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AUTOMATED X-RAY ORIENTATION FOR QUARTZ CRYSTAL RESONATORS. (U)

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Research and Development Technical Report

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**AUTOMATED X-RAY ORIENTATION FOR
QUARTZ CRYSTAL RESONATORS**

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SEPTEMBER 1981

Interim Report for Period 1 July 1980
to 31 December 1980

DISTRIBUTION STATEMENT

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Prepared for
Electronics Technology and Devices Laboratory

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1. REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER 18 DELET-TR-79-0254-3	2. GOVT ACCESSION NO. AD A304945	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Automated X-ray Orientation for Quartz Crystal Resonators		5. TYPE OF REPORT & PERIOD COVERED Interim Report, no 3 1 Jul 80 - 31 Dec 80	
7. AUTHOR(s) 10 Robert W. Birrell Robert J. Valihura John L. Chambers Myron A. Pugh S. Thomas Workman		8. CONTRACT OR GRANT NUMBER(s) 15 DAAK20-79-C-0254	
9. PERFORMING ORGANIZATION NAME AND ADDRESS 1) P. R. Hoffman Co., Carlisle PA 17013 2) Advanced Research and Applications Corp., Sunnyvale, CA 94086		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 62705A 1L1 62705 AH94 10 02	
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Electronics Research and Development Command, Ft. Monmouth, NJ 07703 ATTN: DELET-MQ		12. REPORT DATE 11 September 1981	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 73		13. NUMBER OF PAGES 69	
		15. SECURITY CLASS. (of this report) Unclassified	
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Quartz crystals, SC-cut, X-ray measurement, angle correction, Laue, X-ray defraction, X-ray orientation, laser processing, quartz X-ray goniometers.			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objective of this program is to develop an automatic X-ray orientation system (AXROS) that is capable of measuring the angles of cut of doubly rotated (SC) quartz crystals, to an accuracy of seconds of arc, on a production basis. The technique selected for the system utilizes recognition of several major spots in a back-reflected Laue pattern in conjunction with a laser measurement of crystal surface orientation to determine the angle of cut. The pattern recognition is done via an algorithm implemented on a dedicated			

20. Abstract (continued).

mini-computer. The same computer also drives servo-mechanisms used to rotate and position the crystal. A secondary objective of the program is to use the AXROS measurements to provide the input for an angle correction device to be implemented in conjunction with the AXROS.

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ABSTRACT

Doubly rotated crystal resonators, particularly the SC-cut, exhibit the highly desirable property of having smaller frequency shifts due to mechanical stresses than the more conventional, singly rotated cuts (e.g., the AT cut). Since stresses are common in the crystal operating environment due to electrode stress, mounting and bonding stress, thermal stress and acceleration, it is important to minimize the frequency shift caused by these stresses to realize the desired goal of high precision frequency control and timekeeping. Doubly rotated quartz cuts have the potential for providing resonators of superior stability in these applications, and the ability to reliably produce SC crystals to tight specifications in a mass production mode is therefore of high priority.

The problem with the SC-cut is that, in many applications, the angles of cut must be accurate to a few seconds of arc. This is currently beyond the state-of-the-art for mass production, and therefore, the use of SC crystals is restricted to cases where the cost of custom crystal production is not prohibitive. The major objective of this program is to develop an automated X-ray orientation system (AXROS) which is capable of measuring the angle of cut of doubly rotated quartz in a semi-automated environment, at a rate of roughly one crystal per minute. A secondary objective is to develop techniques for angle correcting SC crystals which do not significantly impact the throughput of the overall system and which provide highly accurate corrections without the need for many successive iterations. This second objective is important if the full potential of the AXROS machine is to be realized.

SUMMARY

During the initial stages of this project, several X-ray techniques were considered for the measurement of crystal plane orientation within the crystal. The original baseline was the use of a standard three axis goniometer; however, as the study evolved, both the desirability and feasibility of using the Laue technique became apparent. This technique promises to provide both the required accuracy and required throughput via a single X-ray source.

Because of its simple geometry, the traditional Laue back-reflection approach was used as the baseline design for the feasibility study. A computer program was written to enable prediction of the diffraction patterns which would be observed for the various cuts, and identification of pairs of reflections suitable for orientation. A Laue measurement device was subsequently developed to test the feasibility of the method. The device consisted of a tungsten-target continuous-spectrum X-ray source, a rotating stepping motor stage on which the crystal was mounted, a standard NaI scintillator/photomultiplier X-ray detector, a precision stepping motor translating stage for use in scans across the detector face (to determine the exact location of an X-ray spot) and associated pulse-counting, interfacing, and computer-control circuitry.

The inherent precision available from the Laue method is very high. Spot positions can be measured with standard deviations corresponding to $\sim \pm 2$ arc seconds of orientation (given sufficient photon statistics). The X-ray measurement is coupled with a laser reflection measurement of the orientation of the surface of the crystal. These two measurements, taken together, unambiguously determine the angle of cut of the blank.

A secondary objective of the program is to utilize the measured angles to provide input to a high throughput angle correction device. A novel method was devised utilizing a laser to replace the normal chemical etching approach. The new technique shows much promise however lack of funds caused this work to be rescheduled.

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1.0 PROGRAM OVERVIEW

In order to insure optimum performance of the X-ray orientation system (AXROS) at minimum cost to the government, P. R. Hoffman has teamed with Advanced Research and Applications Corporation (ARACOR) of Sunnyvale, California. In the teaming arrangement, P. R. Hoffman makes full use of its mechanical and crystal expertise while utilizing the computer automation and X-ray diffraction expertise of ARACOR. To best accomplish this, ARACOR has been tasked with the evaluation and selection of the X-ray method of angular orientation, implementation of the selected method in a computer-controlled breadboard device and development of the crystal orientation algorithms and control software. Furthermore, ARACOR is to provide the X-ray source, detector, laser and servo-control systems. P. R. Hoffman (PRH) is to design and build the crystal handling mechanical system suitable for operation in a manufacturing environment incorporating the ARACOR-supplied subsystems. System integration is to be carried out at ARACOR. P. R. Hoffman also had the primary task to develop and implement an angle correction method essential for efficient manufacturing of precision SC crystals.

2.0 INTRODUCTION

Details of the work performed during the first twelve months of this project have been described elsewhere (Research and Development Technical Report DELET-TR-79-0254-1, U.S. Army Research and Development Command, Fort Monmouth, NJ 07703; and the annual report from the same source), therefore, results from the first two six-month periods will be summarized following a brief description of the Laue method. The remainder of the report will describe the work performed from July 1 to December 31, 1980.

3.0 THE LAUE METHOD

3.1 OVERVIEW

The characteristic feature of the Laue Diffraction method is use of a continuous-spectrum X-ray source rather than a monochromatic source. The fundamental advantage of the continuous spectrum is that the position of a Bragg reflection (i.e., diffraction maximum) varies in a continuous manner as the crystal orientation is changed, whereas with monochromatic radiation, the reflection disappears as the crystal is rotated out of the Bragg condition. Because reflections are more easily found in the Laue case, a simpler diffractometer geometry and greater ease of automation are possible than in conventional monochromatic techniques. For example, given the ϕ , θ orientation of the blank to 30' or better (readily achievable) at the start, only rotation of the blank about its face (i.e., about ψ) is necessary to position a Laue reflection in a detector. To completely determine the orientation of the blank (ϕ , θ , ψ), X, Y, Z coordinates for a minimum of two reflections are necessary. These two reflections can be chosen such that they are the only pair which enter two detectors simultaneously upon a full rotation about ψ .

