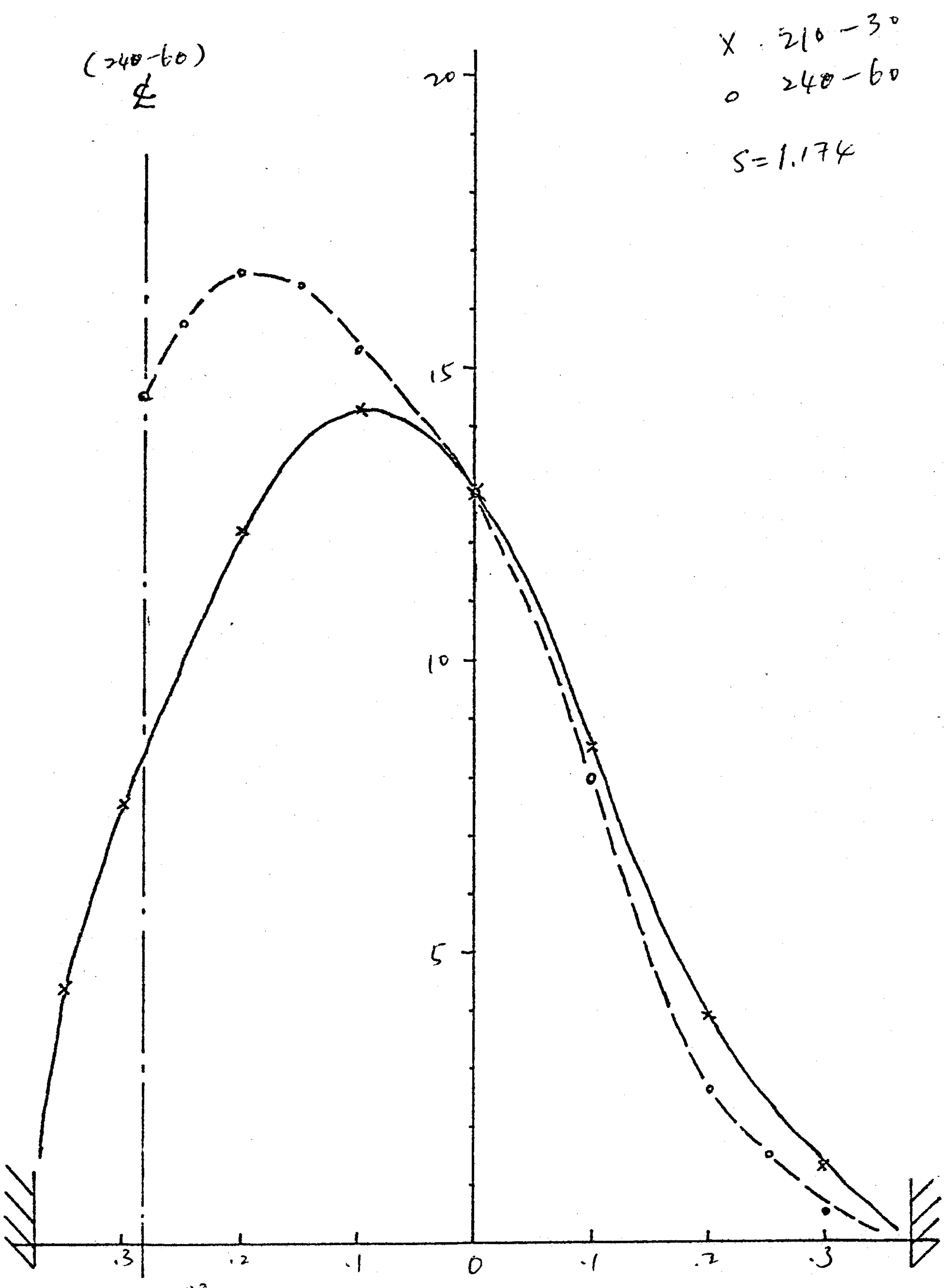


S=0.471
S/D=0.62=f
0 180-0
x 270-90
0.04
20
15
10
5
.3
.2
.1
0
.1
.2
.3
r (in.)



Y = 0.154
℄
× 270-90
∘ 180-0
20
15
10
5
0


℄
(270-90)
℄
(225-45)
V
(mm/s)
20
15
10
5
o 180 — 0
x 270 — 90
+ 225 — 45
.3
.2
.1
0
.1
.2
.3
0.346
0.265



(240-60)
℄
X 210-30
o 240-60
S=1.174
20
15
10
5
.3
.2
.1
0
.1
.2
.3

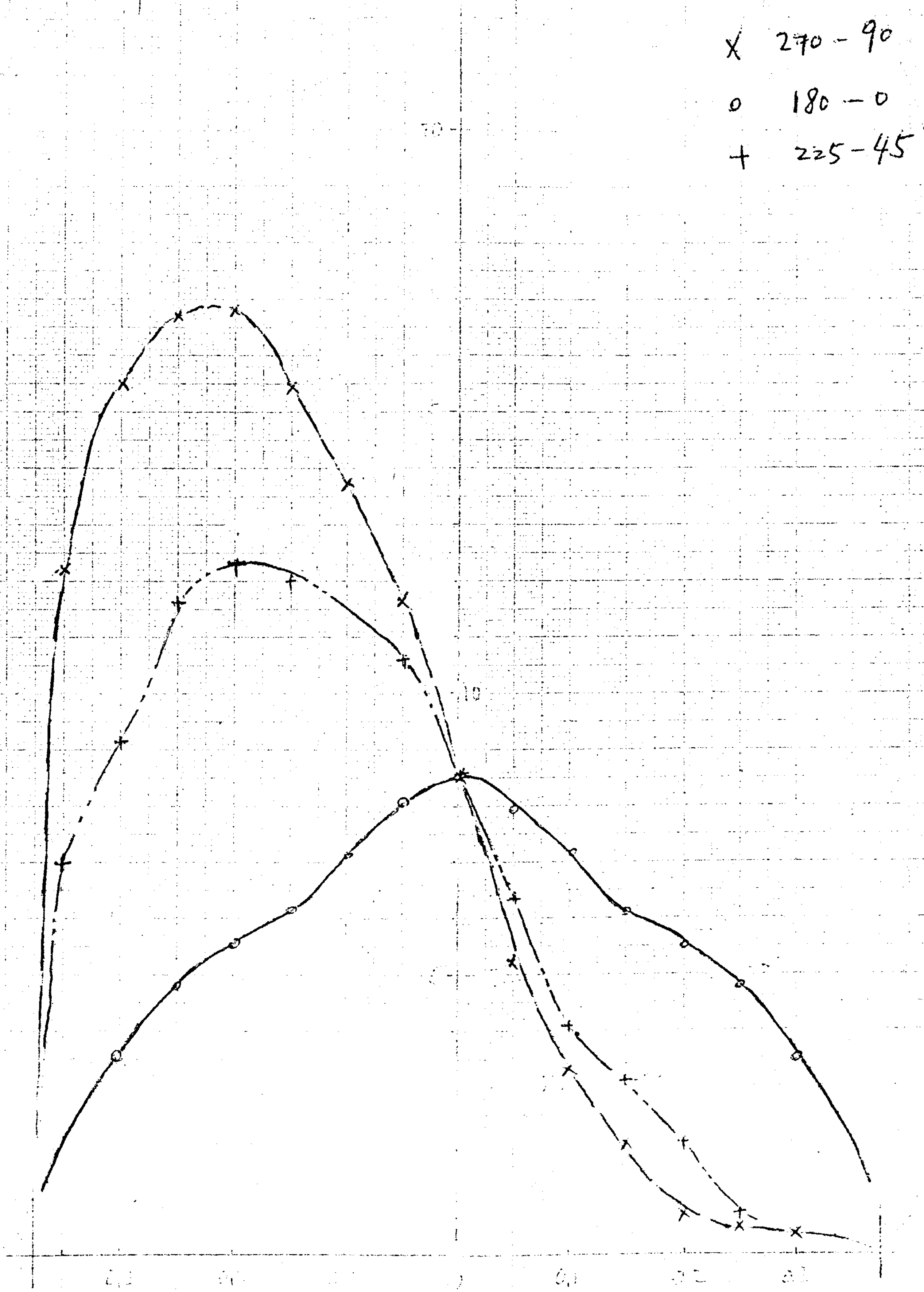


FIG. 6.8 S = 1.429 , S/D = 1.905

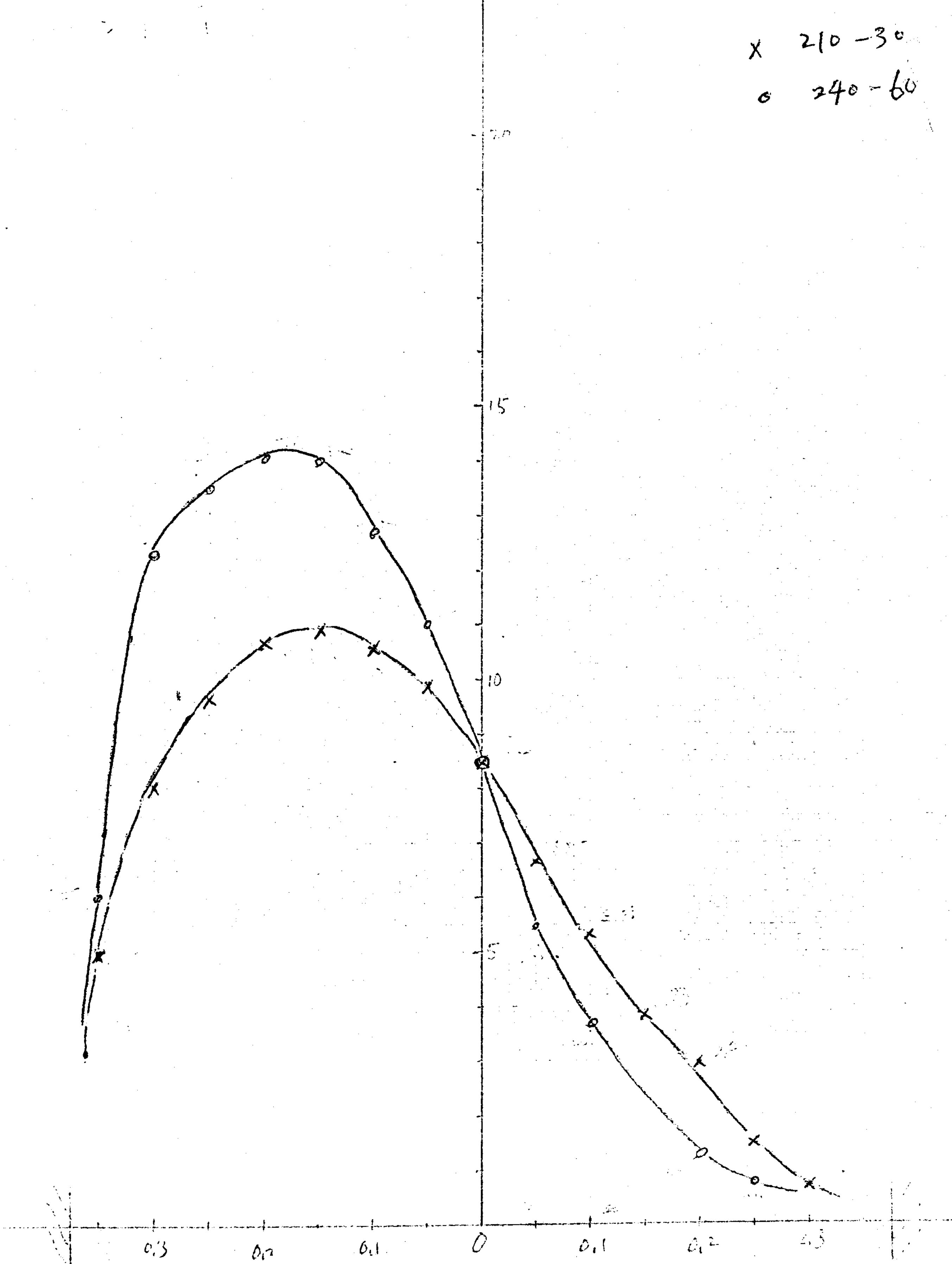


FIG 6.9 $S = 1.429$, $S/D = 1.905$

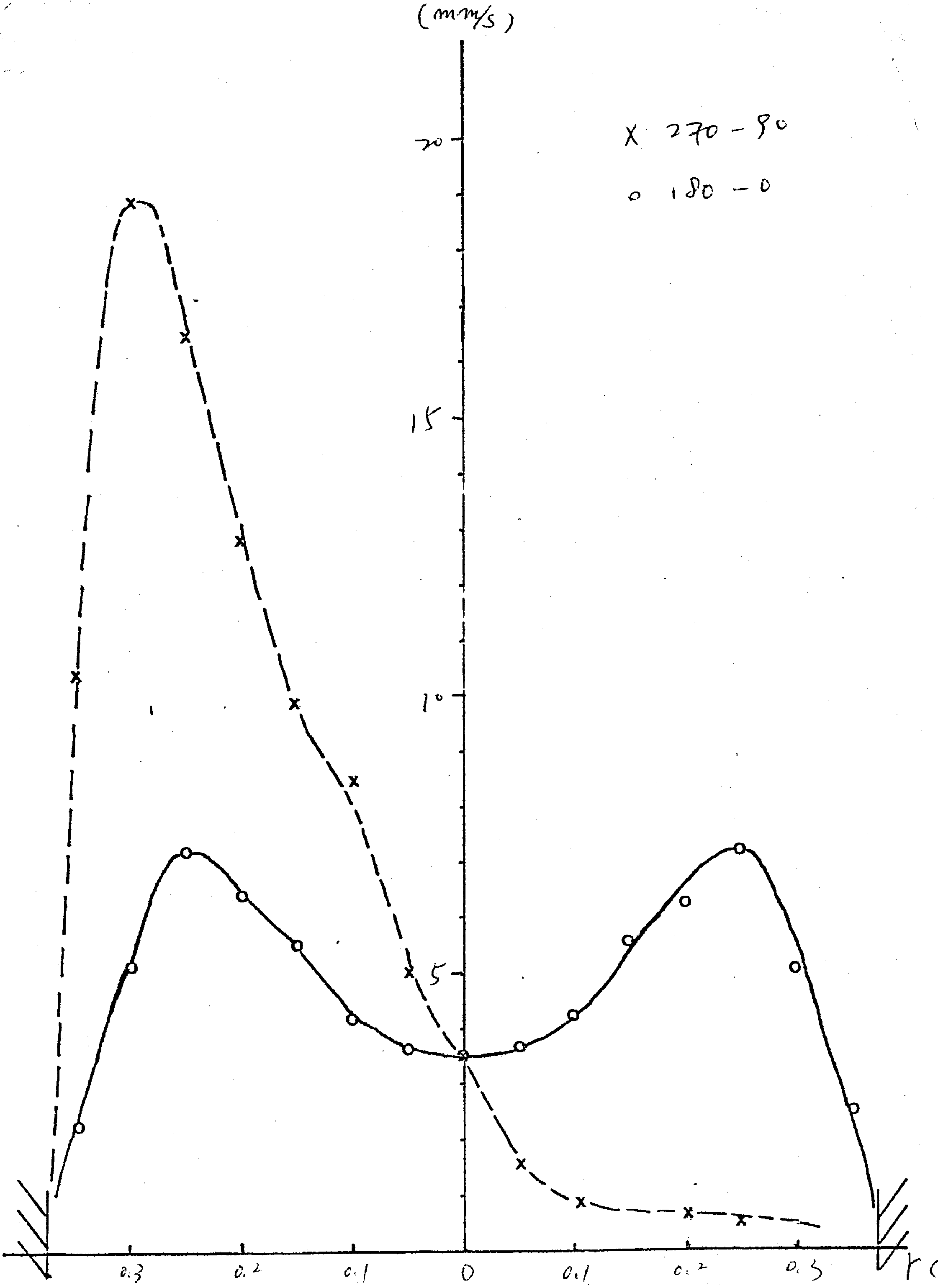


FIG. 6.10 $S = 1.911$, $S/D = 2.548$

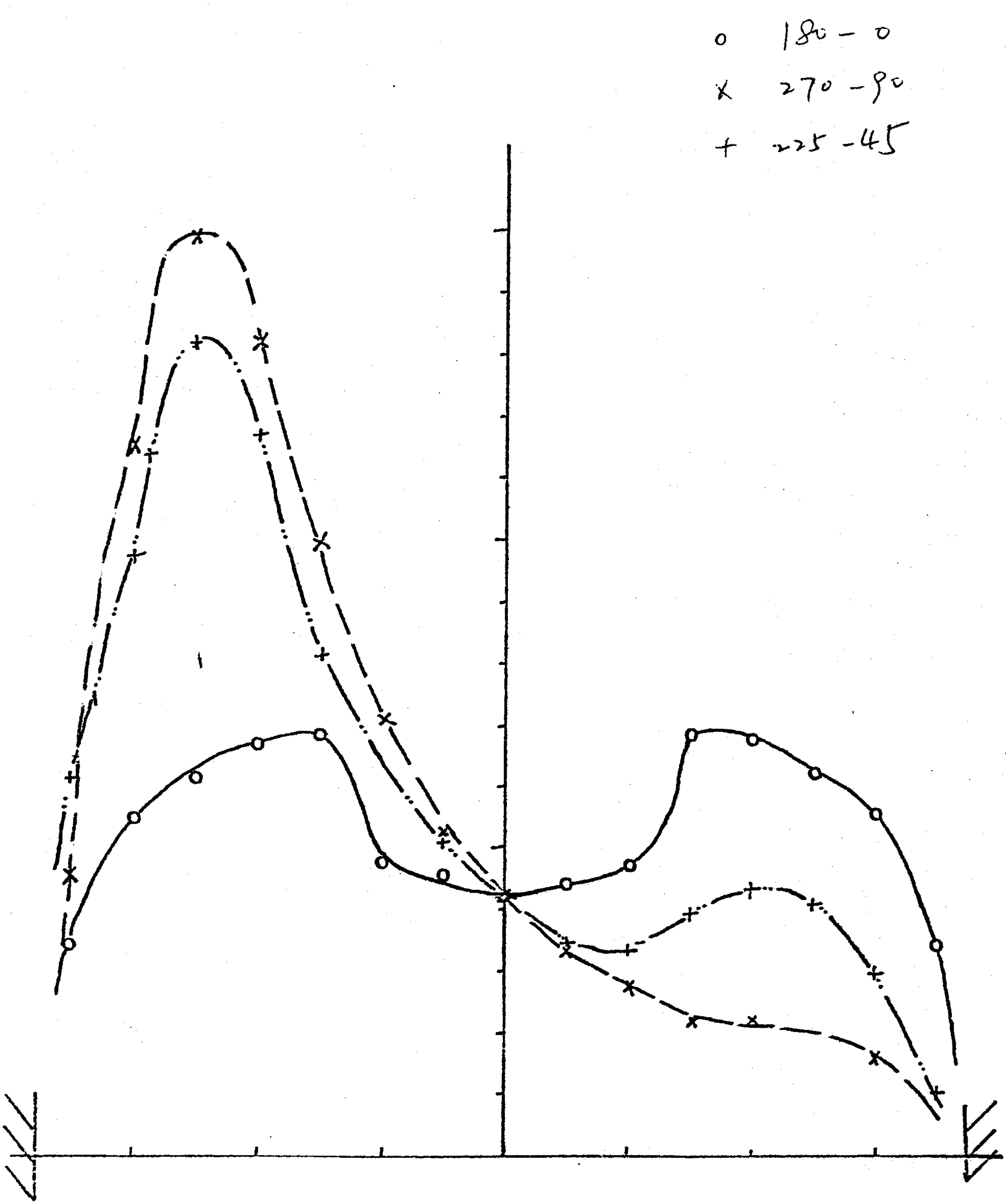
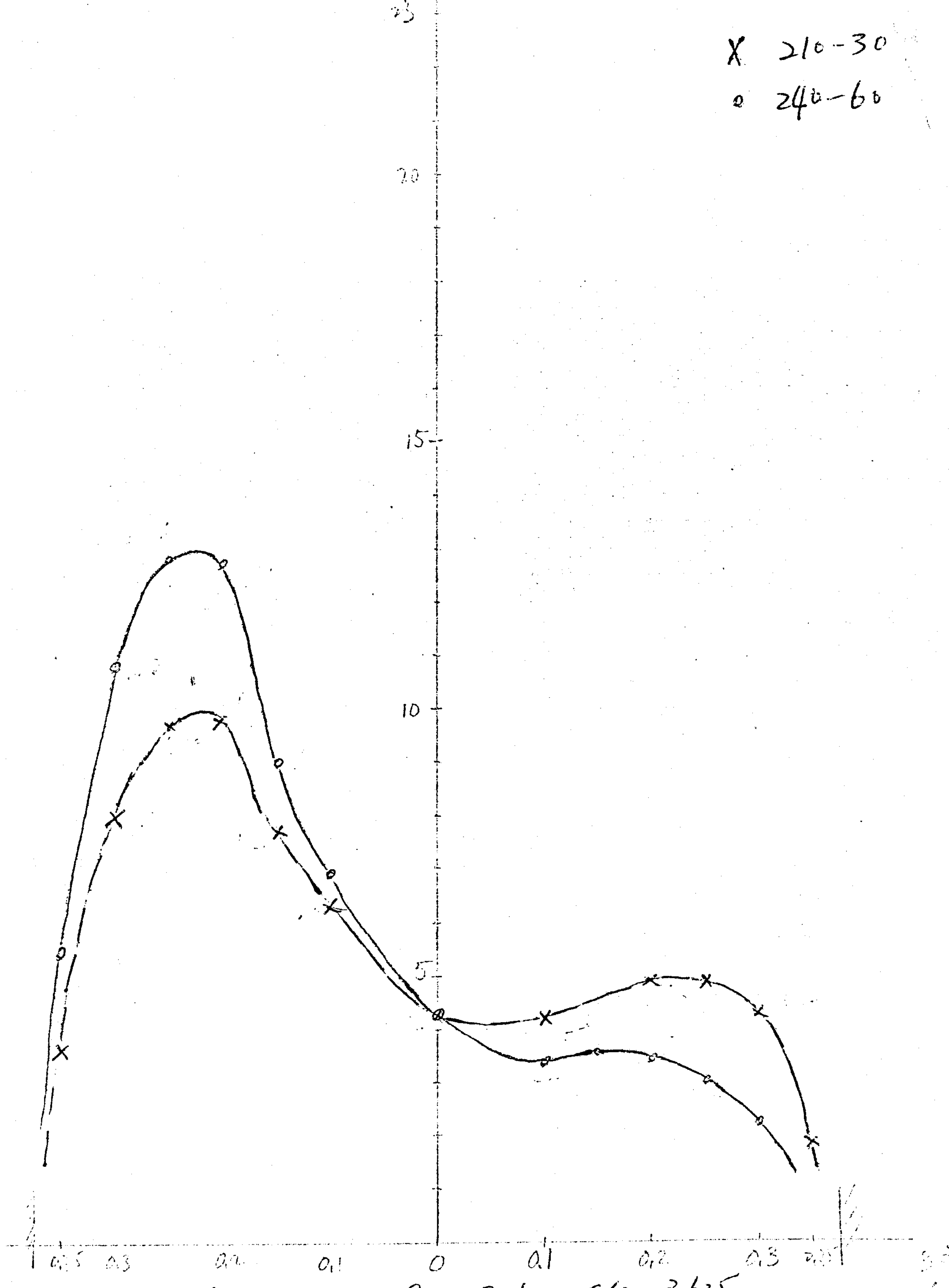


FIG. 6.11 S = 2.726, S/D = 3.635

(180-0, 270-90, 225-45)



X 210-30
o 240-60
20
15
10
5
0.3
0.2
0.1
0
0.1
0.2
0.3

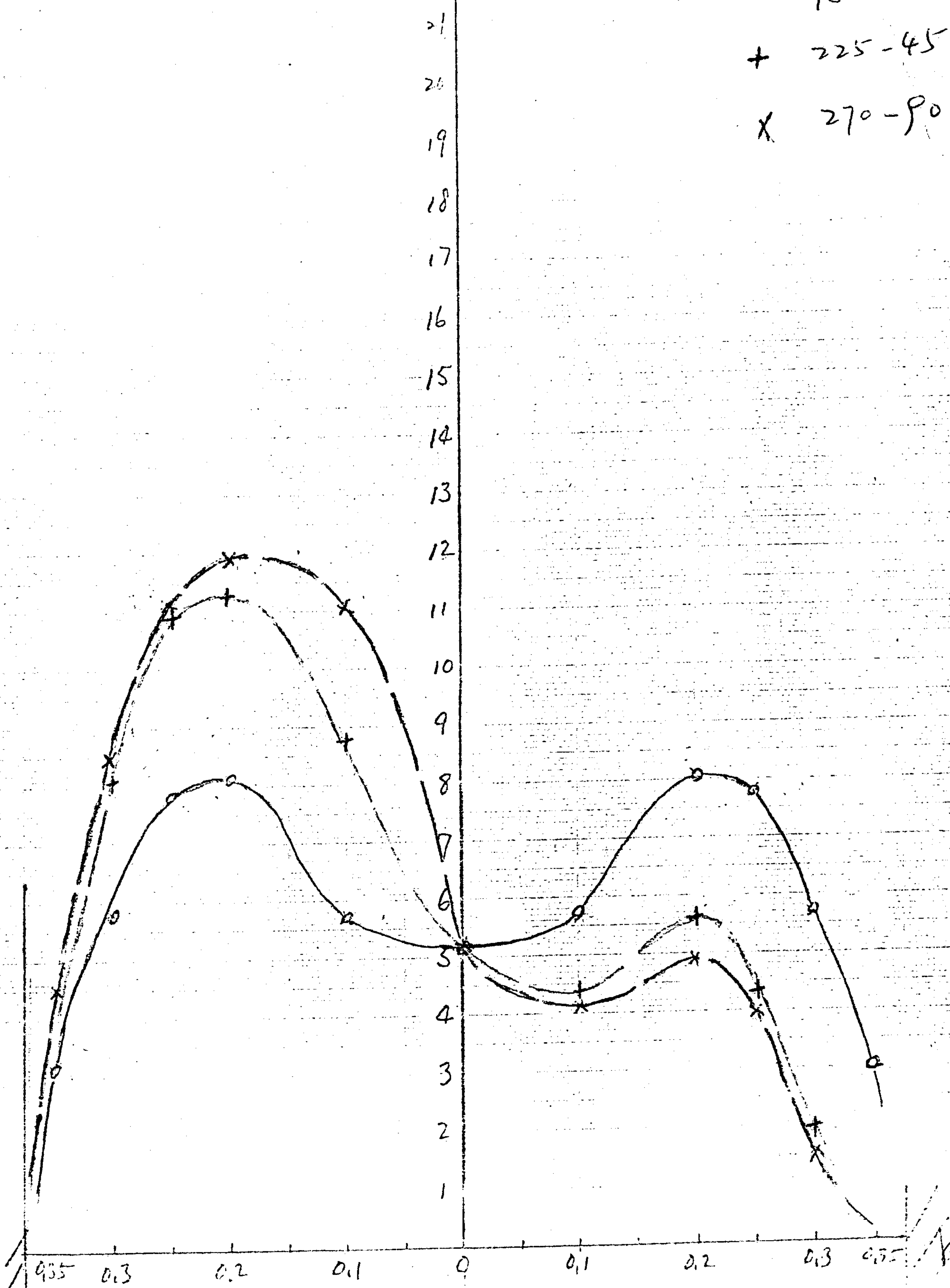
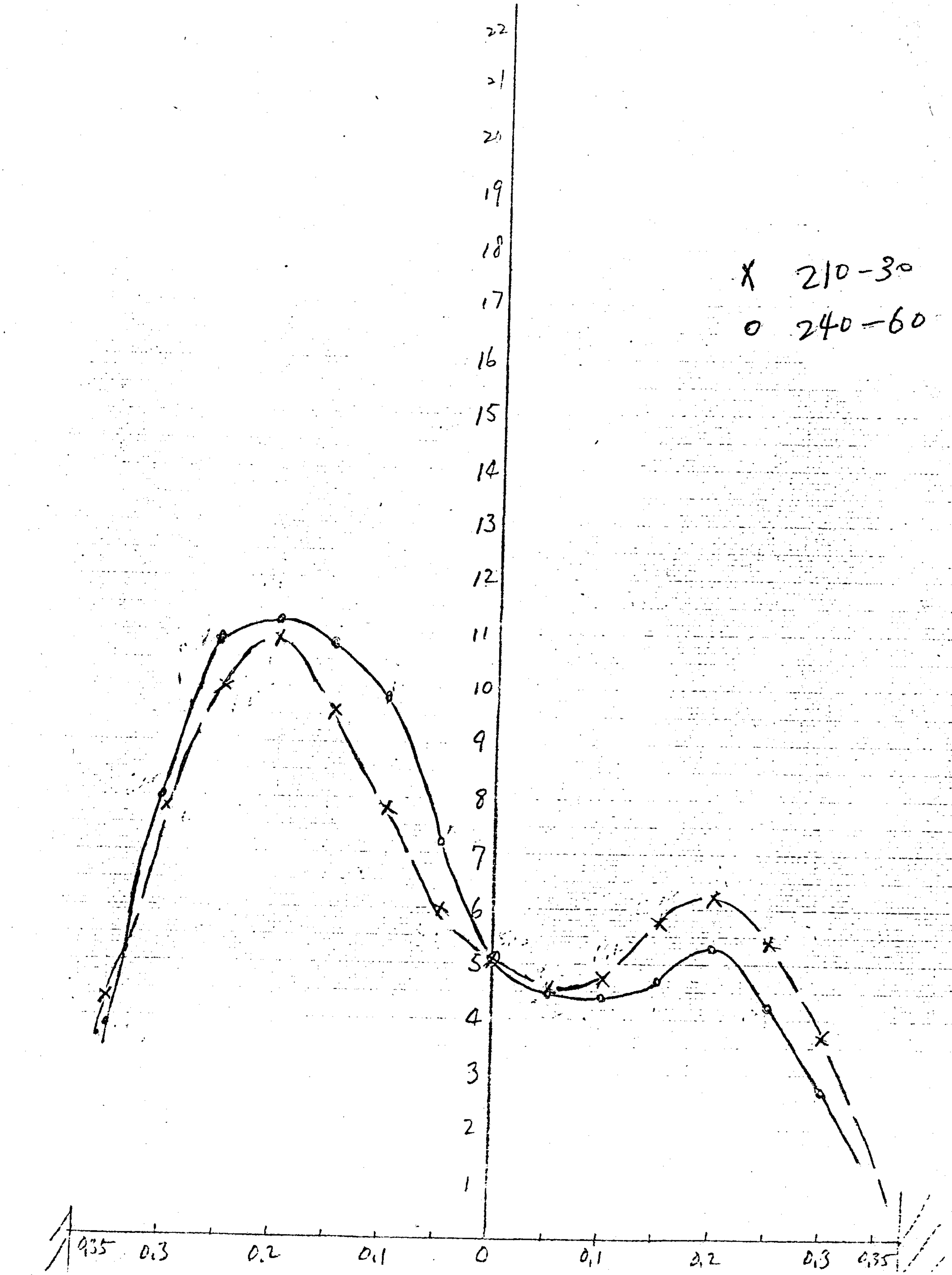


FIG. 6.13 ; S = 3.101 ; S/0 = 4.135



X 210-30
o 240-60
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0.35
0.3
0.2
0.1
0
0.1
0.2
0.3
0.35

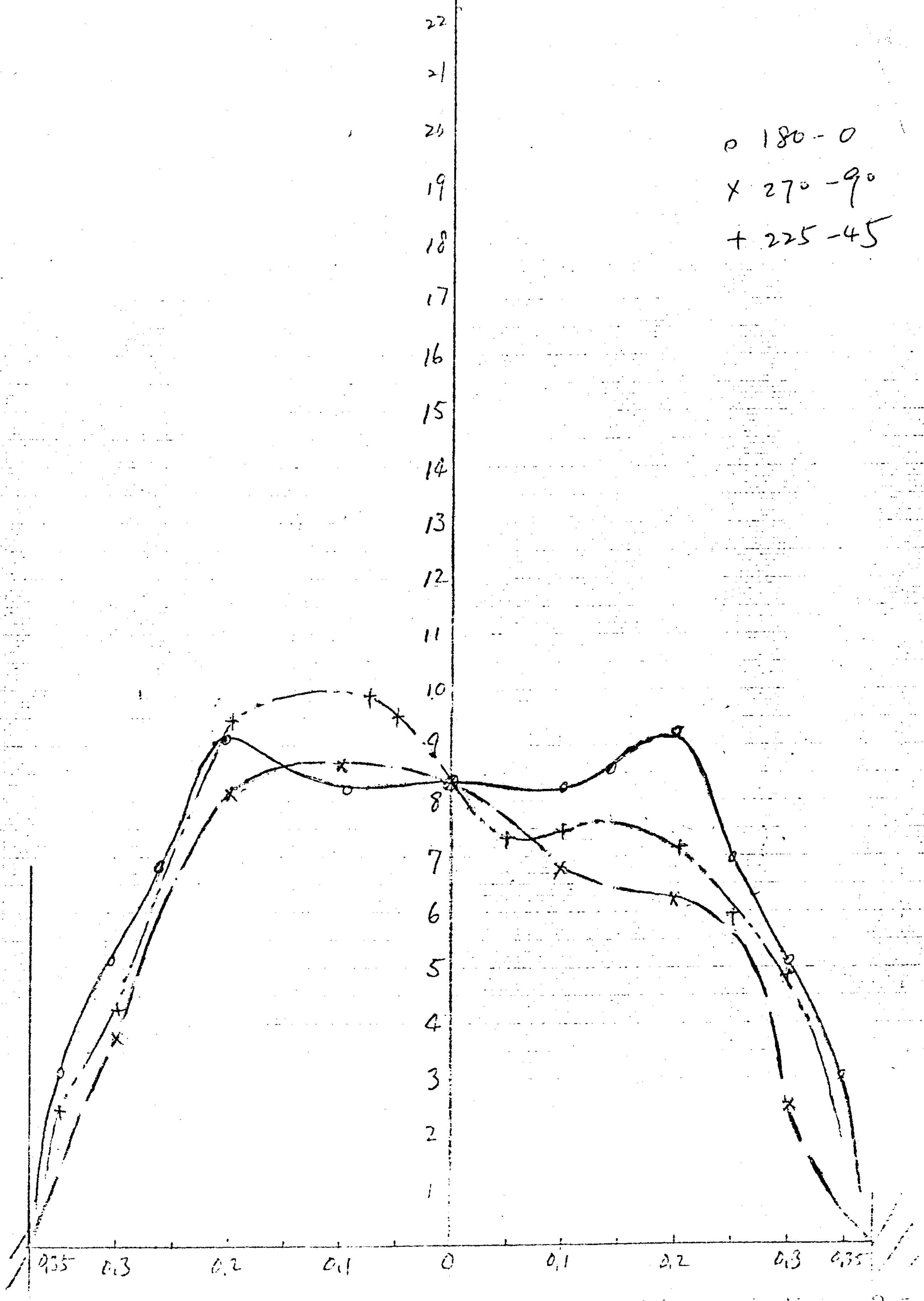
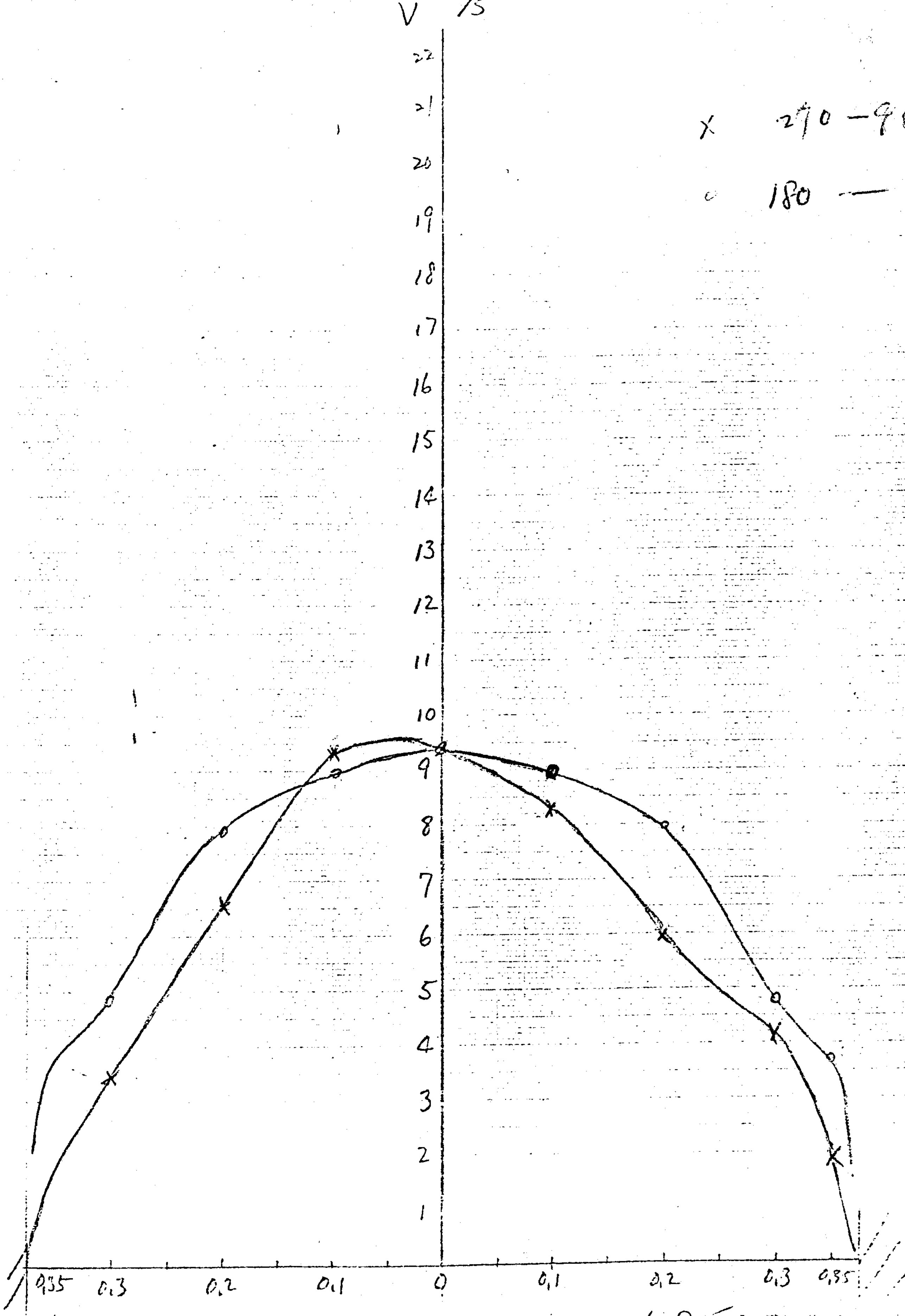
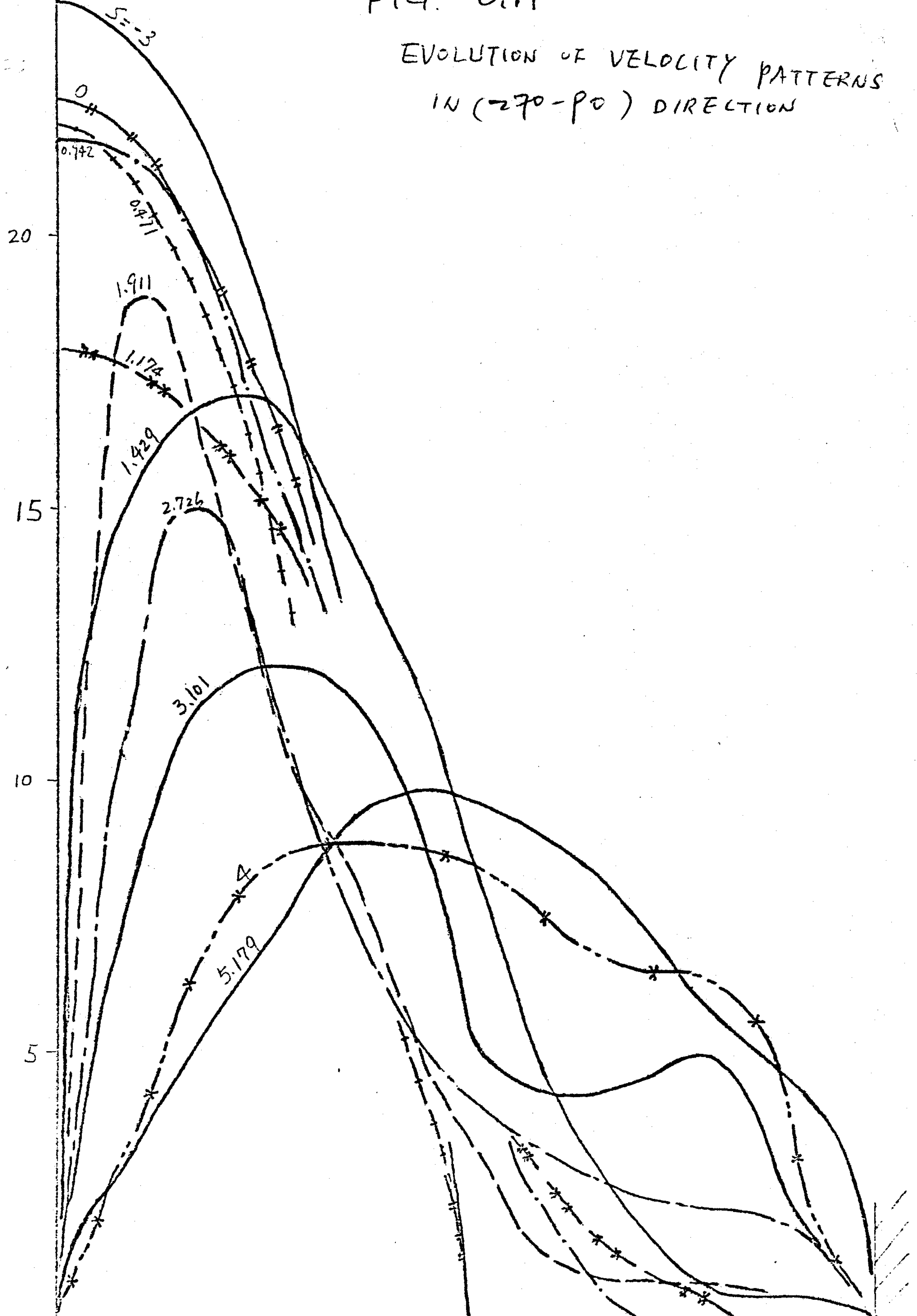


FIG 6.15 S = 4 S/D = 5.333 90


V
15
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0,35
0,3
0,2
0,1
0
0,1
0,2
0,3
0,35
× 270 – 9
○ 180 —