The determination of the spot coordinates thus proceeds in two stages. First, the blank is rotated about ψ until the two reflections simultaneously enter two detector apertures. Second, the position of each spot is precisely determined by scanning both detector apertures in two dimensions and computing the coordinates of each center by least-squares fit of a model spot profile. Since the orientation of the Laue pattern with respect to the face of the blank must be computed, the orientation of the face will also be measured with a reflected laser beam

and a position-sensitive photodiode detector. The degree of precession of the laser beam reflected from the face of the blank as it is rotated about ψ will then be used to compute the face orientation (see J. R. Vig, "A High Precision Laser Assisted X-ray Goniometer for Circular Plates." U.S. Army Electronics Command, Ft. Monmouth, NJ, 1975, published in the Proceedings of the 29th Annual Symposium on Frequency Control, September 1975).

Since the accuracy of the orientation must be on the order of seconds of arc, sensitivity of the Laue spot positions to the crystal orientation is of prime concern. The traditional Laue back-reflection configuration is shown in Figure 1. Only one of the many observable reflections is shown. A rotation of the sample by the angle α changes the vertical position of the spot by $2R\alpha$, where R is the sample-to-detector distance. For $R = 500$ mm, the spot moves 5 microns per arc second. As the spot moves, its diffracted energy changes by an amount which is insignificant for this application. Rotation of the sample about β in Figure 1 produces a horizontal spot motion of $2\beta R \cos (180-2\theta_B)$, where $2\theta_B$ is the diffraction angle. For diffraction angles close to 90° , sensitivity to β is lost, although a second reflection perpendicular to the first along the X-axis would provide the required sensitivity. This suggests that the two reflections used for orientation should be close to 90° apart to insure maximum sensitivity. Rotation of the sample about ψ is simply equivalent to rotation of the film, and causes the spot to move in a circular path around the film center by a distance $R \psi \sin (180-2\theta_B)$. This sensitivity is inherently a factor of two less than for the other rotations. These calculations suggest, for example, that if the X, Y, Z coordinates

of the Laue spots are determined to better than 50 microns for a 500 mm sample-to-detector distance, an accuracy of 10 arc seconds can be achieved.

The suitability of using the Laue reflections for orientation depends on a number of factors. First, they must be of high intensity, since the time required for measurement depends inversely on the counting rate. To obtain high intensity, the diffracted energy (or energies) should correspond to an energy region of high source intensity. Second, the reflections should be sensitive to the crystal orientation, as discussed above (i.e., the diffraction vectors should be as close to 90° apart as possible). The third criterion is that the reflections permit an unambiguous initial positioning of the crystal about ψ . Ideally, this would be achieved by assuring that no other pair of reflections can enter the two detectors simultaneously. If the density of reflections is too high, ambiguities can be removed in some cases by energy discrimination, since over all ψ values, each spot has a characteristic energy associated with it as well as a characteristic intensity. The least desirable (although a perfectly useable) way to eliminate ambiguities is to rely on measurement of the relative intensities of the two reflections, since a pause to accumulate counts would be required for each pair with a resulting loss of time.

3.2 SUMMARY OF WORK PERFORMED DURING THE FIRST SIX MONTHS

Because of its simple geometry the traditional Laue back-reflection approach was used as the baseline design for the feasibility study. A computer program was written to enable prediction of the diffraction patterns which would be observed for the various cuts, and identification of pairs of reflections suitable for orientation. A breadboard Laue measure-

ment device was developed to test the feasibility of the method. The device consisted of a tungsten-target continuous-spectrum X-ray source, a rotating stepping motor stage on which the crystal was mounted, a standard NaI(Tl) scintillator/photomultiplier X-ray detector, a precision stepping motor translating stage for use in scans across the detector face to determine the exact location of an X-ray spot, and associated pulse-counting, interfacing, and computer-control circuitry. A diagram of the breadboard devised at that stage of the project is shown in Figure 2. Results of experiments performed with this device led to the following conclusions and suggestions for future work:

The inherent precision available from the Laue method is very high. Spot positions could be measured with standard deviations corresponding to ± 2 arc seconds in crystal orientation, given enough X-ray photons. However, the X-ray intensities available from the continuous source are reduced considerably from those attained by more conventional, monochromatic techniques. An order of magnitude improvement in the counting rate was desirable.

Methods for improving the intensities were suggested, including use of a higher-powered source, a larger collimator aperture, helium or vacuum X-ray paths, or use of reflections at lower diffraction angles. Experimental location of reflections suitable for orientation was found to agree well with the predictions. Other future tasks identified included development of the algorithm by which the orientation angles ϕ , θ and ψ could be determined given the X-ray measurements, calculation of the expected uncertainties in ϕ , θ and ψ from the X-ray data, enhancement of

the capabilities of the breadboard device to include the other necessary detectors, and design of a prototype system.

3.3 SUMMARY OF WORK PERFORMED DURING THE SECOND SIX MONTHS

A number of methods for improving the diffracted intensities were explored, as suggested above. The most effective of these methods was use of reflections at smaller diffraction angles, leading to a prototype design which utilizes a "glancing angle" geometry (see Figure 3). Optimal methods for mapping the intensity profiles of the spots were investigated. It was determined that only a single translating stage per detector would be required to measure the spot positions. The profile mapping in the second dimension can be performed with use of the rotary stage and a stationary slit over the detector.

The Laue pattern prediction program was enhanced to work with arbitrary diffraction geometries rather than only back-reflection, enabling prediction of patterns and motion of the spots, and selection of suitable reflections for measurement in the glancing angle mode. For SC-cuts, these were the $1\bar{2}1$ and $0\bar{1}0$ reflections. The sensitivities of ϕ , θ , ψ to variations in the measured data were computed, and a least-squares algorithm developed to determine ϕ , θ , ψ given the observed positions of two Laue spots. A least-squares algorithm for determination of the orientation of the face of the blank from the motion of a laser beam reflected from its surface as it rotates was also developed. Experimental work on this laser measurement system was begun.

Much of the FORTRAN control software required for a prototype de-

vice was written. The overall concept for integration of these routines into an automated angle measurement package was developed. The results of these studies led to finalized design parameters for a prototype device, and concept drawings were developed for the prototype.

3.4 SUMMARY OF WORK PERFORMED DURING THE THIRD SIX MONTHS

During the current period, the Laue pattern prediction and reflection selection capabilities were significantly improved by addition of features to display the positions of L-line diffraction peaks on each spot path, and to enable choice of an arbitrary detector position. The least-squares algorithm for determination of the normal to the face of the blank from the laser measurement data was put into final form, including a calculation to determine the translation of the crystal face in the direction of its normal. Top-down organization of the control software into an integrated package with an easily used operator interface was begun. Finally, the design parameters for the prototype measurement device were finalized and fabrication of the instrument was begun by P. R. Hoffman.

3.5 LAUE PATTERN PREDICTION

The number of tungsten L-line reflections could enter the detectors over a $360^\circ\psi$ rotation, and the position of all possible L-line reflections had previously been largely undetermined. This capability has been added to the Laue pattern program as shown in Figs. 4-7. The path for each reflection upon a $360^\circ\psi$ rotation is represented by a dotted line. The position of the reflection at a particular ψ of interest (e.g. 218.12° in Figs. 4 and 5 or 180° in Figs. 6 and 7) is shown with a circle containing cross-

hairs. Those positions on every spot path where the reflection tunes to an L line are denoted by a triangle. Note that there may be a number of triangles on each spot path, related to symmetry equivalent reflections or (usually) to different orders of the reflection. Only when one of the circle/cross-hair targets is directly on top of a triangle is the reflection on an L line at the ψ value of interest. These plots contain a great deal of information. For example, Figs. 6 and 7 indicate that for the $1\bar{2}1$ reflection chosen for SC cuts, no L line interference is expected. The $0\bar{1}0$ reflection is however close to another reflection so that at some value (far from the 218.12° of interest) it will pass through an L line near the $0\bar{1}0$ detector. This prediction was in fact confirmed by the results obtained earlier in the two-detector breadboard setup, where a 25,000 cps reflection was observed by the "outboard" detector at one point in the ψ rotation. No reflection was present in the central aperture at this value.

An additional extension to the program which is expected to be of great utility in the early prototype alignment and crystal measurements is the capability of simulating an arbitrary detector position (i.e. inclination and azimuth). Thus, the program can stimulate exactly what a detector will "see" over the course of a full ψ rotation. Fig. 8 is a picture of the spot paths predicted for the central aperture in the SC-cut configuration, and Fig. 9 is the same for one of the "outboard" detectors. In both cases, the angle subtended by the aperture is $\pm 1.7^\circ$, which covers the $\pm 1.15^\circ$ range of the prototype detector apertures we now have, plus another $\pm 0.5^\circ$ corresponding to ± 15 arc minutes initial blank orientation error. The figures indicate that at the ψ value of interest

(218.12°), only the $1\bar{2}\bar{1}$ and $0\bar{1}0$ reflections are present in the apertures as expected. An L-line reflection will pass through the outboard detectors on a few determinations ($\psi = 177.4^\circ$); however, no reflection will be present in the central aperture at this ψ value, as suggested in the experiments described earlier. One unexpected result which has bearing on the design of the prototype is that the paths of the spots through the "outboard" aperture are nearly straight, but are nearly 60° from vertical. The difference in viewing angle compared with earlier simulations accounts for the change. Since most of the "outboard" reflections will be observed near the equatorial line in Figs. 4-7, the results suggest that, in order to keep the direction of stage travel perpendicular to that of the spot motion, a stage tilt which varies $\pm 30^\circ$ from a nominal 45° default would be appropriate, rather than one which varies from horizontal by plus or minus some amount.

3.6 SELECTION OF REFLECTIONS

Because the equatorial plane of the prototype instrument, containing the azimuth adjustment, is tilted 20° with respect to that in the breadboard, a significant advantage is obtained in the prototype in that the "upper half" of the diffraction pattern (as shown in earlier figures) which is the less densely populated half, is more readily accessible in the prototype. For example, a reflection with inclination and azimuth of $(80^\circ, 0^\circ)$ which is inaccessible in the breadboard is at $(60^\circ, 0^\circ)$ in the prototype. The coordinates given previously for the SC and AT cut reflections corresponded to the breadboard coordinate frame. In the prototype reference frame the SC cut reflections are: $1\bar{2}\bar{1} = (43.89^\circ, 0^\circ)$, $0\bar{1}0 = (18.63^\circ, 33.98^\circ)$, and the alternate reflection $1\bar{1}\bar{1}$ is at $(25.82^\circ,$

32.85°). As shown in Figs. 6 and 7, the $0\bar{2}\bar{1}$ and $\bar{1}\bar{1}\bar{1}$ reflections appear to be good prospects for AT cut crystals. The detector settings for this pair in the prototype reference frame are:

$0\bar{2}\bar{1}$; azimuth = 0°, inclination = 47.5°

$\bar{1}\bar{1}\bar{1}$; azimuth = ± 22.7°, inclination = 24.0°

Reflection candidates were also determined for the first of the SAW cuts specified as stated in paragraph 3C of the Technical Guidelines for the contract. The ϕ , θ and ψ of this cut have been specified as (6.57°, 26.88°, 134.9°). The two reflections selected were the $0\bar{1}\bar{1}$ and the $\bar{1}\bar{1}\bar{1}$, as shown in Figure 10. In the reference frame of the prototype, the inclination and azimuth of the $0\bar{1}\bar{1}$ are (45.21°, 0.00°), and those of the $\bar{1}\bar{1}\bar{1}$ are (33.21°, -37.30°) at a ψ of 24.33°, which place the $0\bar{1}\bar{1}$ at the top of its path. Both of these reflections are strong, are in regions of low reflection density keeping interference from other reflections small, and are far from the tungsten L lines.

3.7 REFERENCE CRYSTAL

During this period, a reference SC-cut crystal was very kindly provided by Jack Kusters of Hewlett-Packard. The crystal has measured angles of $\phi = 21.93^\circ$, $\theta = 34.1128^\circ$. One face of the blank is highly polished. This should be particularly helpful in determination of the effect of surface polish on the intensities. The blank is square and an edge has been marked corresponding to the +x face of the crystal. This will be useful in enabling ψ to be roughly determined "by eye" when the crystal is mounted.

3.8 LASER MEASUREMENT CRITERIA

Development of the algorithm for determination of the crystal face height and orientation from the laser measurement data was completed. In the prototype, a linear position-sensitive photodiode will be used to detect any vertical motion of a laser beam reflected from the face of the blank, as the blank is rotated about the vertical (z) axis of the instrument. The extent of vertical motion is related to the angular deviation of the normal to the blank face from the z axis of the instrument (see Fig. 11).

The full expression for the z component of the reflected beam (which is the quantity to be measured) is:

$$r_z = k_1 \sin 2\delta \cos(\psi - \psi_0) - k_2 (\cos^2(\psi - \psi_0) \sin^2 \delta - \cos^2 \delta) + k_3 \frac{t}{c}$$

where δ is the angle between the face normal and the ψ -rotation axis, and ψ_0 the value at which the x component of the normal is zero, and the y and z components are positive. The translation of the crystal face along the normal to the ψ -rotation axis is given by t_c . The constants k_1 , k_2 , and k_3 are fixed by the Laue glancing angle and machine geometry.

The axial ratio of the teardrop as seen by a detector in the x, z plane, $a = (r_x)_{\max}/(r_z)_{\max}$, is dependent on the glancing angle (T) of the incident beam, and is given by the expression:

$$a = \frac{\sin(T)}{\cos(2T)}$$

Fig. 12 is a plot of axial ratio, a , versus glancing angle T . The sensitive area of the position-sensitive laser detector diode is $1.166'' \times 0.146''$, restricting the useful range of glancing angles to below about 7.5° , if the entire length of the diode is to be used. Use of a small glancing angle also maximizes sensitivity to the crystal translation, which increases the precision of the t_c determination. However, too small a glancing angle restricts the range of t_c which can be measured, or could spread the incident laser beam over an area larger than the blank. The smallest blanks which will be measured are 4 mm on a side, or 2 mm in radius. The maximum range of crystal translation (i.e., tolerance on blank thickness) is ± 1 mm or $\pm 10\%$ of the blank radius, whichever is smaller. It will be necessary to establish a firm limit on this parameter. The radius of the laser beam will be considered to be small, since it can be made small by focusing if necessary. These considerations place a lower limit of 5.7° on the glancing angle, and it thus appears that an angle near 7° will be optimal. A larger angle can be employed with some sacrifice in the amount of diode area utilized.

3.9 CONTROL SOFTWARE

The organization of the major modules in the prototype software is shown in Fig. 13. A very brief description of the components follows.

- 1) Command Monitor: All commands (with the exception of the command to terminate the program) are invoked through and terminate in the monitor. Its function is to interpret the

keyboard commands and invoke the appropriate action routine. A short description of the commands being implemented is given later. This module is now operational.

- 2) **Initializer:** This routine is automatically invoked at start-up, and can also be invoked through the monitor INITIALIZE command. The module initializes or restores all user accessible parameters (e.g., drive speeds, desired precision, least squares tolerances, etc.) to their default values, which may be the ones supplied with the software, or may be a set of values saved from an earlier run.
- 3) **Log Maintenance:** This routine manages log file information, such as a batch title, operator, time, date, type of cut, and all the statistics pertaining to crystals measured within the batch.
- 4) **Help:** This module provides on-line access to the software documentation. Such a facility is simple to implement, and can save a great deal of time otherwise spent leafing through a manual.
- 5) **Automated Data Acquisition:** This routine performs the automatic sequence of laser and X-ray measurement scans, and invokes the least squares routines to perform the profile fitting and orientation determination. The desired precision, drive speeds, estimated time per blank, etc. will have been

already set through the Command Monitor. The least squares routines are already operational, as are most of the scanning routines. Least squares or scanning can be performed independently using monitor commands which directly access the Least Squares or Manual Mode (i.e., scanning, counting, etc.) modules.