EVOLUTION OF VELOCITY PATTERNS IN (270-P0) DIRECTION

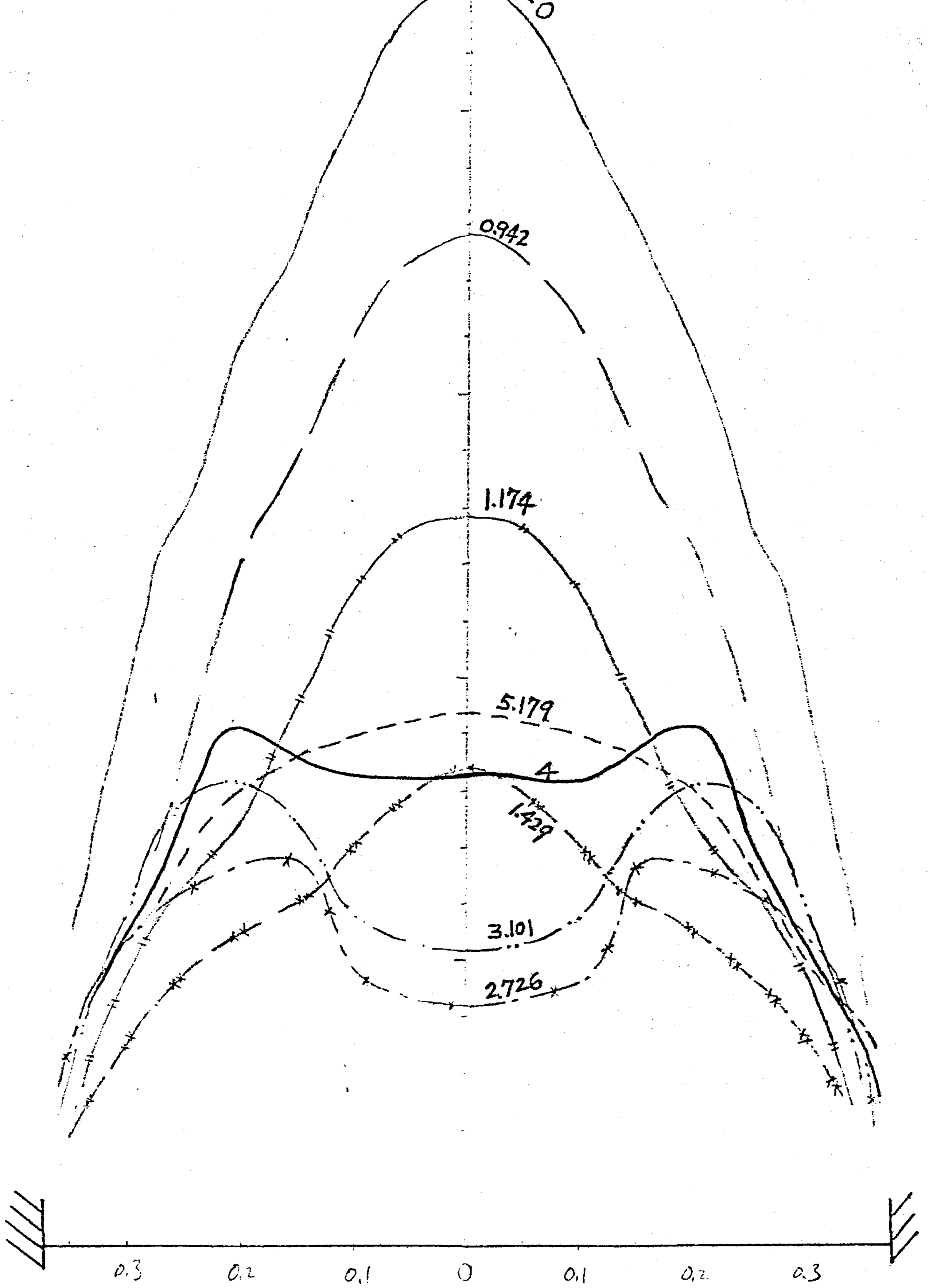
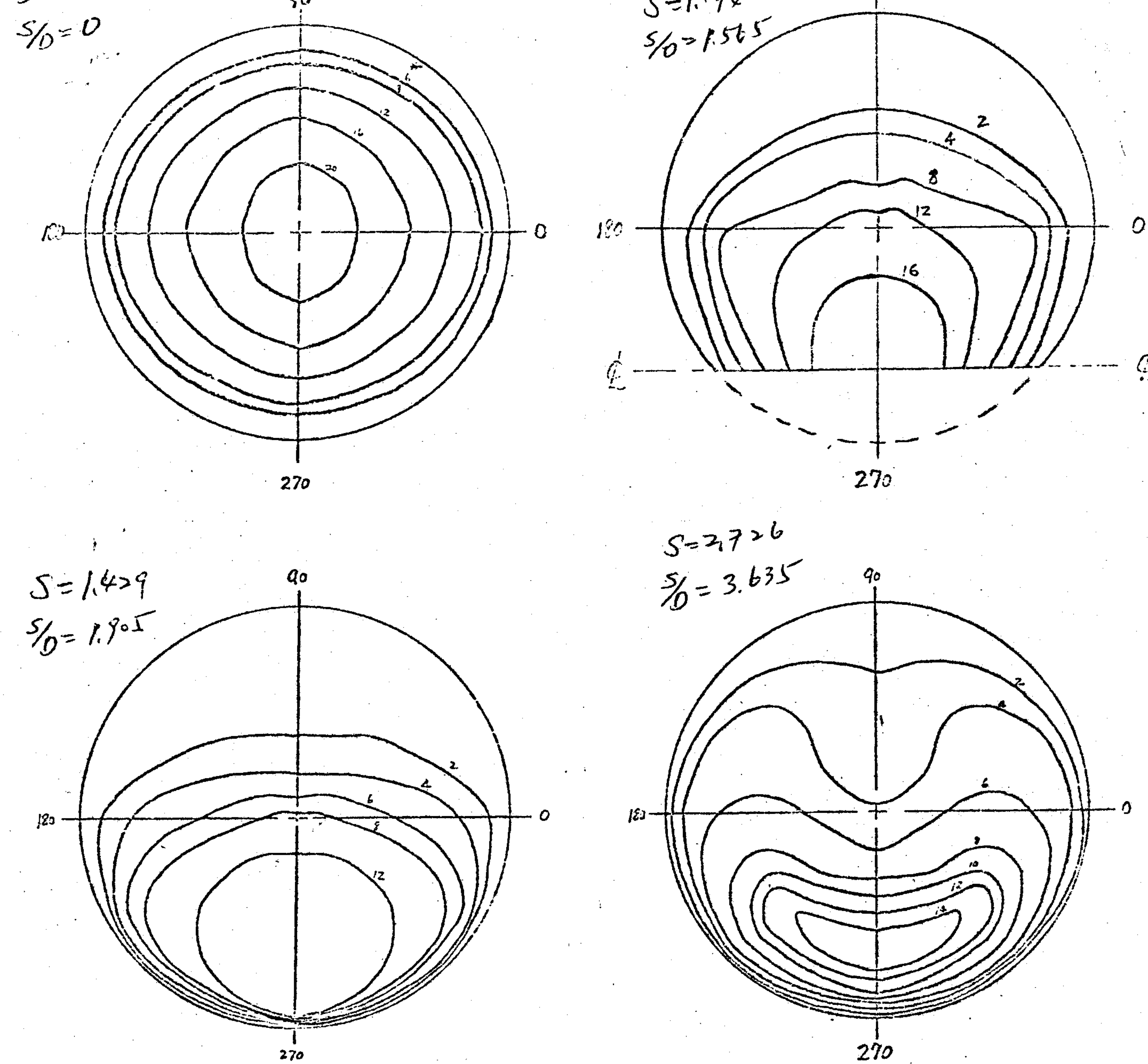


FIG. 6.18 EVOLUTION OF PATTERNS IN



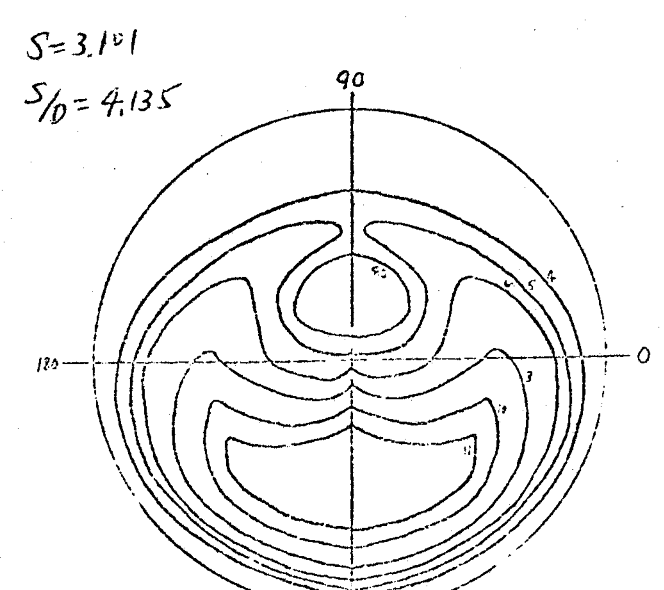


FIG. 6.19
EVOLUTION OF EQUAL
VELOCITY CONTOURS

* Numbers shown are velocitie[s]
in mm/s

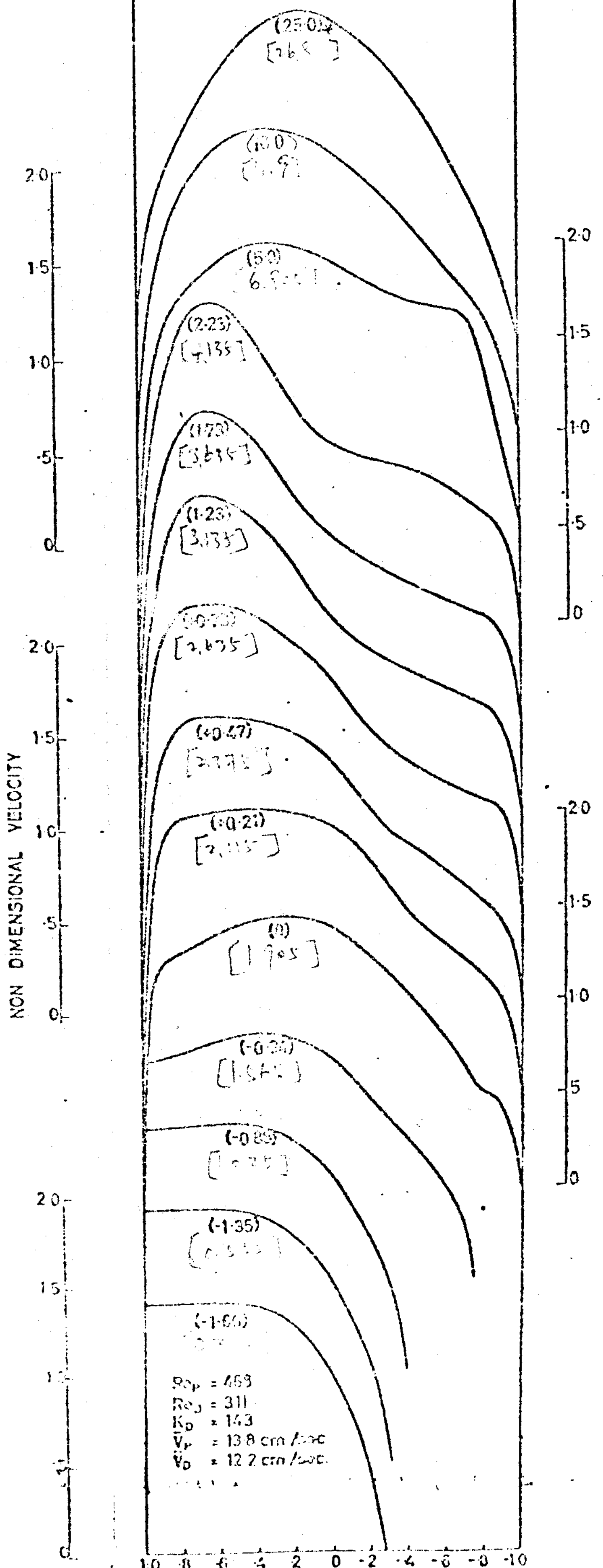


FIG. 6.20
OLSON'S DATA ON MAJOR AXES

* Numbers in parentheses are (S/D). Numbers in brackets are (S/D) based on Sheu's system

CHAPTER 7

CONCLUSION AND FURTHER INVESTIGATIONS

7.1 SUMMARY AND CONCLUSIONS

A forward scattered LDA system with frequency shifter and tracking type signal processor is used here to measure the flow field in a model lung bifurcation. The system was established so that probe positioning and data acquisition are controlled by a PDP-11/34 minicomputer and a SDK-85 micropressor, thus making on-line measurement possible.

The tubewise component of the laminar flow pattern with parabolic inlet condition at about 320 Reynolds number is measured. The divider was found to have a very dominant effect around its vicinity and within five diameters downstream A higher velocity was detected near the inner wall of bifurcation. The flow was found to have 'heaa-shoulder', 'second hump', and 'wing-like' features. These features are contributed by flow inertia and its consequential secondary flow acting on the flow divider. A comparison of the flow pattern in the major direction with Olson's 'hot-wire' data is made. The different situations between the two measurements are noted. Discrepancies in the inlet flow pattern have far less effect on the downstream flow than the divider does.

7.2 SUGGESTED FURTHER INVESTIGATIONS AND COMMENTS

The following paragraphs are comments and suggestions for further investigations:

(1) Velocity measurement on the other two directions:

Measurement on the primary component of the flow field has been carried out here. The other two components can be expressed in either radial/tangential or major/minor axes directions.

According to the present apparatus arrangement, only the directions lying on the plane perpendicular to the axis of optics assembly can be measured. Therefore only one more component can be measured in either choice of coordinates. The third component may be obtained analytically through thecontinuity equation.

Following a similar approach shown in section 3.2, it is possible to pinpoint the beam intersection inside the tube when two beams are in the plane perpendicular to the tube axis. Care shall be taken to examine the actual direction measured, because the beam crossing has, in most cases, been tilted by the curved interface.

(2)Measuring the pulsatile respiration:

Measurement on the pulsatile inspiration/ expiration conditions can be achieved through the following additional measures:

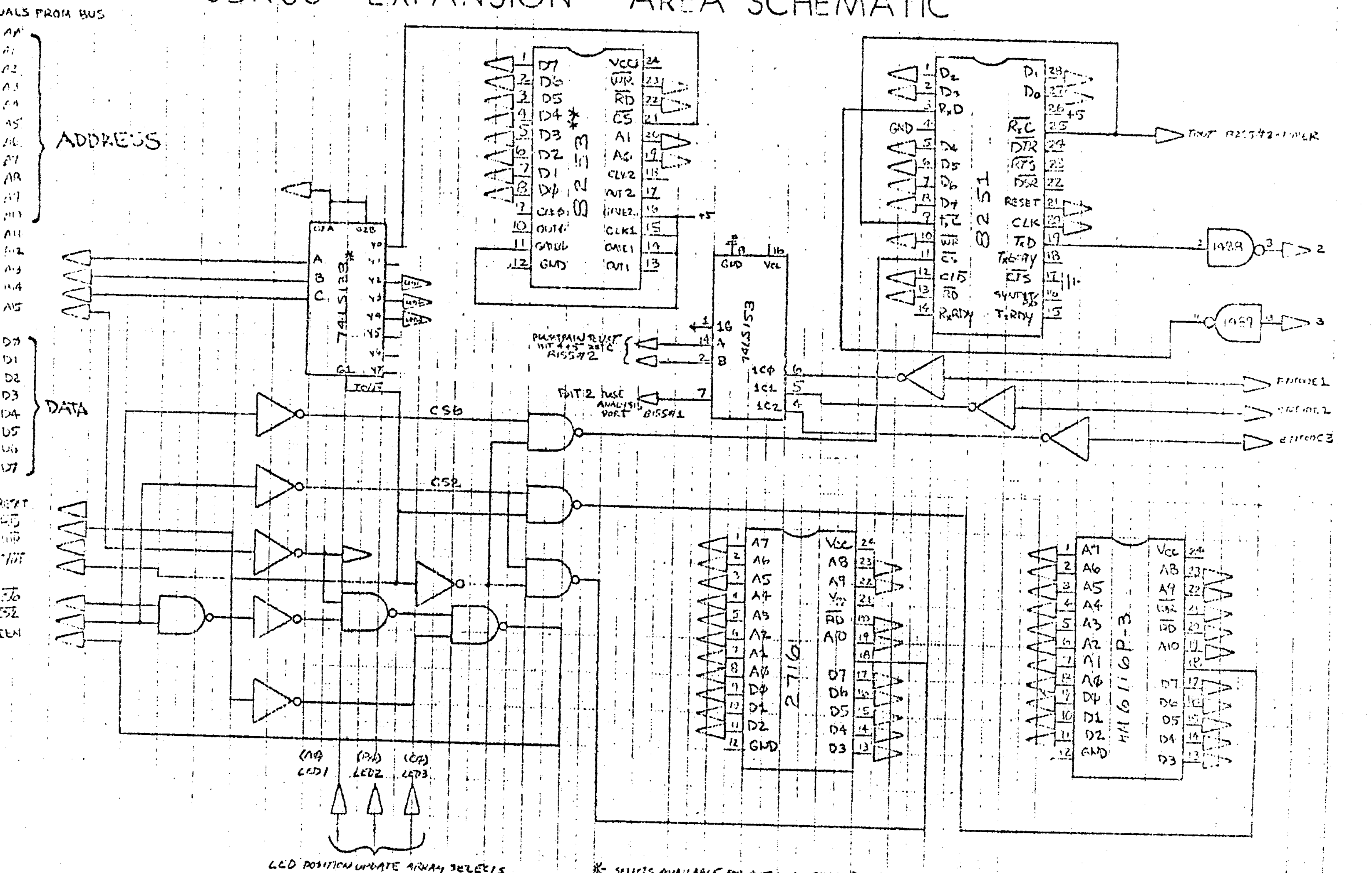
a)Couple the four-way cock in the flow system to a bi-directional motor and link the motor to the microprocessor through any unused port.

b)Include a counting loop in SDK-85 program and periodically reverse the flow direction by alternately rotating the motor. The period can be included in the command sent from PDP-11.

c)Handshakings between the PDP-11 and the SDK-85 shall be established.

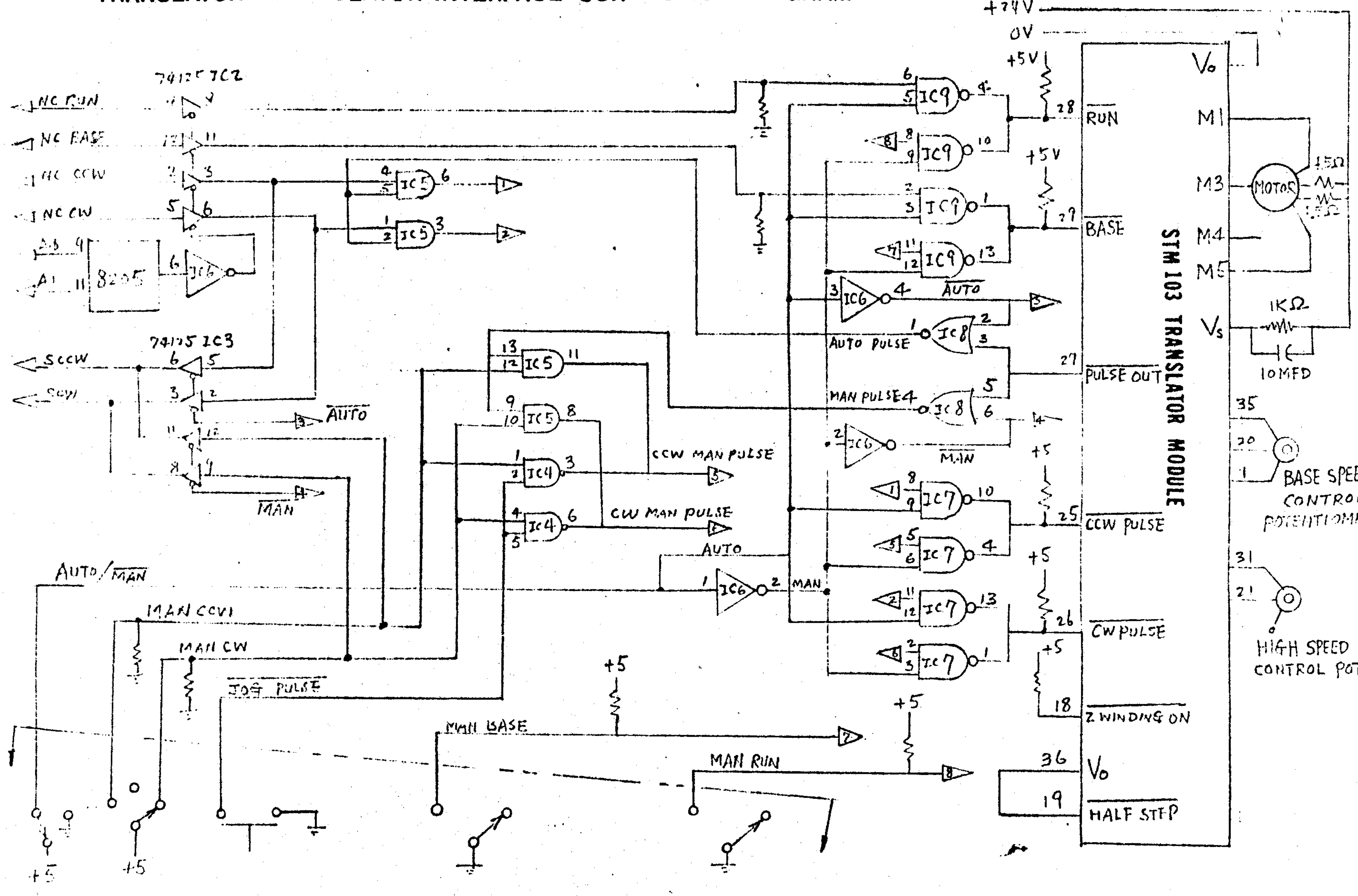
APPENDIX 1

SDK85 EXPANSION AREA SCHEMATIC



APPENDIX 2

TRANSLATOR & TRANSLATOR INTERFACE CONNECTION DIAGRAM



SWITCHES ON FRONT PANNEL

APPENDIX 3

STEPPER MOTOR DRIVING MODE

The stepper motor is controlled by its corresponding STM 103 SLO-SYN translator module.

The three modes are as follows:

(1)Full Step With Two Windings On

This mode drives the motor in steps of 1.8 degrees. The motor windings are energized in the following sequence for clockwise rotation:

FULL-STEP, TWO WINDINGS ON

SWITCHING STEP	MOTOR LEAD OR TERMINAL			
	RED (1) *	WHITE/RED (3)	WHITE/GREEN (4)	GREEN (5)
1	ON	OFF	OFF	ON
2	ON	OFF	ON	OFF
3	OFF	ON	ON	OFF
4	OFF	ON	OFF	ON
1	ON	OFF	OFF	ON

(2)Full Step With One Winding On

This mode drives the motor in steps of 1.8 degrees. The motor windings are energized in the following sequence for clockwise rotation:

FULL-STEP, ONE WINDING ON

SWITCHING STEP	MOTOR LEAD OR TERMINAL			
	RED (1)	WHITE/RED (3)	WHITE/GREEN (4)	GREEN (5)
1	OFF	OFF	OFF	ON
2	ON	OFF	OFF	OFF
3	OFF	OFF	ON	OFF
4	OFF	ON	OFF	OFF
1	OFF	OFF	OFF	ON

(3)Half Step (One Winding On)

This mode drives the motor in steps of 0.9 degree. The motor windings are energized in the following sequence for clockwise rotation:

HALF STEP

SWITCHING STEP	MOTOR LEAD OR TERMINAL			
	RED (1) *	WHITE/RED (3)	WHITE/GREEN (4)	GREEN (5)
1	OFF	OFF	OFF	ON
2	ON	OFF	OFF	ON
3	ON	OFF	OFF	OFF
4	ON	OFF	ON	OFF
5	OFF	OFF	ON	OFF
6	OFF	ON	ON	OFF
7	OFF	ON	OFF	OFF
8	OFF	ON	OFF	ON
1	OFF	OFF	OFF	ON

NOTE: a) Only mode (3) was hardware wired.

b) * (1),(3),(4),(5) correspond to M1,M3,M4,M5 on translator module (See Appendix 2.)

c) If necessary, the direction of motor rotation convention can be reversed by reversing the motor lead connections at terminals M4 and M5.