3.10 COMMAND LIST

The following is a brief description of the monitor commands. The list will probably grow as the software integration is completed. The manner in which many of the commands are executed is set by the parameters in a large user-accessible common block. This common block has been specified and coded, and provides a high degree of flexibility. For example, among the user-accessible parameters (see MODIFY command below) are the CAMAC bin number and subaddress of each device (e.g., counter, or motor controller) in the system. Changing the channel which the cable from a counter runs into thus requires no recompilation of the program, but only a modification of the subaddress in user common. The default parameters for this common are read in from a disk file at startup time, and to make the change "permanent" all that is required is to edit the disk file. In addition, the values in the common block can be saved on a disk through a monitor command, and restored to those values at a later time.

The monitor allows abbreviation of the following commands to the smallest number of letters which is unambiguous. In most cases,

a single letter is sufficient.

AUTOMATIC	Begins automated data acquisition, using the parameters currently in user common.
BYE	Updates log files, prints out appropriate statistics and current motor positions, and terminates the program.
CALIBRATE	Performs the automatic sequence for a reference crystal.
COMMON	Prints out the user common parameters.
COUNT (time) (integration)	Read counters every integration period for specified time, and print counts.
CURRENT	Prints current value of parameters relevant to command.
DRIVE (time) (dest 1) (dest 2) (dest 3) (dest 4)	Drives stages to specified destinations within the specified time. The monitor accepts "@" as a null argument. If a null argument is specified as a destination, that stage is not driven. If a null

	argument is given for "time", the drive speeds in user common are used.
FIT TEARDROP)	Perform least squares fit to data in appropriate arrays; write out results.
FIT GAUSSIAN)	
FIT ORIENTATION)	
HELP (topic)	Prints contents of appropriate docu- mentation file.
INITIALIZE (filename)	Reinitializes user common.
MANUAL	Terminates automatic mode.
MODIFY (parameter name) (offset) (new value)	Sets value of parameter in user common.
SAVE (file name)	Saves user common parameters in file name.
SCAN (time) (integration) (dest 1) (dest 2) (dest 3) (dest 4)	Performs scan, counting while driving. Counts accumulated every integration period are printed along with stage positions.
TURN ON (device)	Removes or restores device to active list.
TURN OFF (device)	Commands are not issued to inactive devices.

UPDATE (pos 1) (pos 2)	Updates stage positions; that is
(pos 3) (pos 4)	tells computer where the stages are.
X-RAYS ON)	Control X-ray shutter.
X-RAYS OFF)	

3.11 STEPPING MOTOR STAGES

In addition to the highly important theoretical aspects of the project, the bench work and the conceptual drawings work at ARACOR has included specification of the stepping motor stages, and making them operational under computer control. The rotating stage is a Klinger Scientific #RT-120. The tilt of the stage from its nominal rotation axis is stated to be less than 2 arc seconds over the full 360° . The step size is 0.01° , yielding a slower rate of $20^{\circ}/\text{sec}$ at the maximum stepping rate imposed by the motor and controller of 2000 steps/sec. Thus, the maximum time spent in the initial reflection search will be 18 sec/blank; and the mean time, 9 sec/blank.

The three translating stages are Klinger Scientific #UT100-PP/10. These stages have a 10 micron step size, permitting a 2 cm/sec slew rate. Thus, the stages can translate over their entire 7.5 cm range in under 4 seconds.

The Joerger stepping motor controllers and associated cabling have been modified for use with the Klinger stages. The modifications included accounting for the reversal in sense of the limit switches, alteration of the pulsing sequence, and installation of

external current limiting resistors. Since these resistors are remote from the stages the heat dissipation at the detector mounts will be significantly reduced. The Klinger stages are now fully operational under computer control. They are fast, very quiet and relatively free from vibration. There appears to be no "missing step" problem running these stages at 2000 steps/sec, as rated. After 4 hours of continuous use at high speed, the heat-sink area of the motor housing was only slightly warm. The stages thus appear to be an excellent choice for this application with their physical size as the only drawback.

3.12 FUTURE WORK

Work during the next interim period will include integration of the prototype with the stepping motor stages, computer system and control software. This will permit performance studies to be initiated, and the first orientation measurements to be made. Completion of the design and fabrication of the laser detection subsystem are anticipated.

4.0 AXROS MACHINE DESIGN

4.1 OVERVIEW OF WORK PERFORMED TO DATE

After considerable study the Laue glancing reflection mode was chosen as the base line X-ray orientation approach. Completion of the preliminary design configuration layout based on this approach allowed the task of translating the configuration into a specific machine design to begin.

The first task was to study the configuration drawings in detail and begin to formulate various machine design concepts likely to produce the most suitable results.

Of particular interest at this stage was the determination of the future mechanical interference problems, primarily due to the broad ranges of complex component spatial positioning requirements inherent in the AXROS. This problem initially manifested itself in the prototype conceptual layout drawing and work was started to overcome the difficulties.

The process of selecting the major components, a key to this area of concern, was therefore initiated and developed in parallel with the design studies.

During the current period considerable progress was made towards moving from this conceptual work to actual hardware. Major activity during this period in this task area concerned development of the conceptual design layout drawings, detailed design of the individual parts followed by the fabrication and coating of the parts. The project is now poised to move forward to actual assembly during the next interim period.

4.2 CONCEPTUAL DESIGN LAYOUT DRAWINGS

4.2.1 AN OVERVIEW

Turning the AXROS conceptual drawings into a working machinery system requires the following steps:

- 1) Review of the concept in terms of exact specifications.
- 2) Design studies in terms of spatial relationships with particular emphasis on interferences.
- 3) Design studies in terms of specific mechanisms to perform each machine function.
- 4) Conceptual design layout drawings encompassing specific mechanism in an iterative approach to determine the most suitable combination.
- 5) Detailed design of the specific parts.
- 6) Re-assembly of parts drawings into working drawings to insure fit.

Earlier work was concerned with the first two above steps, while the current activity concentrated on the latter four steps. Machine specifications were essentially completed during this period except those evolving from the System Integration Task, i.e. laser positioning and shielding. A complete specification listing is to be included with the final report. Because of the iterative nature of the Conceptual Design Layout Task, the second step concerning interferences of machinery components was considered an ongoing task during this present work. With the exception noted above, all the foregoing tasks have essentially been completed. The August/September period provided salient points of activity worthy of note. During early August at the completion of the preliminary design layouts a design review meeting was held with the key technical personnel in the PRH Machine Products Division. This meeting included the Senior Design Engineer and Senior Design Draftsman as well as other individuals who would be used in subsequent phases of the program. Each major mechanical concept was reviewed in detail and agreement reached in terms of design feasibility, cost implication,

ease of manufacturing and overall specifications for key components.

During early September the conceptual design process encountered a major set back when it was determined that the two outboard linear transition stages of the detector heads must function with their centerlines rotated at various angles from the horizontal plane. Computer programmed analytical work at ARACOR involving the glancing mode X-ray reflection patterns indicated a number of design changes would have to be made in the work already completed. Subsequent design changes were implemented as the new specifications were developed.

As the tilt angle of the outboard linear transition stage increased to a maximum of 75° from the horizontal it was decided to abandon the optical table as a base and adapt a contoured ground steel plate as the base. Interference with a commercially available rectangular table could best be overcome by reshaping the table.

For control purposes the design work has been broken down into the following six segments:

- 1) X-ray Tube Adjustable Mounting Assembly
- 2) X-ray Beam Collimator Assembly
- 3) Crystal Mounting System
- 4) Rotation Stage
- 5) X-ray Detector System
- 6) Mounting Table and Shielding

A description of and the function performed by each of these seg-

ments is presented in the following paragraphs. Discussion concerning the individual parts which make up each of these machine segments may be found in the section entitled Detailed Design.