APPENDIX 4

I/O PORT & BIT ASSIGNMENT FOR MICROPROCESSOR

I/O PORT ASSIGNMENT:

(1)ON 8251A (USART):

SYSTEM PORT #	FUNCTION
#10	I/O to PDP-11
#11	Command/Mode/Status reg.

(2)ON 8155A#1:

SYSTEM PORT #	FUNCTION
#20	C/S Reg.
#21 (port A)	unused
#22 (port B)	unused
#23 (port C)	pulse analysis reg. (receive pulse from encoder)
#24,25	timer used by system monitor to support LED's & keypad

(3)ON 8155A#2:

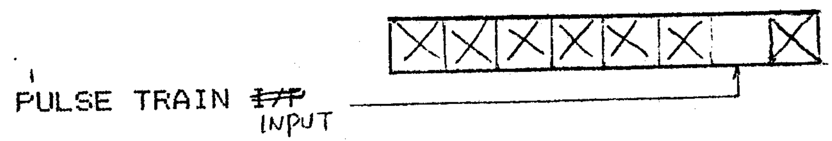
SYSTEM PORT #	FUNCTION
#28	C/S Reg.
#29 (port A)	translator status reg.
#2A (port B)	translator control reg.
#2B (port C)	multipurpose reg. (only pulse train select used)
#2C,2D	timer,baud rate sel. for USART

(4)ON 8255#1 TO #3:

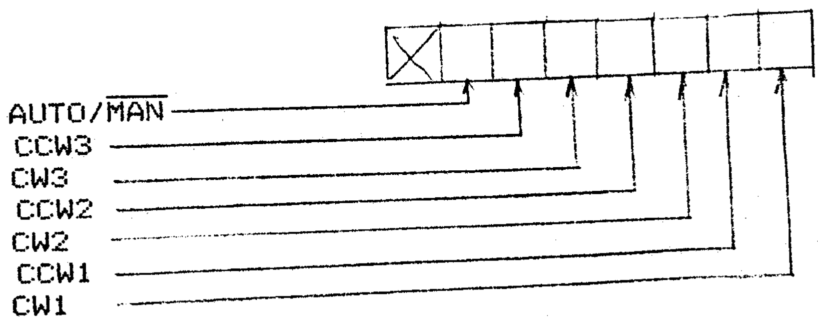
SYSTEM PORT #	FUNCTION
#A0,A1,A2 (P A,B,C)	ports for LED display, axis #1 (on 8255#1)
#A3	control for 8255#1
#B0,B1,C2 (P A,B,C)	ports for LED display, axis #2 (on 8255#2)
#B3	control for 8255#2
#C0,C1,C2 (P A,B,C)	ports for LED display, axis #3 (on 8255#3)
#C3	control for 8255#3

BIT ASSIGNMENT:

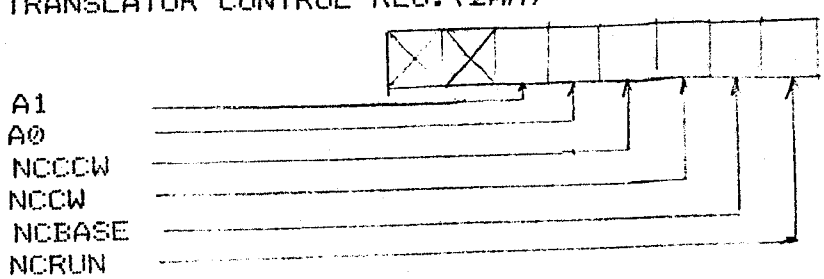
(1)PULSE TRAIN REGISTER(23H)



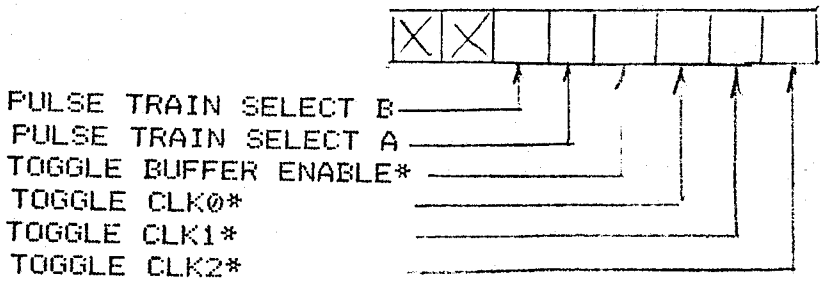
(2)TRANSLATOR STATUS REG.(29H)



(3)TRANSLATOR CONTROL REG.(2AH)



(4)MULTIPURPOSE REG.(2BH)



* UNUSED

APPENDIX 5
PIN ASSIGNMENT

NOTE: This section lists detail pin assignment on translator interface card and the blue flat cable socket connecting SDK-85 and translator cage.

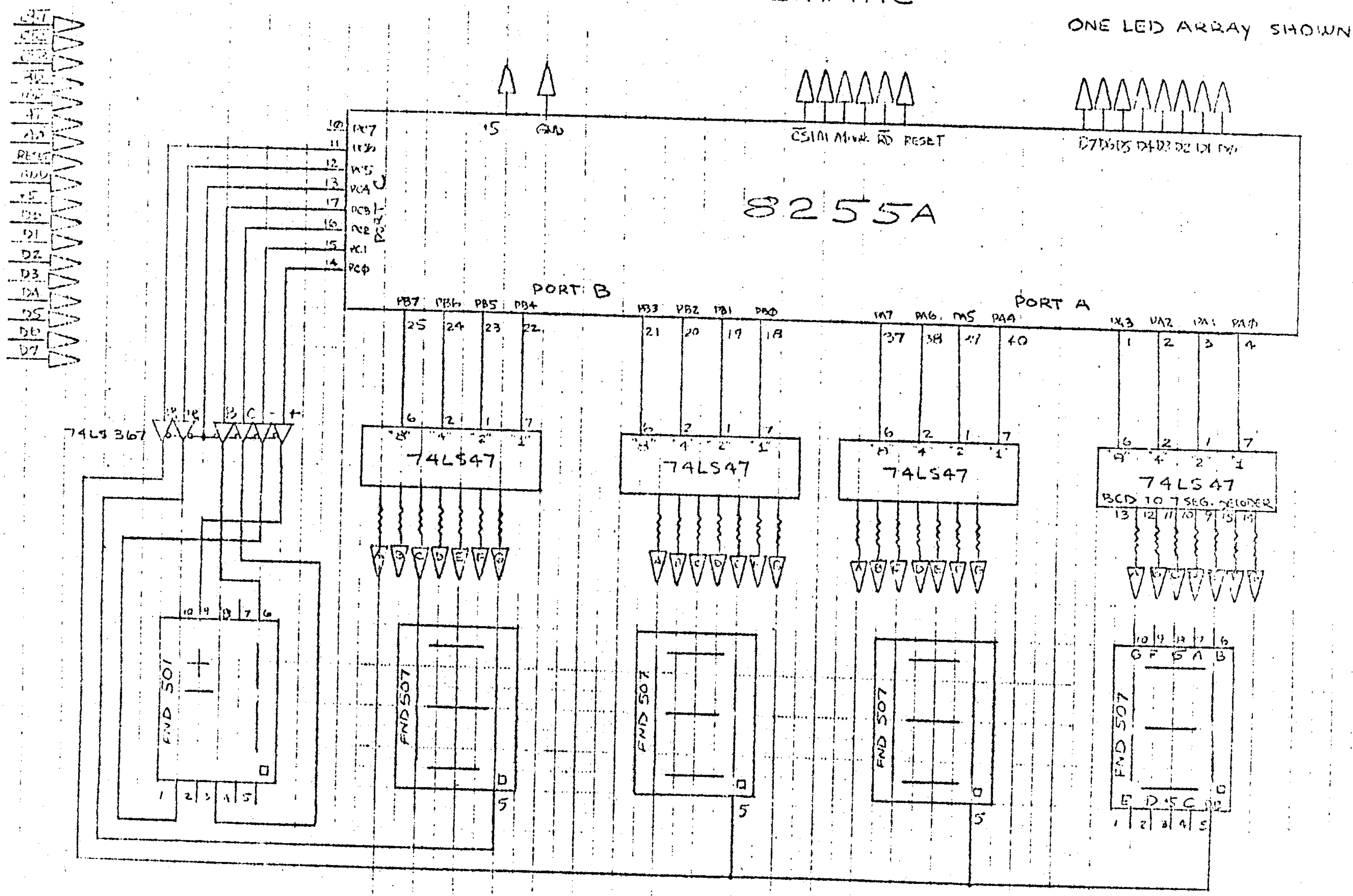
ON TRANSLATOR INTERFACE:

PIN NO.	FUNCTION	PIN NO.	FUNCTION
A,B	+5 V	C	A0
D	A1	E	NCRUN
F	NCBASE	H	NCCW
blank	NCCCW	K	UNUSED
M	AUTO/MANUAL	N	MAN RUN
P	MAN BASE	R	MAN CW
blank	MAN CCW	T~blank	UNUSED
U,W,X	UNSED	Y,Z	GROUND
1	RUN(TO TRANSLATOR)	2	BASE("" "")
3	CCW("" "")	4	CW("" "")
5	PULSE TRAIN (FROM TRANSLATOR)		

ON FLAT CABLE SOCKET(CAGE END):

PIN NO.	FUNCTION	PIN NO.	FUNCTION
1--6	+5V	7	A0
8	A1	9	NCRUN
10	NCBASE	11	NCCW
12	NCCCW	13--18	STATUS REG.
19	AUTO/MAN	20	MAN RUN 1
21	MAN BASE 1	22	MAN CW 1
23	MAN CCW 1	24	JOG(UNUSED)
25	PULSE TRAIN FROM ENCODER 1		
26	UNUSED	27	MAN RUN 2
28	MAN BASE 2	29	MAN CW 2
30	MAN CCW 2	31	UNUSED
32	PULSE TRAIN FROM ENCODER 2		
33	UNUSED	34	MAN RUN 3
35	MAN BASE 3	36	MAN CW 3
37	MAN CCW 3	38	UNUSED
39	PULSE TRAIN FROM ENCODER 3		
40-44	UNUSED	45-50	GROUND

LED INTERFACE SCHEMATIC



APPENDIX 5
PIN ASSIGNMENT

NOTE: This section lists detail pin assignment on translator interface card and the blue flat cable socket connecting SDK-85 and translator cage.

ON TRANSLATOR INTERFACE:

PIN NO.	FUNCTION	PIN NO.	FUNCTION
A,B	+5 V	C	A0
D	A1	E	NCRUN
F	NCBASE	H	NCCW
blank	NCCCW	K	UNUSED
M	AUTO/MANUAL	N	MAN RUN
P	MAN BASE	R	MAN CW
blank	MAN CCW	T~blank	UNUSED
U,W,X	UNSED	Y,Z	GROUND
1	RUN(TO TRANSLATOR)	2	BASE("" "")
3	CCW("" "")	4	CW("" "")
5	PULSE TRAIN (FROM TRANSLATOR)		

ON FLAT CABLE SOCKET(CAGE END):

PIN NO.	FUNCTION	PIN NO.	FUNCTION
1--6	+5V	7	A0
8	A1	9	NCRUN
10	NCBASE	11	NCCW
12	NCCCW	13--18	STATUS REG.
19	AUTO/MAN	20	MAN RUN 1
21	MAN BASE 1	22	MAN CW 1
23	MAN CCW 1	24	JOG(UNUSED)
25	PULSE TRAIN FROM ENCODER 1		
26	UNUSED	27	MAN RUN 2
28	MAN BASE 2	29	MAN CW 2
30	MAN CCW 2	31	UNUSED
32	PULSE TRAIN FROM ENCODER 2		
33	UNUSED	34	MAN RUN 3
35	MAN BASE 3	36	MAN CW 3
37	MAN CCW 3	38	UNUSED
39	PULSE TRAIN FROM ENCODER 3		
40-44	UNUSED	45-50	GROUND

```
C=========================LUNG.FTN==========================================
C       4/3/83  D.SHEU IN TURBULENCE RESEARCH LABORAYORY
C       THIS IS A MAIN PROGRAM FOR INVESTIGATION ON MODELED LUNG
C       BIFURCATION
C       SUBROUTINE CALLED:CAL.FTN,PARAM.FTN,ATOD.FTN,ANA.FTN,TALK.FTN
C         SUBPROGRAM CALLED BY ATOD.FTN: ADPHX.MAC
C       --All section delimited by C*** is to remedy 'Dead Zone' on MOVE.SRC
C               which receives position command  from TALK.FTN
C         MOVE.SRC was written by Bryan Howe and originally named MSME.SRC
C==========================================================================
        PROGRAM LUNG                                   !SUBPROGRAMS INVOLVED:
        COMMON /POSPAR/N1,N2,N3,B,A0                   !CAL
        COMMON /MAXMIN/XMIN,XMAX,YMIN,YMAX,ZMIN,ZMAX   !CAL
        COMMON /SITE/X,Y,Z,RD,DTHETA,SKEW,STD,XMARK    !CAL,TALK,ANA
        COMMON /ANGLES/THET1,THET2,THET3               !CAL,PARAM
        COMMON /XDATA/FACT,SHIFT,FRQT(512),DATA(512),VEL(512),CLOCK
                                                       !PARAM,ATOD
C
        COMMON /DATA1/ISIZE,IDATA(1024)                !ATOD,ANA
        COMMON /PARAMW/IRANGE,RANGE(7),ISIGN,B1,B0     !PARAM,ATOD
        COMMON /INDEX/ANS,BRANCH,CHG2     !CAL,ATOD,PARAM
C       !CHG2 FOR SAMPLING PARAM's,i.e. SAMPLING RATE,# OF SAMPLE/CHAN.
C
        COMMON /SAMPLE/ICHANS,ICHAN1,NSAMPL,ICODE1,ICODE2,IERR
                                                       !ATOD,ANA
C
C***
        COMMON S(3)
        DIMENSION W(3)
C***
        DIMENSION XLOCK(512),FRQD(512)
        EQUIVALENCE (FRQD(1),FRQT(1))     !FRQD=DOPPLER FREQUENCE
                                          !FRQT=TRACKER INPUT FREQ.
C
        EQUIVALENCE (IDATA(1),XLOCK(1))
        LOGICAL*1 ANS,BRANCH
        INTEGER CLOCK
C
        REAL N1,N2,N3
        IPOT1=0
        CHG2='Y'
        OPEN(UNIT=2,NAME='ANALY.DAT',TYPE='NEW',FORM='FORMATTED')
C               ! DATA FILE FOR ANALIZED DATA.
C
        CALL ASSIGN(3,'LP:')
        CALL ASSIGN(4,'TT4:')
        XMARK=999.99    !MARK FOR END OF THE ANALIZED DATA
        WRITE(2,79)XMARK
79      FORMAT(1X,F7.2)
C       ---- INITIALIZATION FOR OPTICAL & TRACKER PARAMETERS---
1050    TYPE *,' Enter REFLECTIVE INDICES N1,N2,N3 '
        ACCEPT *,N1,N2,N3
C
        THET1=.079512 !BEAM SEPARATION SET AT MIDDLE ON BEAM EXPANDER
C       COMPUTE THET1,THET2,THET3
        TT1=SIN(THET1)*N1/N2              !TT1=SIN(THET2)
        IF(TT1 .GE. 1)GO TO 333
        XT1=TT1/SQRT(1-TT1**2)            !XT1=TAN(THET2)
        THET2=ATAN(XT1)
        TT2=SIN(THET2)*N2/N3              !TT2=SIN(THET3)
        IF(TT2 .LT. 1.0)GO TO 222
333     TYPE *,' INCIDENT ANGLE TOO BIG. NO BEAM CROSSING EXIST.'
        TYPE *,' Try changing THET1 or N3'
C
222     XT2=TT2/SQRT(1-TT2**2)            !XT2=TAN(THET3)
```

```
      CALL PARAM
      IF (IOPT1 .EQ. 4)GOTO 1100
C
C      ---INITIALIZATION FOR DATA SAMPLING---
1040  WRITE(5,103)
103   FORMAT(/,'  ENTER FIRST CHANNEL: ',$)
      ACCEPT *,ICHAN1
      IF(ICHAN1 .GT.10)GOTO 1040
      ICHANS=2
      ICODE1=1
C   ---INITIALIZATION FOR TRAVERSING SYSTEM (THEREAFTER REFERRED AS LDA)
      XMIN=-6.
      XMAX=6.
      YMIN=-5.5
      YMAX=5.5
      ZMIN=-5.5
      ZMAX=5.5
      B=.9725
      A0=11.69482
C
1100  WRITE(5,1001)'
1001  FORMAT(/,' TYPE:  1 --TO RELOCATE PROBE PT.'
    C ,/,8X,'2 --TO SAMPLE DATA',/,8X,'3 --TO CHANGE SAMPLING RATE'
    C ,/,8X,'4 --TO CHANGE OPTICAL OR TRACKER PARAMETERS',/
    C ,8X,'5 --TO PRINT OUT THE ANALIZED DATA',
    C /,8X,'6 --TO EXIT PROGRAM',/)
      ACCEPT *,IOPT1
      GO TO (1010,1020,43,1050,1800,2000)IOPT1
      TYPE *,'ILLEGAL OPTION. TRY AGAIN!'
      GO TO 1100
1010  WRITE(5,880)
880   FORMAT(1X,'TYPE: X--TO GO ALONG WITH (X,Y,Z) SYSTEM ONLY.
    C ',/,7X,'R--TO RELOCATE PROBE WITH (STD,r,THETA) SYSTEM')
      ACCEPT 155,ANS
      IF(ANS .EQ.'R')GOTO 1510
      IF(ANS .EQ. 'X')GOTO 1610
      GO TO 1010
1610  TYPE *,'ENTER (X,Y,Z) in INCHES.'
      ACCEPT *,X,Y,Z
      GO TO 2222
1510  TYPE *,'CHECK WHICH BRANCH TO BE LOCATED. [R/N/L]'
      ACCEPT 155,BRANCH
      CALL CAL
2222  IF(X .LT. XMIN .OR. X .GT. XMAX)GOTO 550
      IF(Y .LT. YMIN .OR. Y .GT. YMAX)GOTO 550
      IF(Z .LT. ZMIN .OR. Z .GT. ZMAX)GOTO 550
C***  THIS PORTION TO BE DELETED
      W(1)=X
      W(2)=Y
      W(3)=Z
      NSTP=0
      DO 677 I=1,3
      IF(S(I)*W(I) .LT. 0.0)GO TO 677
      IF(ABS(W(I)) .GT. ABS(S(I)))GOTO 129
      IF(ABS(W(I)) .GT. .20)GOTO 677
      IF(ABS(S(I)) .GT. .0999 .OR. ABS(S(I)) .LT. .0799)GOTO 677
      GOTO 766
129   IF(ABS(S(I)) .GT. .020)GOTO 677
      IF(ABS(W(I)) .GT. .0999 .OR. ABS(W(I)) .LT..0799)GOTO 677
766   IF(S(I) .GE. 0.)W(I)=.050
      IF(S(I) .LT. 0.)W(I)=-.050
      NSTP=1
677   CONTINUE
```

```
        IF(NSTP .NE. 1)GOTO 1100
        WRITE(5,666)
666     FORMAT(/,'  ***TO CONTINUE, HIT ANY KEY***',$)
        ACCEPT 155,ANS
C***
        CALL TALK(X,Y,Z)
        GO TO 1100
C
43      TYPE *,' ENTER FUNCTION SELECT VALUE:'
        TYPE *,'  2=INTERNAL 150 KHz CLOCK'
        TYPE *,'  4=SOFTWARE GENERATED CLOCK'
        ACCEPT *,ICODE2
        IF(ICODE2 .EQ. 2)GOTO 63
        IF(ICODE2 .NE. 4)GOTO 43
53      WRITE(5,143)
143     FORMAT(1X,' ENTER SAMPLING RATE--100KHz MAX:',$)
        ACCEPT *,CLOCK
        IF(CLOCK .GT.100)GOTO 53
63      WRITE(5,153)
153     FORMAT(1X,' ENTER NUMBER OF SAMPLES/CHANNEL:',$)
        ACCEPT *,NSAMPL
        IF(NSAMPL .GT. 512)GOTO 63
        CHG2='N'
C
1020    IF(CHG2 .EQ. 'Y')GOTO 43
C       ---NBLOCKS OF SAMPLING BEGINS---
        CALL ATOD
        IF(IERR .NE. 0)GOTO 1100
        IF(CHG2 .NE. 'Y')GOTO 1025
        GOTO 43
C
C
1025    TYPE *,'WANT TO ANALYZE DATA? Y/N'
        ACCEPT 155,ANS
        IF(ANS .EQ. 'N')GOTO 1100
        CALL ANA
        GO TO 1100
155     FORMAT(A1)
C
550     TYPE *,'  '
        TYPE *,'OUT OF MANIPULATION RANGE. TASK NEGLECTED.'
        GO TO 1100
C
1800    REWIND 2
1810    READ(2,1700)X10
1700    FORMAT(1X,F7.2)
        IF(X10 .EQ. XMARK)GOTO 1100
        READ(2,800)X1,X2,X3,X4,X5,X6,D1      !X1--X10 & D1 ARE
C                                             !TEMPERARY MEMORY SPACES
800     FORMAT(1X,4F7.3,F6.3,F4.0,A1)
TB      WRITE(3,850)X1,X2,X3,X4,X5,X6,D1
850     FORMAT('  (X,Y,Z)=(',3F7.3,')',' (S,r,THET)=(',F7.3,F6.3,F4.0
     C  ,')',1X,A1)
        READ(2,900)X1,X2,X3,X4,X5,X6,X7,X8,X9
900     FORMAT(1X,2(E11.3,E11.3,F8.2),/,1X,E11.3,E11.3,F8.2,/)
        WRITE(3,950)X1,X2,X3,X4,X5,X6,X7,X8,X9,X10
950     FORMAT(' LOCKED   : VEL=',1PE11.3,' RMS FLUCT.=',1PE11.3,
     C' TURB. INTEN.=',F8.2,/,' UNLOCKED: VEL=',1PE11.3,' RMS FLUCT.='
     C  ,1PE11.3,' TURB. INTEN.=',F8.2,/,' COMBINED: VEL=',1PE11.3,
     C  ' RMS FLUCT.=',1PE11.3,' TURB. INTEN.=',F8.2,' LOCK %=',F7.2,/)
        GOTO 1810
2000    CLOSE(UNIT=2)
```

```
      CALL CLOSE(4)

      STOP '---PROGRAM FINISHED.---'
      END
```

```
C ======================SUBROUTINE CAL.FTN=================================
C  FUNCTION OF THIS SUBPROGRAM:
C    TO RELATE THE 'CYLINDRICAL'COORDINATES ON THE BEAM CROSSING
C       INSIDE THE LUNG BIFURCATION,i.e.(S,r,THETA), TO THE
C       CARTESIAN COORDINATES ON THE TRAVERSING SYSTEM,i.e.(X,Y,Z)
C
C       MAY-8-83'  D.SHEU    TRL
C==========================================================================
        SUBROUTINE CAL
        COMMON /POSPAR/N1,N2,N3,B,A0
        COMMON /MAXMIN/XMIN,XMAX,YMIN,YMAX,ZMIN,ZMAX
        COMMON /SITE/X,Y,Z,RD,DTHETA,SKEW,STD,XMARK
        COMMON /ANGLES/THET1,THET2,THET3
        COMMON /INDEX/ANS,BRANCH,CHG2
        REAL N1,N2,N3
        LOGICAL*1 ANS,BRANCH
        C=0.716             !0.716in
        R=0.375             !0.375in
        DCC=3               !3." DISTANCE CENTER TO CENTER
C-----
123     WRITE(5,124)
124     FORMAT(1X,' ENTER NEW POSITION WITH FORMAT (S,r,THETA)')
        TYPE *,'NB:1)THETA IN DEGREES(0 TO 360),OTHERS in IN.'
        ACCEPT *,STD,RD,DTHETA
        IF(STD .LE. 0)SKEW=0.
        IF(STD .GT. 0.637045*DCC)SKEW=0.637045 !0.637045RAD=36.5DEG
        IF(STD .GT. 0 .AND. STD .LE. 0.637045*DCC)SKEW=STD/DCC
        IF(BRANCH .EQ. 'L')SKEW=-1.*SKEW
        DSKEW=SKEW*45./ATAN(1.)             !TRANSFORM INTO DEGREES
        THET=DTHETA*3.1416/180
C
C       ---RELATION OF (S,r,THET) TO (X,Y,Z)
C
C---- NOTE : TWO WAYS ARE USED FOR DETERMINING THETI
C           1)ITERATED RECURSION   2)MULTIPLE SHOOTING(BACK & FORTH)
C            AS (1) DOES NOT WORK FOR DTHETA BETWEEN <-65,+65> DEGREES FOR
C            RD NEAR .375 (i.e.HIGHER r) ,(2)IS INTRODUCED FOR THIS REGION
C
        REF=1.0             !ARBITRARILY SET 1st. REFERENCE =1.0
        DEC=0.01            !1st. DECRIMENT(INCRIMENT) INTERVAL=.01"
        IND=0               !INDEX=0
        IF(DTHETA .LE. 295. .AND. DTHETA .GE. 65.)IND=1
        IF(IND .EQ. 1)GOTO 660
        IF(DTHETA .LT. 65.)GOTO 669
679     THETII=THET-8*ATAN(1.)-DEC
680     THETII=THETII+DEC
        GO TO 100
669     THETII=THET+DEC
670     THETII=THETII-DEC
        GOTO 100
660     THETII=THET/3. !1st. GUESS OF THETII(WHEN 65 .LE. THET .LE. 295)
100     DELTA=THET-THETII
        FF=RD*RD+R*R-2*R*RD*COS(DELTA)
        F=SQRT(FF)
        FX=RD*SIN(DELTA)/F
        TXF=FX/SQRT(1-FX*FX)
        THETO=ATAN(TXF)
        SXI=N3*SIN(THETO)/N2        !SXI=SIN(THETI)
        TXI=SXI/SQRT(1-SXI*SXI)
        THETI=ATAN(TXI)
        ABSS=ABS(THETI-THETII)
        IF (ABSS .LT. 0.0004) GO TO 200
```

```
      IF(REF .LE. ABSS)DEC=-1*DEC/5.   !IF OVERSHOT,SHORTEN SHOOTING
C                       !INTERVAL BY FIVE TIMES AND SHOOT BACKWARDS
      REF=ABSS          !UPDATE REFERENCE VALUE BY ABSS
      IF(DTHETA .LT. 65.)GOTO 670
      IF(DTHETA .GT. 295.)GOTO 680
700   THETII=THETI
      GO TO 100
200   YC=R*SIN(THETI)
      E=C-R             !ONLY IN THE CASE Y=THETI=0
      IF (THETI .NE. 0.00) E=C-YC*COS(THETI)/SIN(THETI)
      D=F*COS(THETO-THETI)
      SL=D*SIN(THET3)/COS(THET3)
      YL=SL+E*SIN(THET2)/COS(THET2)
      A=(B-YL)*COS(THET1)/SIN(THET1)
      XC=A-A0
      YY=YC*COS(SKEW)
      ZZ=-YC*SIN(SKEW)
      IF(STD .GT. 0.637045*DCC)GOTO 1000
      OVERY=0.
      OVERZ=0.
      GOTO 2000
1000  OVERY=(STD-0.637045*DCC)*ABS(SIN(SKEW))
      OVERZ=(STD-0.637045*DCC)*COS(SKEW)
2000  OFFY=DCC*(1.-COS(SKEW))+OVERY
      IF(BRANCH .EQ. 'L')OFFY=-1.*OFFY
      OFFZ=DCC*ABS(SIN(SKEW))+OVERZ
      Y=YY+OFFY
      IF(STD .LE. 0.)Z=STD
      IF(STD .GT. 0.)Z=ZZ+OFFZ
      X=XC
C     ----
      TYPE *,'UPDATED POSITION:'
      TYPE 500,X,Y,Z,STD,BRANCH,DSKEW,RD,THET,DTHETA
500   FORMAT('  FOR LDA:     X=',F7.3,'    Y=',F7.3,'     Z=',F7.3,
C    /,'  FOR PROBE : S=',F7.3,1X,A1,' SKEW=',F4.0,' r=',
C    F6.3,' THET=',F7.4,' RAD ='F4.0,'DEG')
      IF(RD .GT. R)TYPE *,'-WARNING: RADIAL DIST. out of range.-'
      RETURN
      END
```

```
C====================SUBROUTINE PARAMETER (FOR TRACKER )====================
C        5/3/83' IN TRL
C     THIS SUBROUTINE,CALLED BY LUNG1.FTN ,IS TO SET OPTICAL PARAMETERS:
C        RANGE,FACT,SHIFT,ISIGN
C==========================================================================
         SUBROUTINE PARAM
         COMMON /PARAMW/IRANGE,RANGE(7),ISIGN,B1,B0
         COMMON /XDATA/FACT,SHIFT,FREQ(512),DATA(1024),CLOCK
         COMMON /ANGLES/THET1,THET2,THET3
         COMMON /INDEX/ANS,BRANCH,CHG1,CHG2                  !ONLY ANS USED HERE
         LOGICAL*1 ANS,BRANCH,CHG1,CHG2
C
         RANGE(1) = 10.                         ! RANGE in kHz
         RANGE(2) = 33.3333
         RANGE(3) = 100.
         RANGE(4) = 333.33
         RANGE(5) = 1000.
         RANGE(6) = 3333.3
         RANGE(7) = 10000.
C
         WAVELN=632.8                  !IN NANOMETERS
         FACT  =  1.E-3 * WAVELN / (2. * SIN(THET1))      !CALIBRATION FACTOR
1        TYPE *,'Enter frequency shift in kHz.'
         ACCEPT *,SHIFT                !NET FREQ. SHIFT (CAN BE + OR -)
170      WRITE(5,171)
171      FORMAT(' ENTER 1 --IF DOPPLER FREQ GREATER THAN OR EQUAL TO FREQ
     *   SHIFT',/,'        0 --IF DOPPLER FREQ LESS THAN FREQ SHIFT.',/
     *   ,'**NOTE** COUNT FOR POSITIVE-NEGATIVE CONDITONS FOR BOTH FREQS')
         ACCEPT *,ISIGN
         IF(ISIGN .EQ. 0 .OR. ISIGN .EQ. 1) GO TO 2
         TYPE *,' INVALID NUMBER. TRY AGAIN!'
         GO TO 170
C
2        TYPE *, 'Set the tracker range by entering:'
         TYPE *, '        1 :     1.0   -   10.   kHz'
         TYPE *, '        2 :     3.3   -   33.    "'
         TYPE *, '        3 :    10.0   -  100.    "'
         TYPE *, '        4 :    33.3   -  333.    "'
         TYPE *, '        5 :     0.1   -    1.0  MHz'
         TYPE *, '        6 :     0.33  -    3.3   "'
         TYPE *, '        7 :     1.0   -   10.0   "'
         ACCEPT *,IRANGE
         IF(IRANGE .GE.1 .AND. IRANGE .LE. 7)GO TO 5
         TYPE *,'IMPROPER RANGE SETTING.  TRY AGAIN.'
         GO TO 2
5        GOTO(910,920,930,940,950,960,970)IRANGE
910      B1=.97966      !SEE ATOD.FTN FOR MEANING OF B1,B0
         B0=-.09580
         GOTO 3
920      B1=.97971
         B0=-.06872
         GOTO 3
930      B1=.97968
         B0=-.10372
         GOTO 3
940      B1=.98829
         B0=-.07236
         GOTO 3
950      B1=.98876
         B0=-.08060
         GOTO 3
960      B1=.99197
         B0=-.09197
```

```
      GOTO 3
970   B1=.97346
      B0=-.03645
3     TYPE 59,IRANGE
59    FORMAT(/,' RANGE SETTING      =        ',I1)
      TYPE 60,FACT
60    FORMAT(' CONVERSION FACTOR = ',F10.6,'  m/s/kHz')
      TYPE 65,SHIFT
65    FORMAT(' FREQUENCY SHIFT    =  ',F8.0,'  kHz')
      IF(ISIGN .EQ. 1)TYPE *,'  FsubD > FsubS'
      IF(ISIGN .EQ. 0)TYPE *,'  FsubD < FsubS'
      TYPE *,'   '
C
      TYPE *,'Are you happy with these? (Y/N)'
      ACCEPT 22,ANS
22    FORMAT(1A1)
      IF(ANS .NE. 'Y') GO TO 1
C
      RETURN
      END
```

```
C
C AUTHOR: DLS
C   DATE: 4/22/83
C        NOTE:THE READING FROM ANALOG OUTPUT PORT ON TRACKER IS
C             CONSISTANTLY HIGHER THAN THE CORRESPONDING DIGITAL DISPLAY
C             IT WAS DETERMINED THAT ANALOG O/P SHOULD BE CORRECTED
C             BY THE FOLLOWING EQ:
C               Y=B1*X+B0     WHERE Y=CORRECTED ANALOG O/P(BASED ON DIGITAL
C                                                          DISPLAY)
C                                   X=THE MEASURED ANALOG O/P
C                                  B1,B0=CONSTANTS FOR LINEAR REGRESSION
C        DECISION BASED ON:1)THE PROVEN TRUTH OF LINEARITY BTN X & Y
C                          2)THE DIGITAL DISPLAY ON TRACKER IS ALWAYS
C                           CONSISTANT BY ITSELF WHEN PLAYING AROUND
C                           WITH VARIOUS FREQ. SHIFT
C                          3)COUNTER READING=C* TRACKER READING
C                               WHERE C=1.273  ,ALWAYS
C                          4)TRACKER READOUT IS CONSISTANT W/T OSCILLOSCOPE
C=========================================================================
        SUBROUTINE ATOD
        COMMON /XDATA/FACT,SHIFT,FRQT(512),DATA(512),VEL(512),CLOCK
        COMMON / DATA1 / ISIZE, IDATA(1024)
        COMMON /PARAMW/IRANGE,RANGE(7),ISIGN,B1,B0
        COMMON /INDEX/ANS,BRANCH,CHG2
        COMMON /SAMPLE/ICHANS,ICHAN1,NSAMPL,ICODE1,ICODE2,IERR
        DIMENSION XLOCK(512),FRQD(512)
        EQUIVALENCE (FRQD(1),FRQT(1))
        EQUIVALENCE (IDATA(1),XLOCK(1))
        LOGICAL*1 ANS,BRANCH,FLNAME(20)
        INTEGER CLOCK
        DATA IOUT,KB,FLNAME(20)/1,5,.FALSE./
        ISIZE = 1024
C
        IF(ICODE2 .EQ. 4)GO TO 999
        TYPE *,'SAMPLING RATE= 150 Khz'
        GOTO 1010
999     WRITE(5,1000)CLOCK
1000    FORMAT(1X,'SAMPLING RATE=',1X,I3)
1010    TYPE *,'No. OF SAMPLES/CHANNEL= ',NSAMPL
        TYPE *,'ARE YOU HAPPY WITH THIS?  Y/N'
        ACCEPT 220,ANS
        IF(ANS .EQ. 'Y')GOTO 1020
1040    CHG2='Y'          !CHG2=Y  TO CHANGE SAMPLING PARA.
        RETURN
1020    IERR = 0
        CALL ADPHX(ICHANS,ICHAN1,NSAMPL,ICODE1,ICODE2,IERR)
        IF(IERR .NE. 0) GO TO 500
        N = ICHANS*NSAMPL
C
        TYPE *,'  ANA O/P(V)    FREQ(KHz)      VEL(M/S)        LOCK'
        DO 1030 I = 1, N/2
80      DATA(I) = 10. * FLOAT(IDATA(2*I-1))/FLOAT("37777)
C               ! DATA(I)=ACTUAL VOLTAGE MEASURED (FOR VEL SIGNAL)
        TYPE *,'ANA O/P= ',DATA(I)
        DATA(I)=B1*DATA(I)+B0 !CORRECTED ANALOG O/P FROM TRACKER
        TYPE *,'CORRECTED ANA O/P= ',DATA(I)
        FRQT(I)=DATA(I)*RANGE(IRANGE)/10. !TRACKER I/P FREQ.
        TYPE *,'FRQT=',FRQT(I)
        IF(ISIGN .EQ. 0)FRQD(I)=SHIFT-FRQT(I)!WHEN FsubD<SHIFT
        IF(ISIGN .EQ. 1)FRQD(I)=SHIFT+FRQT(I)!WHEN FsubD>SHIFT
        VEL(I)=FACT*FRQD(I)/1000          !DOPPLER FREQ SHOULD BE IN MHz
C                                         ! IN ORDER TO GET VEL IN m/sec
```

```
      XLOCK(I)=10.*FLOAT(IDATA(2*I))/FLOAT("3777.) !TRUE VOLTAGE FOR
C             !LOCK SIGNAL OUTPUT
      XLOCK(I)=1.0143443-XLOCK(I)/4.88 !1=FULL LOCKED ,0=FULL UNLOCKED
C             !LOCK VOLTAGE RANGE: <.07,4.95>
      IF(XLOCK(I) .GT. 1.)XLOCK(I)=1.0
      IF(XLOCK(I) .LT. 0.)XLOCK(I)=0.0
      WRITE(5,3100)DATA(I),FRQD(I),VEL(I),XLOCK(I)
3100  FORMAT(3X,F6.2,6X,1PE11.3,3X,1PE11.3,9X,F4.2)
1030  CONTINUE
C
  90  WRITE(5,190)
 190  FORMAT(1X,' DO YOU WISH TO TAKE MORE DATA ? [Y/N]:',$)
      ACCEPT 220,ANS
      IF(ANS .EQ. 'N') RETURN
      WRITE(5,200)
 200  FORMAT(1X,' DO YOU WISH TO CHANGE PARAMETERS ? [Y/N]: ',$)
      ACCEPT 220,CHG2
      IF(CHG2 .EQ. 'Y')RETURN
      GOTO 1020
C
 500  IF(IERR .EQ. 1)TYPE *,'POWER NOT ON TO A/D.'
      IF(IERR .EQ. 2)TYPE *,'A/D REMOTE SWITCH NOT SET.'
      IF(IERR .EQ. 3)TYPE *,'PHEONIX IS NOT RESETING
     C (DSTAT C not clearing)'
      IF(IERR .EQ. 4)TYPE *,'TOO MANY SAMPLES REQUESTED.'
      IF(IERR .EQ. 4)GOTO 1040
      IF(IERR .EQ. 5)TYPE *,'ILLEGAL FUNCTION BITS (DSTAT C SET)'
      TYPE *,' DO YOU WANT TO TRY AGAIN ? '
      WRITE(5,210)
 210  FORMAT(1X,' TYPE [Y/N] WHEN READY.',$)
      ACCEPT 220,ANS
 220  FORMAT(A1)
      IF(ANS .EQ. 'Y')GO TO 1020
      RETURN
      END
```

```
;==================================ADPHX.MAC====================================
;
;	This is a driver for the TRL Phoenix A/D converter which
;is designed for use with RSX-11 in a mapped system.  It assumes
;that the memory management registers and the DMA registers can
;be accessed through a device partition which must be included
;in the LINK instructions.
;
;	This program must be called by a Fortran program containing
;the following COMMON BLOCK and CALL statements:
;
;		CALL ADPHX(ICHANS,ICHAN1,NSAMPL,ICODE1,ICODE2,IERR,CLOCK)
;where
;		ICHANS = number of channels
;		ICHAN1 = first channel in scan
;		NSAMPL = number of samples/channel
;		ICODE1 = 1 for single word transfer
;		         0 for double word transfer
;		ICODE2 = 2 for internal clock
;		         3 for external clock
;		         4 for software clock
;		IERR   = 0 if all OK
;		         1 if power off
;		         2 if A/D not in remote mode
;		         3 if Phenix not resetting propperly
;		         4 if too many samples
;		         5 if illegal function bits
;		CLOCK  = software clock count down word
;
;	The  common block is defined by
;
;		COMMON / DATA1 / ISIZE,IDATA
;
;This program was written by Scott Woodward for gereral use.  DLS,7/19/'83
;
;==============================================================================
;
	.TITLE ADPHX
;
	.GLOBL ADPHX,LKS
	.GLOBL DRWC,DRBA,DRST,DRDB
	.GLOBL PARU0,PARU1,PARU2,PARU3
	.GLOBL PARU4,PARU5,PARU6,PARU7
;
	.PSECT DATA1,D,GBL,OVR
ISIZE:	.BLKW	1
IDATA:	.BLKW	1
	.PSECT
;
;		STORE REGISTERS ON STACK
;
ADPHX:	MOV	R0,-(SP)
	MOV	R1,-(SP)
	MOV	R2,-(SP)
	MOV	R3,-(SP)
	MOV	R4,-(SP)
;
;		GET ARGUMENTS
;
	MOV	@2(R5),ICHANS	;NUMBER OF CHANNELS
	MOV	@4(R5),ICHAN1	;FIRST CHANNEL
	MOV	@6(R5),NSAMPL	;NUMBER OF SAMPLES/CHANNEL
	MOV	@10(R5),ICODE1	;DOUBLE/SINGLE WORD CODE
```

```
        MOV     @12(R5),ICODE2    ;CLOCK MODE
        MOV     @14(R5),CLOCK     ;CLODK COUNT DOWN WORD
        MOV     NSAMPL,NSMPL      ;DUPLICATE NUMBER OF SAMPLES FOR LATER USE
;
;               RESET PHOENIX AND DISABLE LINE CLOCK
;
        CLR     LKS               ;DISABLE LINE CLOCK, NO INTERUPTS
        MOV     #1,DRST           ;RESET PHOENIX
;
;               CHECK IF PHOENIX IS WORKING PROPERLY
;
        MOV     DRST,R0           ;GET STATUS WORD
        BIT     #2000,R0          ;CHECK FOR POWER ON
        BNE     SKIP
        JMP     ERR1              ;IF NOT SET BRANCH
SKIP:   BIT     #4000,R0          ;CHECK IF REMOTE
        BEQ     SKIP2
        JMP     ERR2              ;IF SET BRANCH
SKIP2:  BIT     #1000,R0          ;ILLEGAL FUNCTION BITS
        BEQ     SKIP3
        JMP     ERR3              ;PHENIX IS NOT RESETING PROPERLY
;
SKIP3:  MOV     ICHANS,R0
        MOV     NSAMPL,R1
        MUL     R0,R1             ;REQUIRED MEMORY
        MOV     R1,NSAMPL         ;STORE IN NSAMPL
        TST     ICODE1            ;CHECK IF DOUBLE WORD
        BNE     FLAG1             ;SKIP IF SINGLE WORD
        ASL     NSAMPL            ;DOUBLE NUMBER
FLAG1:  CMP     ISIZE,NSAMPL      ;CHECK IF ARRAY BIG ENOUGH
        BGT     SKIP4
        JMP     ERR4              ;IF NOT BRANCH
SKIP4:  NEG     NSAMPL            ;2'S COMPLEMENT
        MOV     NSAMPL,DRWC       ;LOAD WORDCOUNT REGISTER
;
;               DETERMINE ABSOLUTE ADDRESS OF IDATA
;
;                       Determine Displacement in Blocks (DIB)
;
        MOV     #IDATA,R3         ;Get virtual address
        BIC     #177700,R3        ;Keep 6 lowest bits. DIB in R3
;
;                       Determine Block Number (BN)
;
        MOV     #IDATA, R4        ;Get virtual address again
        BIC     #160077,R4        ;Keep bits 6 - 12
        ASL     R4                ;Prepare for shift right
        ASL     R4                ;    "
        SWAB    R4                ;Finish shift right. BN in R4.
;
;                       Determine Active Page Field (APF)
;
        MOV     #IDATA,R1         ;Get virtual address again
        BIC     #17777,R1         ;Keep bits 13 - 15
        TST     R1                ;Clear carry bit
        ROL     R1                ;Start shift to bits 0 - 2
        ROL     R1                ;Remember carry bit
        ROL     R1                ;is included.
        ROL     R1                ;Finished. APF in R1.
;
;                       Determine Physical Address Register (PAR)
;
        MOV     PARU0(R1),R1
        ADD     R1,R4             ;Construct Physical Block Number
```

```
;               GET TWO MSB'S FOR STATUS REGISTER
;
        MOV     R4,R2           ;SETUP STATUS WORD IN R2
        BIC     #171777,R2      ;CLEAR ALL BUT 2 MSB'S
        SWAB    R2              ;PREPARE SHIFT TO BITS 4 & 5
        ASL     R2
        ASL     R2              ;DONE BUT STILL NEED FUNCTION ...
;
;               FINISH UP AND LOAD ADDRESS REGISTER
;
        ASL     R4              ;Need to shift to bits 6 - 17
        ASL     R4
        ASL     R4
        ASL     R4
        ASL     R4
        ASL     R4              ;Finished with 6 left shifts
;
        ADD     R3,R4           ;Add DIB to get Physical Address
;
        MOV     R4,DRBA         ;Load Address Register in DMA
;
;               SETUP AND LOAD PHOENIX DATA WORDS
;
        CLR     R0              ;PREPARE R0 FOR DATA WORD
        TST     ICODE1          ;SINGLE OR DOUBLE WORD
        BEQ     FLAG2           ;IF DOUBLE SKIP
        BIS     #100000,R0      ;BIT 15 SINGLE/DOUBLE WORD 1-SINGLE WORD
FLAG2:  BIS     #70000,R0       ;BIT 14 SEQUENTIAL SRT PNT 1-PROG START CHAN
                                ;BIT 13 AUTO/PROG SEQUENCE 1-AUTO SEQUENCE
                                ;BIT 12 RANDOM/SEQUENTIAL  1-RANDOM
        ADD     ICHAN1,R0       ;ADD START CHANNEL
        MOV     R0,DRDB         ;LOAD DATA BUFFER REGISTER
        MOV     #3,DRST         ;STROBE PHOENIX
;                               ;FIRST STROBE LOADS THE FIRST CHANNEL ADDRESS
;                               ;SECOND STROBE LOADS THE LAST CHANNEL ADDRESS
;                               ;IF BIT 12 RAND/SEQU IS 0-SEQUENTIAL
;
        CMP     #1,ICHANS       ;CHECK FOR MULTIPLE CHANNELS IF ONLY
        BEQ     FLAG3           ;ONE EACH CTC WILL CONVERT CHANNEL JUST LOADED
;
        BIC     #10017,R0       ;CLEAR BITS 0 - 3 AND 12
        ADD     ICHAN1,ICHANS   ;COMPUTE LAST CHANNEL PLUS ONE
        DEC     ICHANS          ;SUBTRACT THE ONE
        ADD     ICHANS,R0       ;ADD LAST CHANNEL
        MOV     R0,DRDB         ;LOAD DATA BUFFER REGISTER AGAIN
        MOV     #3,DRST         ;STROBE PHOENIX
;
FLAG3:  MOV     ICODE2,R4       ;GET CLOCK CODE
        ASL     R4              ;SHIFT TO FUNCTION BITS (1-3)
        INC     R4              ;ADD #1 FOR GO BIT
        ADD     R4,R2           ;R2 CONTAINS 2 MSB OF DATA BUF +FUNC & GO BITS
        CMP     ICODE2,#4       ;BRANCH TO SOFTWARE CLOCK ROUTINE
        BEQ     SFTCLK          ;IF ICODE2 = 4
        MOV     R2,DRST         ;TELL PHOENIX TO GO
;
WAIT:   MOV     DRST,R0         ;LOAD STATUS REG TO
        BIT     #200,R0         ;CHECK READY BIT 7
        BEQ     WAIT            ;DONE WHEN SET
        BR      DONE
;
;       SOFTWARE CLOCK TIMING LOOP
;
SFTCLK: MOV     R2,DRST         ;TELL PHOENIX TO SAMPLE
```

```
        DEC     NSMPL               ;KEEP TRACK OF SAMPLES TAKEN
        BMI     DONE
        MOV     CLOCK,R0            ;LOAD COUNT DOWN WORD
TIMELP: DEC     R0                  ;WAIT LOOP
        BEQ     SFTCLK
        BR      TIMELP              ;CONTIUE WAITING
;
DONE:   MOV     DRST,R0             ;LOAD STATUS REG
        BIT     #1000,R0            ;CHECK FOR ILLEGAL FUNCTION BITS
        BNE     ERR5                ;IF DSTAT C IS SET BAD FUNC BITS
        BR      FLAG4               ;SKIP IF OK
;
ERR1:   MOV     #1,IERR             ;POWER OFF
        BR      FLAG4
ERR2:   MOV     #2,IERR             ;REMOTE NOT SET
        BR      FLAG4
ERR3:   MOV     #3,IERR             ;PHENIX NOT CLEARING DSTAT C ON RESET
        BR      FLAG4
ERR4:   MOV     #4,IERR             ;TOO MANY SAMPLES
        BR      FLAG4
ERR5:   MOV     #5,IERR             ;ILLEGAL FUNCTION BITS
;
FLAG4:  MOV     #100,LKS            ;RESTORE LINE CLOCK
        MOV     (SP)+,R4
        MOV     (SP)+,R3
        MOV     (SP)+,R2
        MOV     (SP)+,R1
        MOV     (SP)+,R0
        MOV     IERR,@14(R5)        ;RETURN ERROR CODE TO PROGRAM