4.2.2 X-RAY TUBE/MOUNTING ASSEMBLY

This assembly consists of the X-ray tube which is suspended inside the water cooled tube shield; the shutter assembly for turning the beam off and on; the beam connector which connects the shutter to the collimator and finally the adjustable mechanical mounting assembly. The X-ray tube and power source have been purchased and are now in use at ARACOR on the laboratory apparatus. The tube is a Phillips 1600 watt normal focus with a 6° take off angle. The tube shield and shutter assembly are of ARACOR design and are also being used on the laboratory apparatus. The X-ray beam connector provides a connecting path from the shutter assembly to the collimator and is to be provided by ARACOR during System Integration. The major design task within this section concerned the adjustable mounting assembly for the X-ray tube or more correctly the tube shield which surrounds the tube.

The ARACOR conceptual drawings and bench work to date indicate that the X-ray tube should be mounted in the horizontal plane. Also, as indicated in earlier reports, because of alignment problems, only one tube port (one work station) would be utilized in the prototype unit. A mechanism was devised which would give the X-ray tube assembly the necessary adjustment, i.e., horizontal translation, vertical translation and rotational adjustment in each of these planes.

Subsequent realization by ARACOR that the outboard detectors must now have rotational capabilities imposed new mechanical design considerations which necessitated lateral supports for the detector. These supports interfered with the X-ray tube adjustment mechanism when the azimuth plates were positioned at 90° .

After detailed discussions a compromise solution was reached where the X-ray tube assembly was mounted in a vertical plane. This necessitated the redesign of the mounting mechanism. Fortunately, the contractors' past experience with X-ray equipment allowed the rapid adaptation of previously tested mechanical adjusting devices. Figures 14, 15 and 16 show the resulting design.

4.2.3 X-RAY COLLIMATOR

One of the most important components in the AXROS design is the collimator for the X-ray beam. Though mechanically simple its configuration and accurate location are critical to the successful operation of the equipment. A laboratory device has been devised and is at use at ARACOR, however, it is anticipated that an improved version will be designed and fabricated. The mechanical task in this instance is to precisely mount the collimator at a 20° inclination to the horizontal such that the X-ray beam impinges upon the center of the measured crystal. The collimator is essentially a straight cylindrical tube so that the preliminary design approach utilized a "V" groove type mounting. The original concept required that the collimator be mounted and fixed to the machine base and that all other components be mated to it.

However, due to the reassignment of specific tasks within the contract between PRH and ARACOR it was felt that the collimator assembly should be adjustable for the initial set up. Therefore a design was conceived in which the collimator was suspended at either end by collars incorporating three adjustment screws. The collars are significantly larger than the tube so as to allow the three screws to totally suspend the tube. This assembly and others such as the arch/base assembly are to be doweled after alignment during the Integration Phase.

4.2.4 CRYSTAL MOUNTING SYSTEM

Proper support of the crystal during rotation is critical to the success of the AXROS equipment. Therefore the method chosen to support the crystal is a stable three-point chuck arrangement which is capable of precise vertical adjustment. This device must be able to accomodate the crystal thickness variations encountered in different production process lots and maintain the three points of the chuck in a plane perpendicular to the vertical axis.

The prototype machine employs two methods to do this but it is expected that only one method will be required in subsequent units. The first method will accomplish the task within the imposed tight specifications but may be rather cumbersome to operate. The second method is far more convenient to use.

The originally approved design required the three point chuck supporting the crystal be mounted to the top of the rotary stage.

The rotary stage in turn was mounted to a large "Y" shaped base supported at the three corner extremities by adjustment screws. These adjustment screws would allow vertical location of the base plate to be determined to $\pm .0025$ mm (.0001 inches). A calibration crystal and the control computer would compensate for any slight misalignment of the horizontal plane of the 3-point chuck and the median horizontal plane of the instrument. (Ideally these should be coincident). Lot to lot thickness variations were to be compensated for by the three screw adjustment. However, a problem arose when it was subsequently realized that the calibration crystals are normally considerably thicker than production lot crystals. In order to measure properly the top surface of the crystal must be in the exact median horizontal plane of the instrument. It can readily be seen that after the calibration crystal is removed and replaced with a production crystal, the new crystal will fall short of reaching the critical median horizontal plane and therefore must be moved upwards. The slightest bit of misalignment in moving upwards will substantially distort the crystal angular readings, therefore this vertical motion must be made with great preciseness. Moving the crystal upwards by adjusting the three leveling screws of the stage mounting is cumbersome even though this can be controlled to $\pm .0025$ mm (.0001 inches). It was therefore decided to simplify this adjustment. Mechanism was needed which could move the crystal in the vertical direction 2.54 mm (.1 inches) with no lateral motion. A novel mechanical linear motion device was designed and built upon which the 3-point chuck was mounted. The

assemblage in turn was fastened to the rotary stage. With this arrangement the "Y" base press has essentially become a means for setup adjustment. A less elaborate base for the rotary stage might be used in future designs. It need only suspend the rotary stage above the center bearing. Horizontal setup adjustment of the stage would be via screws.

4.2.5 ROTATING STAGE

The Klinger rotary stage discussed in earlier reports was chosen. This was originally to be mounted directly to the table top. However, the need to precisely orient the crystal to a median horizontal plane over the center bearing necessitated the use of an adjustable base for this unit.

Threaded screws at the end points provide stand-offs from the table frame and allow precision adjustment of the horizontal plane for the three point chuck.

4.2.6 X-RAY DETECTOR SYSTEM

The X-ray Detector System employs three separate assemblies each consisting of a detector, a tantalum slot plate mounted on a linear stage actuated by a stepping motor and an X-ray scatter shield. See Figure 14.

These three detector assemblies are deployed in free space about the crystal mounting chuck in the following configuration.

One central detector mechanically fixed at 0° azimuth, but mechanically adjustable in elevation from $+20^{\circ}$ to $+65^{\circ}$.

Two moveable outboard detectors which are mechanically adjustable from $\pm 20^{\circ}$ to 90° in azimuth and $+20^{\circ}$ to 65° in elevation.

The machine design problem was to provide a mechanically stable, yet easily adjustable supporting structure capable of positioning these detector assemblies accurately in free space. This involved holding the radial distance from the crystal to the detector face at $400 \text{ mm} \pm .1 \text{ mm}$ ($15.745 \text{ inches} \pm .004 \text{ inches}$) regardless of azimuth or elevation and at the same time maintaining precise detector center-line alignment to the crystal. It also involved structural consideration for static and dynamic loading, thermal distortion and the avoidance of mechanical interferences. During actual design interference by the detector heads in the extreme positions required considerable design iterations of head component positions to cover all the specifications. The arches also presented similar design iterations. Various thicknesses, radii as well as single, double and both full and half-segment arch combinations were evaluated before settling on a half-segment (parallel) arch concept as the detector head support structure.

A number of schemes for moving and securing the arch bases in azimuthal direction were also evaluated. Among these were a circular "T" slot machine in the table top; a circular rail segment mounted on the table top; a circular rail annulus suspended slightly above

the table top and finally a pivoting arrangement from the table top center. This latter pivoting arrangement was chosen as the most suitable for accurately maintaining the fixed detector to crystal distance requirement.

The detector heads also presented special problems in design to prevent interference. The basic head concept consisted of a linear stepping motor stage to which a slotted plate was mounted. This slotted plate was moved in direction orthogonal to the reflected X-ray beam. A detector mounted above the slotted plate records the intensities of the beam as the slotted plate is indexed across the detector face. A scatter shield positioned between the crystal and slotted plate is used to minimize unwanted reflected X-rays. This assembly is mounted to a base which subsequently secures to the arch. The substantial length of the stepping stages presented particularly awkward spatial problems. A number of design iterations were attempted. Cantilevering of slot plate to the stage side and front were studied as was positioning of the stepping stages on its base and side. Compounding the problem was the realization after completion of the design that the outboard detector must also pivot so that the slotted plate could be adjusted perpendicular to the motion of the X-ray beam at all positions. A compromise solution was reached where in the outboard stepping stages were mounted flat on their bases and the center stepping stage mounted on its side. This required redesign as well as an increased number of parts. A secondary base and support were required for the outboard detector stepping stages and an additional support for the outboard arches.

4.2.7 MOUNTING TABLE AND SHIELDING

A table is required to provide a stable base for the working apparatus, provide the proper work height and be cost effective. A number of alternative solutions to this section of the machine were presented in the April 1981 12 Months Report. Of these a fabricated steel table using a reinforced square tubing support frame was selected. It was originally anticipated that a square or rectangular table top would be used with all apparatus being above the table surface. However, the requirement that the outboard detector head be allowed to pivot necessitated a semi-circular table at the arch end of the table while a rectangular shape was most suitable for the X-ray end. In the extreme down position the detector heads protrude below the table surface.

Inherent in the Laue principle is the scattering of the X-rays making shielding a particularly difficult task. Except for totally enclosing the apparatus in a box-like structure, the optimal positioning of shielding material would be difficult. Therefore, it has been decided that the shielding requirements could best be determined on the equipment once the X-ray was operational. A number of approaches were suggested such as enclosing the crystal within a dome, moveable and overlapping shield plates and even flexible metallic materials. AROCOR has now been tasked with this procedure.

4.3 DETAILED DESIGN

Upon completion and acceptance by all parties of the Conceptual Design Layout Drawings, detailed design work on the individual section parts was in order. This work entailed; part structural configurations, dimensions, material and specific methods of manufacturing. A total of 53 part drawings and 92 manufactured parts were specified. The following descriptive sections parallel the machine component groupings utilized earlier in the Conceptual Design Layout reports.

4.3.1 X-RAY TUBE /MOUNTING ASSEMBLY

This assembly consists of 5 parts whose function is to securely hold the X-ray tube (shield) assembly while also providing suitable adjustment in 4 directions: these parts are the Shaft Clamp, Shaft Holder, Mounting Shaft, Shaft Adjusting Plate, Adjusting Collar and finally Shield Clamp. These parts may be noted in the layout drawings, figures 14, 15, and 16. The Shield Clamp provides a "cradle" for the X-ray tube assembly and is tightened with screws to securely hold the tube assembly. Loosening these screws will allow rotational movement of the tube assembly around its axis and hence rotational movement of the X-ray beam.

The Adjusting Collar is also affixed to this tube assembly. Three screws in this piece allow linear adjustment of the X-ray beam along the tube assembly axis.

The Shield Clamp is fastened directly to the Mounting Shaft which in turn is suspended at either end by the Shaft Holders. The Shaft Clamps located above the shaft securely fasten the shaft down against

the Shaft Holders. Slightly loosening these clamps (via clamp screws) allows rotational movement of the X-ray beam around this axis by a secondary set of adjustment screws. Adjustment along this axis can be provided by the Shaft Adjusting Plate which in turn allows lateral movement of the X-ray beam.

4.3.2 X-RAY BEAM COLLIMATOR ASSEMBLY

This assembly consists of 2 pieces, the Collimator, a long slender tube through which the beam passes on its way to the crystal, and the bracket to hold the Collimator. The bracket has two collars, one at either end, with three screws in each collar to suspend and adjust the Collimator. Though seemingly simple this device is extremely important to the critical alignment of the X-ray beam. The bracket has been fabricated to hold the Collimator at precisely 20° to the horizontal equatorial axis of the machine. This bracket has been selected as the base around which the alignment of the machine will be determined therefore, no means for gross adjustment has been built into this device - only the collar adjustment indication above. This device is a welded assembly of steel.

4.3.3 CRYSTAL MOUNTING SYSTEM

The crystal mounting system employs a 3-point chuck mounted on a vertical motion mechanism. This assembly in turn is mounted to the rotary stage. Three chuck sizes were required to handle the full range of crystals. The middle size was selected to be built which accomodates crystals from 5.08 mm (.198 inches) square or diameters to 17.78 mm (.693 inches). This chuck consists of 8 parts. The Base piece into which three Stand Off Pins are mounted, three sapphire

jewels (for wear), one in the face of each Stand Off Pin and finally an Adjustable Centering Gauge to ensure the crystal is properly centered on the three Stand Off Pins. Except for the jewels the remaining parts were made of steel.

This 3-point chuck is mounted to a special mechanism designed to move in an extremely accurate manner over small distances in a vertical direction without lateral motion. The novel design consists of a vertically-mounted square linear-bearing mounted inside of the center hole of the rotary stage. A square slide sets within the bearing and provides vertical motion of the 3-point chuck mounted to the top of the slide. Ball detents in two faces of the square bearing hold the slide firmly against one corner of the square bearing thereby preventing lateral motion as the slide is moved vertically. An internally threaded ring mating to threads in the head of the slide is used to move the slide.

This vertical motion mechanism consists of 12 different parts. These are 1) Locating Sleeve Segment, 2) Retaining Sleeve Segment, 3) Mounting Plate, 4) Slide, 5) Mounting Ring, 6) Adjusting Collar, 7) four gauge blocks, 8) rotating coupling, 9) Rotary Coupling Bracket, 10) nipple, 11) Teflon gasket, and finally 12) two ball detents. The Locating Sleeve Segment and Retaining Sleeve Segment are fastened to the lower side of the mounting plate and form a square linear bearing for the Slide. Two of the gauge blocks are placed vertically in the two side faces of the Locating Sleeve Segment and two are placed in the opposing faces of the Slide to provide a set of highly accurate

bearing surfaces for the Slide to move upon. Ball detents in the Retaining Ring Segment press the Slide gauge blocks against the vertical gauge blocks of the Locating Sleeve Segment allowing zero clearance between slide and bearing and hence, no lateral motion during vertical adjustment.

The Slide Mounting Ring and 3-point chuck form one unit which is moved vertically with the Threaded Adjusting Collar. The Mounting Plate holds this entire assemblage and is in turn mated to the rotary stage. Four bolts and a locating pin secure this assembly to the rotary stage.

A Teflon gasket is placed between the 3-point chuck and Mounting Ring. Its purpose is to ensure a vacuum tight filling between the two parts while being compressible enough to allow some setup tilt-adjustment of the horizontal plane of the 3-point chuck.

A pipe nipple attached to the bottom of the Slide allows vacuum to be ported up through a hole in the Slide to the 3-point chuck. A commercial rotary joint held by the Rotary Coupling Bracket allows the 3-point chuck assembly freedom to rotate in either direction as many turns as required.

4.3.4 ROTARY STAGE/MOUNTING

As indicated in the Annual Report the Klinger rotary stage was chosen as the means to rotate the crystal. This stage is fastened to a "Y" shaped plate called the Rotary Stage Mounting Plate which acts

as an adjustable base. A screw assembly at each extreme end of the mounting plate provides vertical adjustment. The screw assembly consists of 1) Elevation Screw, 2) Bushing, 3) Screw Washer, 4) Adjusting Screw, and 5) Adjusting Knob. The Elevation Screw Bushing is fastened to the table and acts as a base piece. The Adjusting Screw inserts into this threaded bushing. The brass washer sets on a shoulder of the specially shaped Adjusting Screw. The Mounting Plate rests upon the washer and is secured by the Elevation Adjusting Knob. The Knob is pinned to the Adjusting Screw. This Knob provides a hand grasp and is secured in place after adjustment by a small screw.

4.3.5 X-RAY DETECTION SYSTEM

The detection system employs three separate detector assemblies, a center detector assembly and two outboard detector assemblies. Each assembly consists of an arch support section and the main element - the detector head section.