        RTS     PC                  ;GO BACK TO MAIN
;
;
ICHANS: .WORD   0
ICHAN1: .WORD   0
NSAMPL: .WORD   0
NSMPL:  .WORD   0
ICODE1: .WORD   0
ICODE2: .WORD   0
IERR:   .WORD   0
CLOCK:  .WORD   0
;
        .END
```

```
      SUBROUTINE ANA
      COMMON /XDATA/FACT,SHIFT,FROT(512),BATA(512),VEL(51...
      COMMON /DATA1/ISIZE,IDATA(1024)
      COMMON /SAMPLE/ICHANS,ICHAN1,NUM,ICODE1,ICODE2,IERR
      COMMON /SITE/X,Y,Z,RD,DTHETA,SKEW,STD,XMARK
      COMMON /INDEX/ANS,BRANCH,CHG2
      LOGICAL*1 ANS,BRANCH
      DIMENSION XLOCK(512)
      EQUIVALENCE (IDATA(1),XLOCK(1))
      DOUBLE PRECISION DVEL,SVEL,TVL,TVUL,TV,TSVL,TSVUL,TSV
      DOUBLE PRECISION AVL,AVUL,AV,ASVL,ASVUL,ASV
      TSVL=0.             !TOTAL SQUARE VEL ,LOCKED
      TVL=0.              !TOTAL VEL ,LOCKED
      TVUL=0.             !TOTAL VEL ,UNLOCKED
      TSVUL=0.            !TOTAL SQR. VEL, UNLOCKED
      TV=0.               !TOTAL VEL LOCKED & UNLOCKED
      TSV=0.              !TOTAL SQR VEL LOCKED & UNLOCKED
      LOK=0               !NUMBER OF LOCKED VEL
      TLOCK=0.
      DO 100 I=1,NUM      !NUM=No. OF SAMPLES
      DVEL=VEL(I)         !CONVERT IN TO DOUBLE PRECISION TO AVOID
                          !  TRANCATION ERROR WHEN VEL**2 OCCURS
C
      IF(XLOCK(I) .LT. 0.5)GOTO 1000
      LOK=LOK+1
      TVL=TVL+DVEL
      TSVL=TSVL+DVEL**2
      GOTO 1100
1000  TVUL=TVUL+DVEL
      TSVUL=TSVUL+DVEL**2
1100  TV=TV+DVEL
      TSV=TSV+DVEL**2
      TLOCK=TLOCK+XLOCK(I)
100   CONTINUE
C     ---Compute mean quantities---
C---FOR LOCKED & UNLOCKED DATA---
      AV=TV/NUM                   !AVG. VEL,LOCKED & UNLOCKED
      ASV=TSV/NUM                 !AVG. SQR. VEL, COMBINED
      ASF=ASV-AV**2               !AVG. SQR. FLUCT. VEL,COMBINED
      RMS=SQRT(ASF)               !RMS FLUCT.VEL ,COMBINED
      TRBI=100.*RMS/ABS(AV)       !TURBULENCE INTENSITY(%),COMBINED
C---FOR LOCKED DATA----
      IF(LOK .EQ. 0)GOTO 600      !IF NO LOCK AT ALL OMIT IT !
      AVL=TVL/LOK                 !AVERAGED VEL,LOCKED(i.e.'MEAN' VEL)
      ASVL=TSVL/LOK               !AVG. SQR. VEL, LOCKED
      ASFL=ASVL-AVL**2            !MEAN SQR. FLUCT. VEL,LOCKED
      RMSL=SQRT(ASFL)             !ROOT MEAN SQR. FLUCT.,LOCKED
      TRBIL=100.*RMSL/ABS(AVL)!TURBULENCE INTENSITY(%),LOCKED
C---FOR UNLOCKED DATA---
      IF(NUM .EQ. LOK)GOTO 700      !ALL LOCKED, OMIT THE UNLOCKED
600   AVUL=TVUL/(NUM-LOK)         !AVG. VEL ,UNLOCKED
      ASVUL=TSVUL/(NUM-LOK)       !AVG. SQR. VEL, UNLOCKED
      ASFUL=ASVUL-AVUL**2         !AVG. SQR. FLUCT. VEL ,UNLOCKED
      RMSUL=SQRT(ASFUL)           !RMS FLUCT. VEL ,UNLOCKED
-B    TRBIUL=100.*RMSUL/ABS(AVUL)      !TURBULENCE INTENSITY ,UNLOCKED
C
C
700   PLOCK=100.*TLOCK/NUM        !LOCK PERCENTAGE
      WRITE(5,200)
200   FORMAT(10X,'  MEAN VEL m/s    RMS FLUCT.    TURB. INTENSITY ')
      WRITE(5,250)
250   FORMAT(1X,'---------------------------------------------------',
     '-------')
```

```
      IF(LOK .EQ. 0)GOTO 610
      WRITE(5,300)AVL,RMSL,TRBIL
300   FORMAT(' LOCKED      ',1PE11.3,3X,1PE11.3,7X,F8.2,' %')
      WRITE(5,250)
C
      IF(NUM .EQ. LOK)GOTO 710
610   WRITE(5,400)AVUL,RMSUL,TRBIUL
400   FORMAT(' UNLOCKED    ',1PE11.3,3X,1PE11.3,7X,F8.2,' %')
      WRITE(5,250)
C
710   WRITE(5,450)AV,RMS,TRBI
450   FORMAT(' COMBINED    ',1PE11.3,3X,1PE11.3,7X,F8.2,' %')
      WRITE(5,250)
C
      WRITE(5,500)PLOCK
500   FORMAT(/,' LOCK PERCENTAGE =',F7.2,'%')
      WRITE(5,190)
190   FORMAT(1X,'DO YOU WANT TO STORE THE DATA? [Y/N]')
      ACCEPT 155,ANS
155   FORMAT(A1)
      IF(ANS .EQ. 'N')RETURN
      BACKSPACE 2
      WRITE(2,800)PLOCK,X,Y,Z,STD,RD,DTHETA,BRANCH
800   FORMAT(1X,F7.2,/,1X,4F7.3,F6.3,F4.0,A1)
      WRITE(2,810)AVL,RMSL,TRBIL,AVUL,RMSUL,TRBIUL,AV,RMS,TRBI
810   FORMAT(1X,2(E11.3,E11.3,F8.2),/,1X,E11.3,E11.3,F8.2,/)
      WRITE(2,79)XMARK
79    FORMAT(1X,F7.2)
      RETURN
      END
```

```
C===================TALK.FTN===============================
C        THIS SUBROUTINE IS USED TO TALK WITH SDK-85 CONTROLLER
C        TO MOVE THE LDA SYSTEM(i.e. TRAVERSING SYSTEM)
C        NOTE : 1)X,Y,Z ARE MULTIPLIED BY 1,000. BEFORE SENDING TO
C                  SDK-85
C               2)X CORRESPONDS TO AXIS #3 ON THE TRAVERSING SYS.
C                 Y   "           "     #2    "         "
C                 Z   "           "     #1    "         "
C        DATE:5/4/83'     D. SHEU IN TRL
C==========================================================
         SUBROUTINE TALK(X,Y,Z)
C ***
         COMMON S(3)
C ***
         IF(X .GE. 0.)IX=1000*X+0.49999  !TO ROUND OFF (AVOID
         IF(X .LT. 0.)IX=1000*X-0.49999  !  TRANCATION ERROR ALSO TAKE
         IF(Y .GE. 0.)IY=1000*Y+.49999   !   CARE OF NEGATIVE CONDITIONS
         IF(Y .LT. 0.)IY=1000*Y-.49999   !    )
         IF(Z .GE. 0.)IZ=1000*Z+.49999   !
         IF(Z .LT. 0.)IZ=1000*Z-.49999   !
         WRITE(4,200)IZ,IY,IX
200      FORMAT(1X,'/',I6,'*/',I6,'*/',I6,'*')
C ***
         S(1)=X
         S(2)=Y
         S(3)=Z
C ***
         RETURN
         END
```

```
                              ;=========================================
                              ;   PROGRAM FOR SDK-85   4-14-83
                              ;   T.R.L.       RM 309 ENGINEERING EAST ,SUNYAB
                              ;=========================================
2000                                  ORG     2000H
2000  F5                      PTCHAR: PUSH    PSW             ;SAVE CHARACTOR
2001  DB 11                   VDM1:   IN      11H             ;GET STATUS
2003  E6 01                           ANI     01              ;TX DONE?
2005  CA 01 20                        JZ      VDM1            ;NO, POLL AGAIN
2008  F1                              POP     PSW             ;YES, SEND IT
2009  D3 10                           OUT     10H
200B  C9                              RET
200C  DB 11                   GCHAR:  IN      11H
200E  E6 02                           ANI     02H             ;RX DONE ?
2010  CA 0C 20                        JZ      GCHAR           ;NO, POLL AGAIN
2013  DB 10                           IN      10H             ;YES, SEND CHAR
2015  C9                              RET
2016  3E 40                   BAUD:   MVI     A,40H           ;8155 #2 TO OUTPUT
2018  D3 2D                           OUT     2DH             ;       CONTINUOUS SQUA
201A  3E 28                           MVI     A,28H           ;3.072MZ/(64*1200BAUD)=
201C  D3 2C                           OUT     2CH             ;LOW BYTE OF TIMER CNT
201E  3E 0E                           MVI     A,0EH           ;LOAD MODE AND HIGH 6-I
2020  D3 28                           OUT     28H             ;PORT #28 IS COMMAND/ST
2022  C9                              RET
                              ;8251-A INITIALIZATION :
2023  3E 00                   USET:   MVI     A,00            ;COMMAND NOP
2025  D3 11                           OUT     11H             ;FORCE TO
2027  D3 11                           OUT     11H             ;       KNOWN COMMAND S
2029  D3 11                           OUT     11H             ; PORT #11 IS COM/MODE
202B  3E 40                           MVI     A,40H           ;INTERNAL RESET
202D  D3 11                           OUT     11H             ;
202F  3E 4F                           MVI     A,4FH           ;MODE INSTRUCTION ( 1 S
2031  D3 11                           OUT     11H             ;       8-BIT WORD, BAUD
2033  3E 37                           MVI     A,37H           ;COMMAND INSTRUCTION
2035  D3 11                           OUT     11H             ;  ENABLE Rx,Tx,etc.
2037  C9                              RET
2800                                  ORG     2800H           ; 8155 RAM FOR STORAGE
                              ;
2800                          ASCIIX: DS      07H
2807                          ASCIIY: DS      07H
280E                          ASCIIZ: DS      07H
2815                          OBCDX:  DS      03H
2818                          TBCDX:  DS      03H
281B                          NBCDX:  DS      03H
281E                          OBCDY:  DS      03H
2821                          TBCDY:  DS      03H
2824                          NBCDY:  DS      03H
2827                          OBCDZ:  DS      03H
282A                          TBCDZ:  DS      03H
282D                          NBCDZ:  DS      03H
2830                          NZERO:  DS      01H
2831                          PZERO:  DS      03H
```

```
2834        TMPHL:  DS      02H
2836        TMPDE:  DS      02H
2838        TMPBC:  DS      02H
283A        AXIS:   DS      01H
283B        LED:    DS      01H
            ;
            ;
3000                ORG     3000H           ; 6116 RAM FOR ALGORITHM
            ;
            ;
28FF        STACK   EQU     28FFH           ; 8155#2 RAM LOACATIONS
0000        SDK85   EQU     0000H           ; SDK85 MONITOR PROGRAM
002F        ASCIIL  EQU     2FH             ; LOWER BOUNDRY OF ASCII NUMBERS
0039        ASCIIH  EQU     39H             ; UPPER BOUNDRY FOR BASE 10 NUMBERS
0000        ZERO    EQU     00H             ; ZERO
0001        ONE     EQU     01H             ; ONE
0099        NNINE   EQU     99H             ; NINETY NINE FOR FUDGEING DECIMAL SUB
                                            ; TRACTION WITH AN ADDITION OPERATION
0010        NZER    EQU     10H             ; ZERO FOR NEGATIVE AXES
0040        BLNKBF  EQU     40H             ; BLANK 40H BYTES OF  RAM
0363        UPDAD   EQU     0363H
036E        UPDDT   EQU     036EH
            ;
            ;       TRANSLATOR INTERFACE CONTROL PORT LOCATIONS
            ;
0028        TRCR    EQU     28H             ; 8155 #2 CONTROL REGISTER
0029        TRSTS   EQU     29H             ; THE TRANSLATOR STATUS PORT
002A        TRWRD   EQU     2AH             ; THE CONTROL WORD PORT
002B        PLSENP  EQU     2BH             ; THE PULSETRAIN SELECT PORT
000E        TRIWR   EQU     0EH             ; PORT INITIALIZATION WORD
            ;
            ;       TRANSLATOR INTERFACE CONTROL WORDS
            ;
0000        AXIS1   EQU     00H                     ; CONTROL NIBBLES TO SELECT AXES
0010        AXIS2   EQU     10H
0020        AXIS3   EQU     20H
            ;
0006        CWB     EQU     06H                     ; CONTROL NIBBLE FOR BASE SPEED
                                                    ; CLOCKWISE ROTATION
000A        CCWB    EQU     0AH                     ; CONTROL NIBBLE FOR BASE SPEED
                                                    ; COUNTER CLOCKWISE ROTATION
0000        DEAD    EQU     00H                     ; STOPPED MOTORS
            ;
            ;       TRANSLATOR INTERFACE STATUS WORDS
            ;
0000        OFF     EQU     00H
0001        CW1     EQU     01H
0002        CCW1    EQU     02H
0004        CW2     EQU     04H
0008        CCW2    EQU     08H
0010        CW3     EQU     10H
0020        CCW3    EQU     20H
```

```
0000                MANC    EQU     00H
00C0                AUTOC   EQU     0C0H
                    ;
                    ;       PULSE ANALYSIS WORDS
                    ;
0002                PLLIP   EQU     02H                 ; INIT WORD
0020                PLREG   EQU     20H                 ; 8155#2 CONTROL REGISTER
0023                POLPRT  EQU     23H                 ; PULSE ANALYSIS REGISTER
0008                PULSE1  EQU     08H                 ; PULSE TRAIN1 SELECT
0018                PULSE2  EQU     18H                 ; PULSE TRAIN2 SELECT
0028                PULSE3  EQU     28H                 ; PULSE TRAIN3 SELECT
                    ;
                    ;       POSITION UPDATE (LED) INTERFACE CONTROL WORDS AND LOCATIONS
                    ;
0080                LEDIP   EQU     80H                 ; INITIALIZATION WORD
00A0                LED1    EQU     0A0H                ; ARRAY FOR AXIS1
00B0                LED2    EQU     0B0H                ; ARRAY FOR AXIS2
00C0                LED3    EQU     0C0H                ; ARRAY FOR AXIS3
                    ;
                    ;       R3D2 CONTROL ALGORITHM
                    ;
3000  31 FF 28      FIRST:  LXI     SP,STACK            ; INITIALIZE THE STACK
3003  21 07 30              LXI     H,R3D2
3006  E9                    PCHL
3007  CD F1 30      R3D2:   CALL    INITP               ; INITIALIZE 8155 #2 PORTS
300A  CD 09 31              CALL    INITD               ; INITIALIZE DATA BUFFERS
300D  CD 02 31              CALL    INITSP              ; INITIALIZE COMMUNICATION LINK
3010  CD 35 31      TEST:   CALL    SWITCH              ; AUTO/MAN SWITCH
3013  47                    MOV     B,A                 ; COMPARE WITH B
3014  3E 00                 MVI     A,ZERO              ; 00H =MANUAL MODE
3016  B8                    CMP     B                   ;
3017  CA 31 31              JZ      MANOP               ; FALL THROUGH IF AUTO MODE
301A  3E 01                 MVI     A,ONE
301C  B8                    CMP     B                   ; CHECK TO BE SURE
301D  C2 10 30              JNZ     TEST                ; IF NOT READ SWITCH AGAIN
3020  CD E5 31      AUTOP:  CALL    LINK                ; TALK TO PDP
3023  11 00 28              LXI     D,ASCIIX            ; START OF ASCII BUFFER IN DE
3026  21 1B 28              LXI     H,NBCDX             ; HL LOCATES BCD STRING BUFFER
3029  22 34 28              SHLD    TMPHL               ; START OF BCD BUFFER IN TMPHL
302C  EB                    XCHG
302D  22 36 28              SHLD    TMPDE               ; START OF ASCII BUFFER IN TMPDE
3030  EB                    XCHG
3031  CD 61 31              CALL    ASCBCD              ; CONVERT TO BCD AND STORE IT
3034  11 07 28              LXI     D,ASCIIY
3037  21 24 28              LXI     H,NBCDY
303A  22 34 28              SHLD    TMPHL
303D  EB                    XCHG
303E  22 36 28              SHLD    TMPDE
3041  EB                    XCHG
3042  CD 61 31              CALL    ASCBCD
3045  11 0E 28              LXI     D,ASCIIZ
3048  21 2D 28              LXI     H,NBCDZ
```

```
304B  22 34 28            SHLD    TMPHL
304E  EB                  XCHG
304F  22 36 28            SHLD    TMPDE
3052  EB                  XCHG
3053  CD 61 31            CALL    ASCBCD
                    ;;;
3056  01 18 28      XMOV: LXI     B,TBCDX
3059  21 34 28            LXI     H,TMPHL
305C  71                  MOV     M,C
305D  23                  INX     H
305E  70                  MOV     M,B
305F  11 1B 28            LXI     D,NBCDX
3062  21 36 28            LXI     H,TMPDE
3065  73                  MOV     M,E
3066  23                  INX     H
3067  72                  MOV     M,D
3068  21 3A 28            LXI     H,AXIS
306B  36 00               MVI     M,AXIS1
306D  21 3B 28            LXI     H,LED
3070  36 A0               MVI     M,LED1
3072  21 15 28            LXI     H,OBCDX
3075  3E 08               MVI     A,PULSE1
3077  D3 2B               OUT     PLSENP
3079  CD 12 32            CALL    MOVE
                    ;;;
307C  0E 03               MVI     C,03H
307E  11 15 28            LXI     D,OBCDX
3081  21 1B 28            LXI     H,NBCDX
3084  CD 1D 31            CALL    SWAPP
                    ;;;

                    ;
                    ;     PROGRAM CONTROL IS RETURNED HERE WHEN THE AXIS IS SUCCESSFULLY
                    ;     POSITIONED AND POSITION IS UPDATED ON FRONT PANNEL
                    ;
3087  01 21 28      YMOV: LXI     B,TBCDY
308A  21 34 28            LXI     H,TMPHL
308D  71                  MOV     M,C
308E  23                  INX     H
308F  70                  MOV     M,B
3090  11 24 28            LXI     D,NBCDY
3093  21 36 28            LXI     H,TMPDE
3096  73                  MOV     M,E
3097  23                  INX     H
3098  72                  MOV     M,D
3099  21 3A 28            LXI     H,AXIS
309C  36 10               MVI     M,AXIS2
309E  21 3B 28            LXI     H,LED
30A1  36 B0               MVI     M,LED2
30A3  21 1E 28            LXI     H,OBCDY
30A6  3E 18               MVI     A,PULSE2
30A8  D3 2B               OUT     PLSENP
```

```
30AA  CD 12 32          CALL    MOVE
30AD  0E 03             MVI     C,03H
30AF  21 24 28          LXI     H,NBCDY
30B2  11 1E 28          LXI     D,OBCDY
30B5  CD 1D 31          CALL    SWAPP
                ;
30B8  01 2A 28  ZMOV:   LXI     B,TBCDZ
30BB  21 34 28          LXI     H,TMPHL
30BE  71                MOV     M,C
30BF  23                INX     H
30C0  70                MOV     M,B
30C1  11 2D 28          LXI     D,NBCDZ
30C4  21 36 28          LXI     H,TMPDE
30C7  73                MOV     M,E
30C8  23                INX     H
30C9  72                MOV     M,D
30CA  21 3A 28          LXI     H,AXIS
30CD  36 20             MVI     M,AXIS3
30CF  21 3B 28          LXI     H,LED
30D2  36 C0             MVI     M,LED3
30D4  21 27 28          LXI     H,OBCDZ
30D7  3E 28             MVI     A,PULSE3
30D9  D3 2B             OUT     PLSENP
30DB  CD 12 32          CALL    MOVE
30DE  0E 03             MVI     C,03H
30E0  21 2D 28          LXI     H,NBCDZ
30E3  11 27 28          LXI     D,OBCDZ
30E6  CD 1D 31          CALL    SWAPP
                ;
                ;       THE CORE ALGORITHM GOES HERE
                ;
30E9  3E 44             MVI     A,44H           ;44H='D' IN ASCII CODE
30EB  CD 00 20          CALL    PTCHAR
30EE  C3 10 30          JMP     TEST            ; TEST FRONT PANEL SWITCHES
                ;
                ;
                ;       INITIALIZE ALL PARALLEL PORTS ON 8155 AND 8255 CHIPS
30F1  3E 02     INITP:  MVI     A,PLLIP         ; INITIALIZATION FOR 8155#1
30F3  D3 20             OUT     PLREG
30F5  3E 0E             MVI     A,TRIWR         ; INIT 8155#2
30F7  D3 28             OUT     TRCR
30F9  3E 80             MVI     A,LEDIP         ; 8255 1,2 AND 3 ARE ALL OUTPUT PORTS
30FB  D3 A3             OUT     LED1+3
30FD  D3 B3             OUT     LED2+3
30FF  D3 C3             OUT     LED3+3
3101  C9                RET                     ; PARALLEL PORTS INITIALIZED
3102  CD 16 20  INITSP: CALL    BAUD            ; SET UP BAUD RATE
3105  CD 23 20          CALL    USET            ; INITIALIZE TO 1200 BAUD
3108  C9                RET
3109  21 00 28  INITD:  LXI     H,ASCIIY        ; POINT TO 8155#2 RAM
310C  0E 40             MVI     C,BLNKBF        ; C HAS # OF POSITIONS TO BE BLANKED
310E  AF                XRA     A               ; CLEAR ACCUMULATOR FOR COMPARE
```

```
 310F  36 00      BLNKLP: MVI     M,ZERO
 3111  0D                 DCR     C
 3112  23                 INX     H
 3113  B9                 CMP     C
 3114  C2 0F 31           JNZ     BLNKLP          ; LOOP ALL CHAR ZERO
 3117  21 30 28           LXI     H,NZERO         ; "NEGATIVE" ZERO IN THE NZERO BUFFER
 311A  36 10              MVI     M,NZER
 311C  C9                 RET
                  ;       SUBROUTINE SWAPP ...    # OF BUFF CHARACTERS IN REG C
                                                  ; HL HAS POINTER TO NEW POSITIONS
                                                  ; DE HAS POINTER TO OLD POSITION BUFFER
 311D  46         SWAPP:  MOV     B,M             ; B HAS NEW POSITION
 311E  23                 INX     H               ; TURN NEW POSITION POINTER
 311F  EB                 XCHG                    ; SWAP IT WITH OLD POSITION POINTER
 3120  70                 MOV     M,B             ; STORE IN THE OLD POSITION BUFFER
 3121  23                 INX     H               ; TURN OLD POSITION POINTER
 3122  EB                 XCHG                    ; HL HAS NEW POINTER
                                                  ; DE HAS OLD POINTER
 3123  0D                 DCR     C               ; COUNT CHARACTERS
 3124  3E 00              MVI     A,ZERO          ;
 3126  B9                 CMP     C               ; LAST CHARACTER ?
 3127  C2 1D 31           JNZ     SWAPP           ; LOOP TIL BUFFER SWAPPED
 312A  C9                 RET                     ; RETURN WHEN DONE
                  ;
                  ;       TELL PDP YOU ARE DONE
                  ;
 312B  3E 44      MDNE:   MVI     A,'D'           ; D MEANS DONE
 312D  CD 00 20           CALL    PTCHAR
 3130  C9                 RET                     ; GO CHECK THE SWITCHES
 3131  00         MANOP:  NOP
 3132  C3 10 30           JMP     TEST
                  ;
                  ;
 3135  16 05      SWITCH: MVI     D,05H           ; D COUNTS PASSES THROUGH MAN
 3137  1E 05              MVI     E,05H           ; E THROUGH AUTO
 3139  DB 29      IN:     IN      TRSTS
 313B  47                 MOV     B,A             ; SAVE IN B
 313C  E6 C0              ANI     AUTOC
 313E  4F                 MOV     C,A             ; SAVE ANDED RESULT IN C
 313F  3E C0              MVI     A,AUTOC
 3141  B9                 CMP     C
 3142  CA 57 31           JZ      AUTO
 3145  78                 MOV     A,B             ; GET STATUS WORD
 3146  E6 00              ANI     MANC            ; WAS IT MANUAL ?
 3148  4F                 MOV     C,A             ; USE C TO FIND OUT
 3149  3E 00              MVI     A,MANC          ; COMPARE WITH MANUAL
 314B  B9                 CMP     C
 314C  C2 D7 31           JNZ     ERR             ; IF NOT MANUAL OR AUTO SWITCH
                                                  ; IS BROKEN ... SEND ERROR TO PDP
 314F  15         MAN:    DCR     D
 3150  3E 00              MVI     A,00H           ; 00H IS LASTLOOP COUNT
 3152  BA                 CMP     D
```

```
3153  C2 37 31               JNZ     IN
3156  C9                     RET
3157  1D            AUTO:    DCR     E
3158  3E 00                  MVI     A,00H
315A  BB                     CMP     E
315B  C2 39 31               JNZ     IN
315E  3E 01                  MVI     A,01H
3160  C9                     RET
                    ;
                    ;        TMPDE HAS START OF ASCII STRING
                    ;        TMPHL HAS START OF BCD BUFFER
                    ;        S1.XXX BECOMES MNL WHERE M= SIGN , TENS OF INCHES
                    ;                                 N= INCHES , TENTHS
                    ;                                 L= HUNDREDTH , THOUSANDTHS
                    ;
                    ;        RESULT IS RETURNED IN THE BCD BUFFER
                    ;
3161  2A 36 28      ASCBCD:  LHLD    TMPDE          ; SCAN ASCII FOR SIGNS
3164  0E 06                  MVI     C,06H          ;;;
3166  CD C4 31               CALL    SIGN           ; - SIGN = 10H IN ACCUMULATOR
3169  EB                     XCHG                   ; + SIGN = 00H
316A  2A 34 28               LHLD    TMPHL
316D  77                     MOV     M,A            ; STORE SIGN IN BCD BUFFER
316E  EB            ABSVAL:  XCHG                   ; DE POINTS TO BCD BUFFER
316F  2A 36 28               LHLD    TMPDE          ; GET LEADING ASCII LOCATION AGAIN
3172  23                     INX     H              ; TURN POINTER TO NEXT LOCATION
3173  0E 05                  MVI     C,05H          ; FIVE CHARACTERS LEFT IN ASCII BUFFER
3175  CD 9D 31               CALL    DATAS          ; GET THE NEXT ASCII CHARCTER - RETURN
                                                    ; WITH BCD IN ACCUMULATOR
3178  0D                     DCR     C              ; COUNT THE CHARCTER
3179  EB                     XCHG                   ; POINT TO BCD BUFFER
317A  86                     ADD     M              ; ADD LOW AND HIGH NIBBLES TO FORM MSB
                                                    ; OF THE BCD REPRESENTATION
317B  77                     MOV     M,A            ; SAVE IN THE MSB OF THE BCD BUFFER
317C  23                     INX     H              ; TURN BCD BUFFER POINTER
317D  EB                     XCHG                   ; SWAP REG - POINT AT ASCII
317E  23                     INX     H              ; TURN POINTER TO NEXT ASCII CHARCTER
317F  CD 9D 31      LOP2:    CALL    DATAS          ; GET BCD CHARCTER
3182  0D                     DCR     C              ; COUNT IT
3183  37                     STC                    ; SET CARRY BEFORE THE RAL INSTRUCTION
3184  3F                     CMC                    ; COMPLIMENT IT TO BE SURE IT IS CLEARED
3185  17                     RAL
3186  17                     RAL
3187  17                     RAL
3188  17                     RAL                    ; BCD IS MOVED INTO THE TOP NIBBLE
3189  EB                     XCHG                   ; POINT TO NEXT BCD STORAGE LOCATION
318A  77                     MOV     M,A            ; STORE TOP NIBBLE HERE
318B  EB                     XCHG                   ; POINT TO LAST ASCII
318C  23                     INX     H              ; THEN TURN POINTER
318D  CD 9D 31               CALL    DATAS          ; CONVERT TO BCD
3190  0D                     DCR     C
3191  EB                     XCHG                   ; POINT TO TOP NIBBLE LOCATION
```

```
3192  86                    ADD     M          ; ADD TOP NIBBLE TO BOTTOM
3193  77                    MOV     M,A        ; AND STORE IT IN MEMORY
3194  23                    INX     H          ; TURN BCD POINTER TO NEXT STORAGE
3195  EB                    XCHG               ; POINT TO ASCII NOW WITH HL
3196  23                    INX     H          ; TURN ASCII POINTER TO NEXT PAIR
3197  AF                    XRA     A
3198  B9                    CMP     C          ; HAVE WE COUNTED ALL THE CHARACTERS?
3199  C2 7F 31              JNZ     LOP2       ; IF NOT GO AND CONVERT THEM TO BCD
319C  C9                    RET                ; IF SO WE HAVE CONVERTFD FROM FORTRAN
                                               ; I6 ASCII TO HOWE FORMAT BCD
319D  7E          DATAS:    MOV     A,M
319E  47                    MOV     B,A
319F  3E 20                 MVI     A,' '      ; IS IT A BLANK
31A1  B8                    CMP     B
31A2  C2 A8 31              JNZ     NTST
31A5  3E 00       BKWRD:    MVI     A,ZERO
31A7  C9                    RET
31A8  3E 2D       NTST:     MVI     A,'-'
31AA  B8                    CMP     B
31AB  CA A5 31              JZ      BKWRD
31AE  78                    MOV     A,B
31AF  CD B3 31              CALL    NUMBER
31B2  C9                    RET
31B3  47          NUMBER:   MOV     B,A
31B4  3E 2F                 MVI     A,ASCIIL
31B6  B8                    CMP     B
31B7  F2 D7 31              JP      ERR
31BA  3E 39                 MVI     A,ASCIIH
31BC  B8                    CMP     B
31BD  FA D7 31              JM      ERR
31C0  78                    MOV     A,B
31C1  D6 30                 SUI     30H
31C3  C9                    RET
31C4  46          SIGN:     MOV     B,M
31C5  3E 2D                 MVI     A,'-'
31C7  B8                    CMP     B
31C8  CA D4 31              JZ      MINUS
31CB  0D                    DCR     C
31CC  3E 00                 MVI     A,ZERO
31CE  B9                    CMP     C
31CF  23                    INX     H
31D0  C2 C4 31              JNZ     SIGN
31D3  C9                    RET                          ; SIGN SCAN COMPLETE
31D4  3E 10       MINUS:    MVI     A,10H
31D6  C9                    RET
31D7  3E 45       ERR:      MVI     A,'E'      ; SEND E TO PDP-11/34
31D9  CD 00 20              CALL    PTCHAR
31DC  C3 00 00              JMP     SDK85
31DF  3E 52       REDY:     MVI     A,'R'
31E1  CD 00 20              CALL    PTCHAR     ; SEND R TO PDP-11/34
31E4  C9                    RET
                  ;
```

```
                           ;        COMMUNICATION LINK WITH PDP-11/34 EXECUTIVE COMPUTER
                           ;
                           ;
31E5   21 00 28    LINK:    LXI     H,ASCIIX          ; BUFFER LOCATION HL
31E8   CD F8 31             CALL    STRING            ; GET MESSAGE IN BUFFER
31EB   21 07 28             LXI     H,ASCIIY
31EE   CD F8 31             CALL    STRING
31F1   21 0E 28             LXI     H,ASCIIZ
31F4   CD F8 31             CALL    STRING
31F7   C9                   RET
                           ;
                           ;        PUTS A STRING OF CHARACTERS IN A BUFFER POINTED TO BY HL
                           ;
31F8   CD 0C 20    STRING:  CALL    GCHAR             ; IS THIS A LINE FEED ?
31FB   FE 2F                CPI     2FH               ;2FH='/'
31FD   CA 03 32             JZ      INPUT
3200   C3 F8 31             JMP     STRING
3203   CD 0C 20    INPUT:   CALL    GCHAR             ; GET A CHARACTER AND TEST IT
3206   47                   MOV     B,A
3207   FE 2A                CPI     2AH               ;2AH='*'
3209   CA 11 32             JZ      STAR
320C   70                   MOV     M,B               ; IF NOT <LF> STORE IN MEMORY
320D   23                   INX     H
320E   C3 03 32             JMP     INPUT
3211   C9          STAR:    RET
                           ;
3212   CD 3A 32    MOVE:    CALL    MASKI             ; BRING IN MASKED SIGN BIT
3215   CA 29 32             JZ      PLUS0
3218   EB                   XCHG                      ; DE POINTS TO OLD
                                                      ; HL POINTS TO NEW
3219   CD 3A 32             CALL    MASKI
321C   CA 24 32             JZ      NIP0
321F   EB                   XCHG                      ; HL POINTS TO OLD
                                                      ; DE POINTS TO NEW
3220   CD 41 32             CALL    POS00
3223   C9                   RET                       ; MOVE IS COMPLETE
3224   EB          NIP0:    XCHG                      ; HL POINTS TO OLD
                                                      ; DE POINTS TO NEW
3225   CD 33 33             CALL    POS01
3228   C9                   RET                       ; MOVE COMPLETE
3229   EB          PLUS0:   XCHG                      ; DE POINTS TO OLD
                                                      ; HL POINTS TO NEW
322A   CD 3A 32             CALL    MASKI
322D   CA 35 32             JZ      NIP1
3230   EB                   XCHG                      ; HL POINTS TO OLD
                                                      ; DE POINTS TO NEW
3231   CD 3A 33             CALL    POS10
3234   C9                   RET
3235   EB          NIP1:    XCHG
3236   CD B9 32             CALL    POS11
3239   C9                   RET                       ; ALL AXIS MOVES ARE FILTERED AND
                                                      ; PERFORMED
```

```
323A  7E          MASKI:  MOV     A,M
323B  E6 10               ANI     10H                 ; STRIP TO LEAVE SIGN
323D  47                  MOV     B,A
323E  AF                  XRA     A
323F  B8                  CMP     B
3240  C9                  RET
                  ;
                  ;       POS00 TAKES CARE OF MOVES WITH BOTH POSITIONS ON NEGATIVE AXIS
                  ;
3241  7E          POS00:  MOV     A,M         ; GET OLD MSB
3242  E6 0F               ANI     0FH                 ; STRIP THE SIGN
3244  4F                  MOV     C,A                 ; SAVE IN REG B
3245  B9                  CMP     C
3246  FA B0 35            JM      FLSHR               ; FLASH ON ERROR
3249  EB                  XCHG
324A  7E                  MOV     A,M                 ; DE=OLD,HL=NEW
324B  E6 0F               ANI     0FH                 ; STRIP SIGN
324D  47                  MOV     B,A
324E  3E 01               MVI     A,01H
3250  B8                  CMP     B
3251  FA B0 35            JM      FLSHR               ; C CAN'T BE >1 EITHER
3254  C2 62 32            JNZ     TSTZ                ; IF NOT ONE MUST BE ZERO
3257  AF                  XRA     A                   ; C IS ONE
3258  B9                  CMP     C                   ; B=0?
3259  CA 9D 32            JZ      LPA01
325C  3E 01               MVI     A,01H
325E  B9                  CMP     C
325F  CA 6B 32            JZ      LPA11               ; IF SO BOTH ARE 1X.XXX
                                                      ; DO FURTHER TESTS
3262  3E 01       TSTZ:   MVI     A,01H
3264  B9                  CMP     C
3265  CA AC 32            JZ      LPA10
3268  C3 93 32            JMP     LPA00
326B  EB          LPA11:  XCHG
326C  23                  INX     H                   ; HL=OLDBUF NSB
326D  13                  INX     D                   ; DE = NEWBUF NSB
326E  4E                  MOV     C,M                 ; PUT NSB IN C
326F  3E 1F               MVI     A,1FH               ; >12 INCH TRAVERSE ?
3271  B9                  CMP     C                   ;
3272  FA B0 35            JM      FLSHR
3275  EB                  XCHG
3276  46                  MOV     B,M
3277  3E 1F               MVI     A,1FH
3279  B8                  CMP     B
327A  FA B0 35            JM      FLSHR
327D  EB                  XCHG                        ; DE=NEWBUF+1,HL=OLDBUF+1
327E  78          ENTRYA: MOV     A,B
327F  B9                  CMP     C
3280  C2 8A 32            JNZ     NXTMOV              ; B&C NE IS ENOUGH TO MOVE AXIS
3283  23                  INX     H                   ; HL=OLDBUF+2
3284  13                  INX     D                   ; DE=NEWBUF+2
3285  4E                  MOV     C,M
```

```
3286  EB                    XCHG
3287  46                    MOV     B,M
3288  78                    MOV     A,B
3289  B9                    CMP     C               ; RESULT=B-C=NEW-OLD
328A  CA 79 33     NXTMOV:  JZ      NOMOVE
328D  FA 5D 33              JM      DCRCCW          ; MOVE TO MORE POS DIRECT
3290  C3 4F 33              JMP     INCCW           ; MOVE TO MORE NEG DIRECT
3293  EB           LPA00:   XCHG                    ; NEITHER MSB IS 1
3294  23                    INX     H               ; HL=OLDBUF+1
3295  13                    INX     D               ; DE=NEWBUF+1
3296  4E                    MOV     C,M             ; OLD NSB
3297  EB                    XCHG
3298  46                    MOV     B,M             ; NEW NSB
3299  EB                    XCHG
329A  C3 7E 32              JMP     ENTRYA          ; TEST THE REST OF THE PSITNS
329D  EB           LPA01:   XCHG                    ; NEWMSB=1,OLD IS 0
329E  23                    INX     H               ; HL=OLDBUF+1
329F  13                    INX     D               ; DE=NEWBUF+1
32A0  EB                    XCHG
32A1  46                    MOV     B,M             ; C HAS NEWBUF NSB
32A2  3E 1F                 MVI     A,1FH
32A4  B8                    CMP     B
32A5  FA B0 35              JM      FLSHR
32A8  EB                    XCHG
32A9  C3 4F 33              JMP     INCCW           ; MOVE TO MORE NEG POSITION
32AC  EB           LPA10:   XCHG                    ; HL=OLDBUF
32AD  23                    INX     H               ; +1
32AE  13                    INX     D               ; DE = NEWBUF+1
32AF  4E                    MOV     C,M             ; B HAS OLD NSB
32B0  3E 1F                 MVI     A,1FH
32B2  B9                    CMP     C
32B3  FA B0 35              JM      FLSHR
32B6  C3 5D 33              JMP     DCRCCW
32B9  7E           POS11:   MOV     A,M
32BA  E6 0F                 ANI     0FH
32BC  4F                    MOV     C,A
32BD  3E 01                 MVI     A,01H
32BF  B9                    CMP     C
32C0  FA B0 35              JM      FLSHR
32C3  EB                    XCHG
32C4  7E                    MOV     A,M
32C5  E6 0F                 ANI     0FH
32C7  47                    MOV     B,A
32C8  3E 01                 MVI     A,01H
32CA  B8                    CMP     B
32CB  FA B0 35              JM      FLSHR
32CE  C2 DC 32              JNZ     TESTZ
32D1  AF                    XRA     A
32D2  B9                    CMP     C
32D3  CA 17 33              JZ      LP01
32D6  3E 01                 MVI     A,01H
32D8  B9                    CMP     C
```

```
32D9  CA E5 32              JZ      LP11
32DC  3E 01       TESTZ:    MVI     A,01H
32DE  B9                    CMP     C
32DF  CA 26 33              JZ      LP10
32E2  C3 0D 33              JMP     LP00
32E5  EB          LP11:     XCHG
32E6  23                    INX     H
32E7  13                    INX     D
32E8  4E                    MOV     C,M
32E9  3E 1F                 MVI     A,1FH
32EB  B9                    CMP     C
32EC  FA B0 35              JM      FLSHR
32EF  EB                    XCHG
32F0  46                    MOV     B,M
32F1  3E 1F                 MVI     A,1FH
32F3  B8                    CMP     B
32F4  FA B0 35              JM      FLSHR
32F7  EB                    XCHG
32F8  78          ENTER:    MOV     A,B
32F9  B9                    CMP     C
32FA  C2 04 33              JNZ     NXTMV
32FD  23                    INX     H
32FE  13                    INX     D
32FF  4E                    MOV     C,M
3300  EB                    XCHG
3301  46                    MOV     B,M
3302  78                    MOV     A,B
3303  B9                    CMP     C
3304  CA 79 33    NXTMV:    JZ      NOMOVE
3307  FA 6B 33              JM      DCRCW
330A  C3 41 33              JMP     INCCCW                  ; MORE POS POSITION MOVE
330D  EB          LP00:     XCHG
330E  23                    INX     H
330F  13                    INX     D
3310  4E                    MOV     C,M
3311  EB                    XCHG
3312  46                    MOV     B,M
3313  EB                    XCHG
3314  C3 F8 32              JMP     ENTER
3317  EB          LP01:     XCHG
3318  23                    INX     H
3319  13                    INX     D
331A  EB                    XCHG
331B  46                    MOV     B,M
331C  3E 1F                 MVI     A,1FH
331E  B8                    CMP     B
331F  FA B0 35              JM      FLSHR
3322  EB                    XCHG
3323  C3 41 33              JMP     INCCCW                  ; MORE POS POSITION MOVF
3326  EB          LP10:     XCHG
3327  23                    INX     H
3328  13                    INX     D
```

```
3329  4E                 MOV     C,M
332A  3E 1F              MVI     A,1FH
332C  B9                 CMP     C
332D  FA B0 35           JM      FLSHR
3330  C3 6B 33           JMP     DCRCW
                ;
                ;        POS01 FOR MOVE FROM NEG TO POS AXIS
                ;
3333  CD 20 35  POS01:   CALL    CCWDCZ                 ; HL IS OLD BUFF POINTER
                                                        ; DE IS NEW
3336  CD 41 33           CALL    INCCCW
3339  C9                 RET
                ;
                ;        POS10 FOR MOVE FROM POS TO NEG AXIS
                ;
333A  CD 64 35  POS10:   CALL    CWDCZ
333D  CD 4F 33           CALL    INCCW
3340  C9                 RET
                ;
3341  2A 34 28  INCCCW:  LHLD    TMPHL
3344  3A 3A 28           LDA     AXIS
3347  C6 0A              ADI     CCWB
3349  D3 2A              OUT     TRWRD
334B  CD 7A 33           CALL    INCNT
334E  C9                 RET
                ;
334F  2A 34 28  INCCW:   LHLD    TMPHL
3352  3A 3A 28           LDA     AXIS
3355  C6 06              ADI     CWB
3357  D3 2A              OUT     TRWRD
3359  CD 7A 33           CALL    INCNT
335C  C9                 RET
                ;
335D  2A 34 28  DCRCCW:  LHLD    TMPHL
3360  3A 3A 28           LDA     AXIS
3363  C6 0A              ADI     CCWB
3365  D3 2A              OUT     TRWRD
3367  CD D6 33           CALL    DCRNT
336A  C9                 RET
                ;
336B  2A 34 28  DCRCW:   LHLD    TMPHL
336E  3A 3A 28           LDA     AXIS
3371  C6 06              ADI     CWB
3373  D3 2A              OUT     TRWRD
3375  CD D6 33           CALL    DCRNT
3378  C9                 RET
3379  C9        NOMOVE:  RET
                ;
337A  56        INCNT:   MOV     D,M               ; TEST THE POSITION FIRST
337B  23                 INX     H
337C  46                 MOV     B,M
337D  23                 INX     H
```

```
337E  4E                   MOV   C,M
337F  C3 A4 33             JMP   CMPR      ; CHECK TO SEE IF WE ARE ALREADY
                                           ; AT LAST POSITION
3382  CD 32 34   INCNT1:   CALL  POLL      ; WAIT FOR GOOD PULSE TO OCCUR
3385  56                   MOV   D,M
3386  23                   INX   H         ; HL POINTS TO NSB
3387  46                   MOV   B,M       ; B=NSB
3388  23                   INX   H
3389  4E                   MOV   C,M       ; C=LSB
338A  79                   MOV   A,C
338B  C6 01                ADI   ONE
338D  27                   DAA
338E  4F                   MOV   C,A       ; RESTORE C WITH ADJUSTED VALUE
338F  D2 9F 33             JNC   SKIP
3392  78                   MOV   A,B
3393  C6 01                ADI   ONE       ; CARRY INTO NSD
3395  27                   DAA
3396  47                   MOV   B,A
3397  D2 9F 33             JNC   SKIP
339A  7A                   MOV   A,D
339B  C6 01                ADI   ONE       ; CARRY INTO MSB
339D  27                   DAA
339E  57                   MOV   D,A
339F  71         SKIP:     MOV   M,C
33A0  2B                   DCX   H
33A1  70                   MOV   M,B
33A2  2B                   DCX   H
33A3  72                   MOV   M,D
                                              ; HL = TEMPBUF
33A4  2A 36 28   CMPR:     LHLD  TMPDE        ; HL POINTS AT NEWBUF MSB
33A7  7E                   MOV   A,M
33A8  00                   NOP
33A9  BA                   CMP   D
33AA  C2 BE 33             JNZ   UPLEDA
33AD  23                   INX   H
33AE  7E                   MOV   A,M
33AF  B8                   CMP   B
33B0  C2 BD 33             JNZ   UPLEDB
33B3  23                   INX   H
33B4  7E                   MOV   A,M
33B5  B9                   CMP   C
33B6  C2 BC 33             JNZ   UPLEDC
33B9  C3 CA 33             JMP   STOPR
33BC  2B         UPLEDC:   DCX   H
33BD  2B         UPLEDB:   DCX   H
33BE  2A 34 28   UPLEDA:   LHLD  TMPHL
33C1  CD 59 34             CALL  UPDATE
33C4  2A 34 28             LHLD  TMPHL
33C7  C3 82 33             JMP   INCNT1
33CA  CD A8 35   STOPR:    CALL  STOP
33CD  2B                   DCX   H
33CE  2B                   DCX   H
```

```
33CF   2A 34 28             LHLD    TMPHL
33D2   CD 59 34             CALL    UPDATE
33D5   C9                   RET
33D6   56          DCRNT:   MOV     D,M
33D7   23                   INX     H
33D8   46                   MOV     B,M
33D9   23                   INX     H
33DA   4E                   MOV     C,M
33DB   C3 00 34             JMP     CMPRE
33DE   CD 32 34    DCRNT1:  CALL    POLL                    ; WAIT FOR GOOD PULSE
33E1   56                   MOV     D,M
33E2   23                   INX     H
33E3   46                   MOV     B,M
33E4   23                   INX     H
33E5   4E                   MOV     C,M
33E6   79                   MOV     A,C
33E7   C6 99                ADI     NNINE                   ; COUNT DOWN ONE PULSE
33E9   27                   DAA
33EA   4F                   MOV     C,A
33EB   DA FB 33             JC      SKIPD
33EE   78                   MOV     A,B
33EF   C6 99                ADI     NNINE                   ; BORROW FROM NSM
33F1   27                   DAA
33F2   47                   MOV     B,A
33F3   DA FB 33             JC      SKIPD
33F6   7A                   MOV     A,D
33F7   C6 99                ADI     NNINE                   ; BORROW FROM MSB
33F9   27                   DAA
33FA   57                   MOV     D,A
33FB   71          SKIPD:   MOV     M,C
33FC   2B                   DCX     H
33FD   70                   MOV     M,B
33FE   2B                   DCX     H
33FF   72                   MOV     M,D
3400   2A 36 28    CMPRE:   LHLD    TMPDE
3403   7E                   MOV     A,M
3404   00                   NOP
3405   BA                   CMP     D
3406   C2 1A 34             JNZ     UPLED
3409   23                   INX     H
340A   7E                   MOV     A,M
340B   B8                   CMP     B
340C   C2 19 34             JNZ     UPLED1
340F   23                   INX     H
3410   7E                   MOV     A,M
3411   B9                   CMP     C
3412   C2 18 34             JNZ     UPLED2
3415   C3 26 34             JMP     STOPD
3418   2B          UPLED2:  DCX     H
3419   2B          UPLED1:  DCX     H
341A   2A 34 28    UPLED:   LHLD    TMPHL
341D   CD 59 34             CALL    UPDATE
```

```
3420  2A 34 28            LHLD    TMPHL
3423  C3 DE 33            JMP     DCRNT1
3426  CD A8 35   STOPD:   CALL    STOP
3429  2B                  DCX     H
342A  2B                  DCX     H
342B  2A 34 28            LHLD    TMPHL
342E  CD 59 34            CALL    UPDATE
3431  C9                  RET
3432  1E 00      POLL:    MVI     E,00H              ; USE E TO COUNT POLL
3434  CD 51 34   LOOP:    CALL    GETDTA
3437  C2 34 34            JNZ     LOOP
343A  1C                  INR     E
343B  3E 02               MVI     A,02H
343D  BB                  CMP     E
343E  C2 34 34            JNZ     LOOP
3441  1E 00               MVI     E,00H
3443  CD 51 34   LOOP2:   CALL    GETDTA
3446  CA 43 34            JZ      LOOP2
3449  1C                  INR     E
344A  3E 02               MVI     A,02H
344C  BB                  CMP     E
344D  C2 43 34            JNZ     LOOP2
3450  C9                  RET                        ; COUNT IT
3451  DB 23      GETDTA:  IN      POLPRT
3453  E6 02               ANI     02H
3455  47                  MOV     B,A
3456  AF                  XRA     A
3457  B8                  CMP     B
3458  C9                  RET
3459  3A 3B 28   UPDATE:  LDA     LED
345C  5F                  MOV     E,A
345D  3E A0               MVI     A,LED1
345F  BB                  CMP     E
3460  CA E7 34            JZ      AX1
3463  3E B0               MVI     A,LED2
3465  BB                  CMP     E
3466  CA A8 34            JZ      AX2
3469  7E         AX3:     MOV     A,M
346A  E6 10               ANI     10H
346C  5F                  MOV     E,A
346D  AF                  XRA     A
346E  BB                  CMP     E
346F  CA 8A 34            JZ      PLUS3
3472  7E                  MOV     A,M
3473  E6 0F               ANI     0FH
3475  5F                  MOV     E,A
3476  3E 01               MVI     A,01H
3478  BB                  CMP     E
3479  CA 83 34            JZ      NEG31
347C  3E 42               MVI     A,42H
347E  D3 C2               OUT     LED3+2
3480  C3 9F 34            JMP     AX3C
```

```
3483   3E 4E       NEG31:   MVI     A,4EH
3485   D3 C2                OUT     LED3+2
3487   C3 9F 34             JMP     AX3C
348A   7E          PLUS3:   MOV     A,M
348B   E6 0F                ANI     0FH
348D   5F                   MOV     E,A
348E   3E 01                MVI     A,01H
3490   BB                   CMP     E
3491   CA 9B 34             JZ      PLUS31
3494   3E 40                MVI     A,40H
3496   D3 C2                OUT     LED3+2
3498   C3 9F 34             JMP     AX3C
349B   3E 4C       PLUS31:  MVI     A,4CH
349D   D3 C2                OUT     LED3+2
349F   23          AX3C:    INX     H                       ; POINT TO NSB
34A0   7E                   MOV     A,M
34A1   D3 C1                OUT     LED3+1
34A3   23                   INX     H
34A4   7E                   MOV     A,M
34A5   D3 C0                OUT     LED3
34A7   C9                   RET
34A8   7E          AX2:     MOV     A,M
34A9   E6 10                ANI     10H
34AB   5F                   MOV     E,A
34AC   AF                   XRA     A
34AD   BB                   CMP     E
34AE   CA C9 34             JZ      PLUS2
34B1   7E                   MOV     A,M
34B2   E6 0F                ANI     0FH
34B4   5F                   MOV     E,A
34B5   3E 01                MVI     A,01H
34B7   BB                   CMP     E
34B8   CA C2 34             JZ      NEG21
34BB   3E 42                MVI     A,42H
34BD   D3 B2                OUT     LED2+2
34BF   C3 DE 34             JMP     AX2C
34C2   3E 4E       NEG21:   MVI     A,4EH
34C4   D3 B2                OUT     LED2+2
34C6   C3 DE 34             JMP     AX2C
34C9   7E          PLUS2:   MOV     A,M
34CA   E6 0F                ANI     0FH
34CC   5F                   MOV     E,A
34CD   3E 01                MVI     A,01H
34CF   BB                   CMP     E
34D0   CA DA 34             JZ      PLUS21
34D3   3E 40                MVI     A,40H
34D5   D3 B2                OUT     LED2+2
34D7   C3 DE 34             JMP     AX2C
34DA   3E 4C       PLUS21:  MVI     A,4CH
34DC   D3 B2                OUT     LED2+2
34DE   23          AX2C:    INX     H
34DF   7E                   MOV     A,M
```

```
34E0  D3 B1               OUT     LED2+1
34E2  23                  INX     H
34E3  7E                  MOV     A,M
34E4  D3 B0               OUT     LED2
34E6  C9                  RET
34E7  7E         AX1:     MOV     A,M
34E8  E6 10               ANI     10H
34EA  5F                  MOV     E,A
34EB  AF                  XRA     A
34EC  BB                  CMP     E
34ED  CA 02 35            JZ      PLUS1
34F0  7E                  MOV     A,M
34F1  E6 0F               ANI     0FH
34F3  5F                  MOV     E,A
34F4  3E 42               MVI     A,42H
34F6  D3 A2               OUT     LED1+2
34F8  C3 17 35            JMP     AX1C
34FB  3E 4E      NEG11:   MVI     A,4EH
34FD  D3 A2               OUT     LED1+2
34FF  C3 17 35            JMP     AX1C
3502  7E         PLUS1:   MOV     A,M
3503  E6 0F               ANI     0FH
3505  5F                  MOV     E,A
3506  3E 01               MVI     A,01H
3508  BB                  CMP     E
3509  CA 13 35            JZ      PLUS11
350C  3E 40               MVI     A,40H
350E  D3 A2               OUT     LED1+2
3510  C3 17 35            JMP     AX1C
3513  3E 4C      PLUS11:  MVI     A,4CH
3515  D3 A2               OUT     LED1+2
3517  23         AX1C:    INX     H
3518  7E                  MOV     A,M
3519  D3 A1               OUT     LED1+1
351B  23                  INX     H
351C  7E                  MOV     A,M
351D  D3 A0               OUT     LED1
351F  C9                  RET
3520  2A 36 28   CCWDCZ:  LHLD    TMPDE           ; LOAD HL WITH NEW BUFER POINTER
3523  E5                  PUSH    H
3524  21 36 28            LXI     H,TMPDE
3527  11 30 28            LXI     D,NZERO
352A  73                  MOV     M,E
352B  23                  INX     H
352C  72                  MOV     M,D             ; PUT ZERO IN TEMP BUFFER FOR NOW
352D  2A 34 28            LHLD    TMPHL
3530  7E                  MOV     A,M             ; TEST MSB FOR ZERO
3531  E6 0F               ANI     0FH             ; STRIP THE SIGN
3533  47                  MOV     B,A             ; STORE IN B FOR TEST
3534  AF                  XRA     A               ; CLEAR ACCUMULATOR
3535  B8                  CMP     B
3536  C2 48 35            JNZ     EXIT
```

```
 3539  23                 INX     H
 353A  46                 MOV     B,M
 353B  B8                 CMP     B              ; TEST NSB
 353C  C2 48 35           JNZ     EXIT
 353F  23                 INX     H
 3540  46                 MOV     B,M
 3541  B8                 CMP     B              ; AND LSB ALSO
 3542  C2 48 35           JNZ     EXIT
 3545  C3 55 35           JMP     END1
 3548  2A 34 28   EXIT:   LHLD    TMPHL          ; RELOAD OLD POSITION POINTER
 354B  3A 3A 28           LDA     AXIS
 354E  C6 0A              ADI     CCWB
 3550  D3 2A              OUT     TRWRD
 3552  CD D6 33           CALL    DCRNT
 3555  D1         END1:   POP     D              ; RETREIVE NEW POSITION FROM STACK
 3556  21 36 28           LXI     H,TMPDE
 3559  73                 MOV     M,E
 355A  23                 INX     H
 355B  72                 MOV     M,D
 355C  2A 34 28           LHLD    TMPHL
                  ;       NOW TURN THE SIGN TO A POSITIVE ZERO POSITION
 355F  7E                 MOV     A,M
 3560  E6 0F              ANI     0FH
 3562  77                 MOV     M,A
 3563  C9                 RET
 3564  2A 36 28   CWDCZ:  LHLD    TMPDE
 3567  E5                 PUSH    H
 3568  21 36 28           LXI     H,TMPDE
 356B  11 31 28           LXI     D,PZERO
 356E  73                 MOV     M,E
 356F  23                 INX     H
 3570  72                 MOV     M,D
 3571  2A 34 28           LHLD    TMPHL
 3574  7E                 MOV     A,M
 3575  E6 0F              ANI     0FH
 3577  47                 MOV     B,A
 3578  AF                 XRA     A
 3579  B8                 CMP     B
 357A  C2 8C 35           JNZ     EXIT2
 357D  23                 INX     H
 357E  46                 MOV     B,M
 357F  B8                 CMP     B
 3580  C2 8C 35           JNZ     EXIT2
 3583  23                 INX     H
 3584  46                 MOV     B,M
 3585  B8                 CMP     B
 3586  C2 8C 35           JNZ     EXIT2
 3589  C3 99 35           JMP     END2
 358C  2A 34 28   EXIT2:  LHLD    TMPHL
 358F  3A 3A 28           LDA     AXIS
 3592  C6 06              ADI     CWB
 3594  D3 2A              OUT     TRWRD
```

```
3596  CD D6 33            CALL   DCRNT
3599  D1          CND2:   POP    D
359A  21 36 28            LXI    H,TMPDC
                  ;       NOW TURN THE SIGN TO A NEGATIVE ZERO
359D  73                  MOV    M,E
359E  23                  INX    H
359F  72                  MOV    M,D
35A0  2A 34 28            LHLD   TMPHL
35A3  7E                  MOV    A,M
35A4  C6 10               ADI    NZER
35A6  77                  MOV    M,A
35A7  C9                  RET
35A8  3A 3A 28    STOP:   LDA    AXIS
35AB  C6 00               ADI    DEAD
35AD  D3 2A               OUT    TRWRD
35AF  C9                  RET
35B0  00          FLSHR:  NOP
35B1  C3 B0 35            JMP    FLSHR
                          END
```