The center arch support section consists of 1) Base, 2) Bottom Connecting Block, 3) Two Center Arches, and finally 4) the Top Connecting Plate. The base is fastened to the table top while the Bottom Connecting Block is fastened to the base. The connecting block forms a vertical mounting area to which the two arches are attached. The top connecting plate holds the two arch pieces together at the arch tops. The Center Detector Head is made up of parts associated with mounting the detector to the arches and those parts associated with the actual detection. The connecting parts are 1) Center Stage

Elevation Adjusting Block, 2) Elevation Locking Pad, 3) Center Stage Mounting Bracket. The Elevation Adjusting Block sets on the outer face of the arches and is locked against the arch by the Elevation Locking Pad on the opposite side of the arch. A tongue on the Adjusting Blocks fits closely between the two arch pieces and prevents lateral motion. A screw between the tongue and locking pad provides the necessary locking force against the arch. The Center Stage Mounting Bracket is fastened to the Elevation Adjusting Block and provides the mounting surface for the detection associated parts. The parts associated with actual detection are 1) Linear Stepping Stage, 2) Slotted Shield, 3) Center Slotted Shield Holder, 4) Shield Plate Cover, 5) Scatter Shield Holder and finally, 6) the Detector Holder.

The Center Shield Holder Bracket fastens to the Stepping Stage and provides a mounting surface for the Center Slotted Shield Holder. The Slotted Shield Plate is held to the Shield Holder by the Shield Plate Cover. The Scatter Shield Holder and Detector Holder are mounted to opposite sides of the Center Stage Mounting Bracket as shown in Figure 15.

There are two outboard detectors - one essentially the mirror image of the other. However because these detectors must move in azimuth as well as in elevation the parts are somewhat different than the stationary center detector parts. There are three subassemblies associated with each detector - the detector head, arch and moveable base. The moveable bases are arranged so they can pivot around a

bearing at the machine center. This allows the detectors to move in azimuthal direction quite accurately.

There are five manufactured part types (15 parts) associated with the moveable base: These are 1) Bearing, 2) Azimuth Bearing Cap, 3) Three Bearing washers, 4) a Top and Bottom Azimuth Plate, 5) Screw Hold Down / Washers.

The Bearing is fastened to the center of the table. A pilot surface in this piece allows accurate placement of this piece on this table and prevents side motion. The two Azimuth Plates are then placed in this bearing interspersed with the Bearing washers. The Bearing Cap captures this assembly preventing the Azimuth Plates from lifting as they are manually moved to various positions for particular crystal cuts. Screws perform the fastening operation. The Bearing washers are brass and were ground to precision after preliminary assembly indicated the exact thickness required. Such an approach allows make up of the difference between ideal dimensions and actual part dimensions. This precision is required to ensure that the Azimuth Plates move parallel to the table top - a reference surface.

Two purchased Locking Screw Knobs at the outer edge of each Azimuth plate are used as locking hold downs. The Locking Knob washer is placed between the bottom of the Azimuth Plate and the table top. As with the above washers these washers were also ground to precision to allow the Azimuth Plates to move parallel to the table top. With

the exception of the washers all the above parts are made from steel.

The second subassembly consists of the arch and associated parts. Similar parts are required for each of the two detectors. These all carry the prefix title "Outboard". These are 1) Bottom Connecting Block, 2) Top Connecting Plate, 3) Arch-Front Arch-Rear, 4) Arch Support. All these parts are fabricated from steel. The Bottom Connecting Block is fastened with screws to the Azimuth plate mentioned in the previous subassembly. This provides spacing as well as a vertical surface for mounting the Front and Rear arch pieces. Two arch pieces are required. They are essentially similar except for additional bolt holes for holding the Arch support. The Arch support fastens near the top of the arch and is fastened at the bottom to the Azimuth plate. Its function is to provide lateral stability to the arches. The top connecting plate holds the two arch pieces together at the top. The third subassembly consists of parts associated with the detector head. These are the elevation adjusting elements - the Elevation Adjusting Block and Locking Pad, and the elements which attach to this block. The Elevation Block and Locking Pad are similar in form and function to those of the center detector mentioned above; the exception being minor bolt hole spacing on the attaching surface. The elements which attach to this block consist of the actual detection parts while these parts are similar to those of the center detector they differ to the extent that these outboard detection heads must rotate. The part names are all prefixed with the title "Outboard". These are the Outboard 1) Swivel Plate, 2) Swivel Plate Bushing, 3) Swivel Plate Support, 4) Stage Mounting Plate,

5) Detector Holder, 6) Scatter Shield Holder, 7) Slotted Shield Plate, Holder and Cover. Other parts associated with this subassembly are purchased. These are the 1) Klinger Stepping Stage, 2) Holding Collar, and 3) Detector Tube. The Swivel Plate acts as a base for the majority of the foregoing parts and is fastened to the Elevation Adjusting Block mentioned in the previous subassembly. One of the most critical parts in this assembly is the Slotted Shield Plate. It is mounted to the Stepping Stage via the Holder and Cover. The Stepping Stage moves this assembly in small controlled steps intercepting the X-ray beam which is impinging on the detector - thus providing the means to accurately determine the beam location as it impinges on the detector tube face. Careful attention was required in machining the slot to insure that the slot was perpendicular to the plate surface. Originally it was thought that the shield plate would best be made from an X-ray absorbing material such as tantalum which allows little reflection and would give a sharp demarkation during reading. Brass however has been substituted because the requirements now appear less stringent.

The above stepping stage assembly is mounted to the Stage Mounting Plate which in turn mounts to the Swivel Plate. The Stage Mounting Plate has the capability of rotating around the Swivel Plate Bushing thereby giving the Slotted Shield Plate the capability of intercepting the X-ray beam at various angles as opposed to the center stage which is positioned at a fixed angle. A knurled hand screw in the Stage Mounting Plate allows ease of securing the Stepping Stage Assembly at the desired angle via a slot in the Swivel

Plate. A collar in the bottom side of the Swivel Plate on the protruding bushing secures this end of the Mounting Plate to the Swivel Plate.

Also mounted to the top of the Swivel Plate is the Detector Holder and Detector. These parts are arranged so the Detector is suspended over the hole in the Swivel Plate Bushing. The Scatter Shield Holder is mounted on the opposite side of the Swivel Plate so as to allow this Scatter Shield to be in line with the Detector. The function of the Scatter Shield is to reduce the amount of stray X-rays entering the Detector. The majority of the above mentioned manufactured parts in this third subassembly are of aluminum. This is to reduce the weight of the head so as to make adjustment of the detectors easier.

4.3.6 MOUNTING TABLE/SHIELDING

The table top is 91 cm (3 feet) in length by 62 cm (2 1/2 feet) wide made of 12.7 mm (1/2 inch) thick hotrolled steel plate. Steel stiffeners 76.2 mm (3 inches) high by 12.7 mm (1/2 inch) thick were welded to the bottom and are used to brace the bottom surface. The top surface was ground in a Blanchard Grinder and tolerances held flat to .07 mm (.003 inches). A classical three point support design system has been incorporated by means of three stand-offs welded to the bottom of the table which in turn connect to the table support frame. The configuration of one stand-off at the X-ray source location and one stand-off beneath each of the outboard detector arches distributes the weight correctly and contributes to stability.

Two semi-circular slots 13.46 mm (17/32 inches) wide were machined into the table surface along the outer edges at the detector end for use as a "T" bolt hold down for the Azimuth Plates.

A hole was also machined at the table-top center for the Outboard Arch Bearings. Vacuum for the 3-point chuck is also piped up through this hole.

A rectangular cut-out in the table rear end provides clearance for the body of the X-ray tube/shield assembly to protrude below the table top surface. Fastening holes for the X-ray support structure, the three mounting points of the stage support, the X-ray collimator and the fixed center arch base are tapped into the table surface. A clearance hole through each of the three stand-off pads allows a bolt to pass through the table top for fastening the top to the table support frame. A black oxide coating was used to coat this table top.

To support the table a rectangular base, the Table Support Frame, was made using 38.1 mm (1 1/2 inch) steel tubing. The frame measures 68.5 mm (27 inches) deep (front to back) by 55.8 cm (22 inches) wide by 60.96 cm (24 inches) high - welding was used throughout. Gussets in the corners were used for added strength. Threaded stand-off pads are used in each of the four leg bottoms to provide leveling and for operator height adjustment. The frame was painted PRH beige to protect it from rusting.