A	=0007	ABSVAL	316E	ASCBCD	3161	ASCIIH	0039	ASCIIL	002F
ASCIIX	2800	ASCIIY	2807	ASCIIZ	280E	AUTO	3157	AUTOC	00C0
AUTOP	3020	AXIS	283A	AXIS1	0000	AXIS2	0010	AXIS3	0020
AX1	34E7	AX1C	3517	AX2	34A8	AX2C	34DE	AX3	3469
AX3C	349F	B	=0000	BAUD	2016	BKWRD	31A5	BLNKBF	0040
BLNKLP	310F	C	=0001	CCWB	000A	CCWDCZ	3520	CCW1	0002
CCW2	0008	CCW3	0020	CMPR	33A4	CMPRE	3400	CWB	0006
CWDCZ	3564	CW1	0001	CW2	0004	CW3	0010	D	=0002
DATAS	319D	DCRCCW	335D	DCRCW	336B	DCRNT	33D6	DCRNT1	33DE
DEAD	0000	E	=0003	END1	3555	END2	3599	ENTER	32F8
ENTRYA	327E	ERR	31D7	EXIT	3548	EXIT2	358C	FIRST	3000
FLSHR	35B0	GCHAR	200C	GETDTA	3451	H	=0004	IN	3139
INCCCW	3341	INCCW	334F	INCNT	337A	INCNT1	3382	INITD	3109
INITP	30F1	INITSP	3102	INPUT	3203	L	=0005	LED	283B
LEDIP	0080	LED1	00A0	LED2	00B0	LED3	00C0	LINK	31E5
LOOP	3434	LOOP2	3443	LOP2	317F	LPA00	3293	LPA01	329D
LPA10	32AC	LPA11	326B	LP00	330D	LP01	3317	LP10	3326
LP11	32E5	M	=0006	MAN	314F	MANC	0000	MANOP	3131
MASKI	323A	MDNE	312B	MINUS	31D4	MOVE	3212	NBCDX	281B
NBCDY	2824	NBCDZ	282D	NEG11	34FB	NEG21	34C2	NEG31	3483
NIP0	3224	NIP1	3235	NNINE	0099	NOMOVE	3379	NTST	31A8
NUMBER	31B3	NXTMOV	328A	NXTMV	3304	NZER	0010	NZERO	2830
OBCDX	2815	OBCDY	281E	OBCDZ	2827	OFF	0000	ONE	0001
PLLIP	0002	PLREG	0020	PLSENP	002B	PLUS0	3229	PLUS1	3502
PLUS11	3513	PLUS2	34C9	PLUS21	34DA	PLUS3	348A	PLUS31	349B
POLL	3432	POLPRT	0023	POS00	3241	POS01	3333	POS10	333A
POS11	32B9	PSW	=0006	PTCHAR	2000	PULSE1	0008	PULSE2	0018
PULSE3	0028	PZERO	2831	REDY	31DF	R3D2	3007	SDK85	0000
SIGN	31C4	SKIP	339F	SKIPD	33FB	SP	=0006	STACK	28FF
STAR	3211	STOP	35A8	STOPD	3426	STOPR	33CA	STRING	31F8
SWAPP	311D	SWITCH	3135	TBCDX	2818	TBCDY	2821	TBCDZ	282A
TEST	3010	TESTZ	32DC	TMPBC	2838	TMPDE	2836	TMPHL	2834
TRCR	0028	TRIWR	000E	TRSTS	0029	TRWRD	002A	TSTZ	3262
UPDAD	0363	UPDATE	3459	UPDDT	036E	UPLED	341A	UPLEDA	33BE
UPLEDB	33BD	UPLEDC	33BC	UPLED1	3419	UPLED2	3418	USET	2023
VDM1	2001	XMOV	3056	YMOV	3087	ZERO	0000	ZMOV	30B8

No errors detected

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