4.4 PART FABRICATION AND COATING

With the completion of the detailed parts design, the project was finally ready to proceed to the parts fabrication and coating phase. Efforts were made to keep the activity of this phase in the immediate area of PRH to insure tight control, fast delivery and allow ready interface with the vendors. In addition to the P.R. Hoffman Machine Products Division, a number of machine shops within a 50 mile radius of PRH were surveyed. The survey was to determine the skill/equipment available and the most cost effective for manufacturing the AXROS parts. This included both large machine shops (40 men) and small (as few as one man). Prints of the required parts were made and subsequently sent out for quotations to vendors found suitable (usually 3) in efforts to determine the best price and delivery. Orders were subsequently placed. Upon receipt of the parts from the vendors the parts were sand blasted on the non-critical surfaces and sent out for coating. Among the candidate coatings investigated were black oxide, black chromate, yellow anodize, cadmium and chrome. The black chromate and yellow anodize are less desirable because of cosmetic reasons. In addition to being costly, cadmium and chrome allow a prohibitive build-up of materials for critical mating parts. Black oxide MIL-SPEC C-13924B was chosen for the parts of ferrous material. Appearance is excellent and it matches the black color of the linear/rotary stages. Aluminum parts will be black anodized. PRH beige was used to paint non-critical areas such as the table base.

4.5 FUTURE WORK

The Hardware Phase is well underway. The major work during the coming interim period in this phase will concern assembly and shipment of the equipment. Specifically this will encompass:

- 1) The receiving of all mechanical fabricated or purchased parts and inspecting these to insure adherence to design specifications.
- 2) The complete and proper mechanical assembly of the AXROS machine.
- 3) The timely delivery of the assembled AXROS machine to ARACOR for the Integration Phase.

Other future allied work will be to provide mechanical engineering support to ARACOR during the Integration Phase and to revise and update all working drawings to reflect modifications made to parts and assemblies during the Integration Phase.

5.0 QUARTZ CRYSTALS

5.1 DELIVERY STATUS

One of the specific tasks within the contract scope calls for the delivery of 500 doubly rotated resonator plates. Work to date has included the delivery of the four (4) lots of SC crystal blanks to Ft. Monmouth for study. A series of crystal lots are to be produced with varying angle specification for subsequent study of resonator performance relative to blank angle of cut.

Lot 3, Delivered 6 August 1980

25 SC Quartz Crystal Blanks

ZZ $33^{\circ} 38' \pm 5'$

XX $21^{\circ} 56' \pm 20'$

.550" Dia $+.000$
 $-.002$

4.660 MHz $\pm 1/2\%$

1 μ Microgrit Abrasive

Natural Quartz R.H.

$Q = 2 \times 10^6$

Flat on Z

Lot 4, Delivered 6 November 1980

50 SC Quartz Crystal Blanks

ZZ $33^{\circ} 38' \pm 5'$

XX $21^{\circ} 56' \pm 20'$

.550" Dia $+.000$
 $-.002$

4.660 MHz $\pm 1/2\%$

1 μ Microgrit Abrasive

Natural Quartz R.H.

$Q = 2 \times 10^6$

No Flats

5.2 FUTURE WORK

It is expected that the majority of the 370 blanks remaining of the required 500 will be shipped during the next interium period.

6.0 ANGLE CORRECTION

Paramount to the SC crystal program is the ability to angle correct crystal blanks once the crystal angles have been determined. A technique and hardware to accomplish this was part of the program objectives. To support this objective, a novel method was devised to angle correct SC crystals by use of a laser to replace the standard chemical etching approach. This new method appears to be more suitable for use with the AXROS than conventional methods due to the requirement of compound angle correction for SC crystals. This technique consists of applying numerous small pits on the crystal surface by a succession of laser discharges. These pits are located in place of and simulate the mesa produced by the standard chemical etching angle correction technique. Subsequent lapping allows the pitted area to be worn away preferentially and thus, results in a change in crystal angle. A series of preliminary experiments indicate that pitting does not appear to damage the crystal and that subsequent lapping of the pitted crystals effect angle change. The major advantages of this technique are that no hazardous acids are required and the laser pits can be accurately added to the crystal under control of the system computer wherever necessary, thereby allowing the dual angle correction required by the SC crystal with a minimum of iterations. After successful preliminary investigation the program was poised

for indepth study however lack of funding caused a termination of this program task.

7.0 AUTOMATION

The AXROS equipment is intended to be automated in its final configuration. The design work to date has attempted to encompass this future requirement. Automation operational sequences and some specific mechanism have been investigated. Space appears adequate within the structure to add mechanism for automation. The design task is dependent upon the method of angle correction and sorting chosen and at this time appears relatively straight forward. This portion of the project has been terminated due to lack of funding.

FIGURE CAPTIONS

Figure 1. Traditional Laue Back-Reflection Geometry. The motion of the X-ray spot produced by different crystal rotations is illustrated.

Figure 2. Schematic of the breadboard measurement device, as of the first six-months of work. The device was later adapted to glancing-angle geometry.

Figure 3. Diagram of the glancing-angle diffraction geometry employed in the prototype measurement device.

Figure 4. Glancing-angle Laue pattern predicted for an SC-cut crystal. A glancing angle of 20° , as selected for the prototype, was used. The small circumscribed cross-hairs denote the position of diffraction maxima with $h, k, l \leq 2$ at $\psi = 218.12^\circ$. These reflections are the most intense in the pattern. The curved dotted lines show the path of each spot as the blank is rotated about ψ . The triangles indicate the occurrence of tungsten L-line reflections. The aperture shown subtracts 90° at the blank surface, and is elevated 20° from the blank surface, as shown in Figure 3.

Figure 5. SC-cut Laue pattern simulation similar to that in Figure 4, except that all reflections with $h, k, l \leq 3$ are included. The density of reflections, and hence possible

ambiguities in the initial reflection search, increases dramatically. Fortunately, the diffracted intensities fall off substantially as h, k, l increase.

Figure 6. AT-cut Laue pattern simulation, similar to that in Figure 4. Maximum h, k, l is 2.

Figure 7. AT-cut pattern simulation with $h, k, l \leq 3$.

Figure 8. SC-cut pattern simulation with $h, k, l \leq 6$, with the aperture positioned at the central detector position chosen for SC-cut measurements in the prototype. Only the $1\ 2\ \bar{1}$ reflection chosen for SC-cut measurements and its higher orders are visible near the Ψ -value of interest, $\Psi=218.12^\circ$.

Figure 9. Similar to Figure 8, except for one of the "outboard" detectors at Azimuth = 33.98° , as discussed in the text.

Figure 10. Simulation with $h, k, l \leq 2$ for the SAW cut $\phi = 6.57^\circ$, $\theta = 26.88^\circ$, $\psi = 134.9^\circ$, at an instrument ψ -rotation of 24.33° . The aperture is set as in Figure 4. The $0\ \bar{1}\ \bar{1}$ and $\bar{1}\ \bar{1}\ \bar{1}$ reflections are good candidates for measurement, as described in the text.

Figure 11. Definition of the angles δ and ψ_0 used in determination of the motion of a spot reflected from a rotating plane

in glancing-angle mode.

Figure 12. Plot of the axial ratio (width:height) of the tear-drop obtained in the laser detector upon ψ rotation of the crystal, vs. the glancing-angle (i.e., angle of incidence) of the incoming laser beam. This ratio, along with the size of the active photodiode, are set limits on the range of useful glancing-angles, as described in the text.

Figure 13. Block diagram of the organization of the control software.

Figure 14. AXROS Layout Plan View.

Figure 15. AXROS Layout Elevation View Center Detector Stage.

Figure 16. AXROS Layout Elevation View - Outboard Detector Stage.

Figure 17. 3-point Vacuum Chuck Assembly.

TRADITIONAL LAUE
BACK-REFLECTION METHOD



Figure 2.

BREADBOARD SCHEMATIC

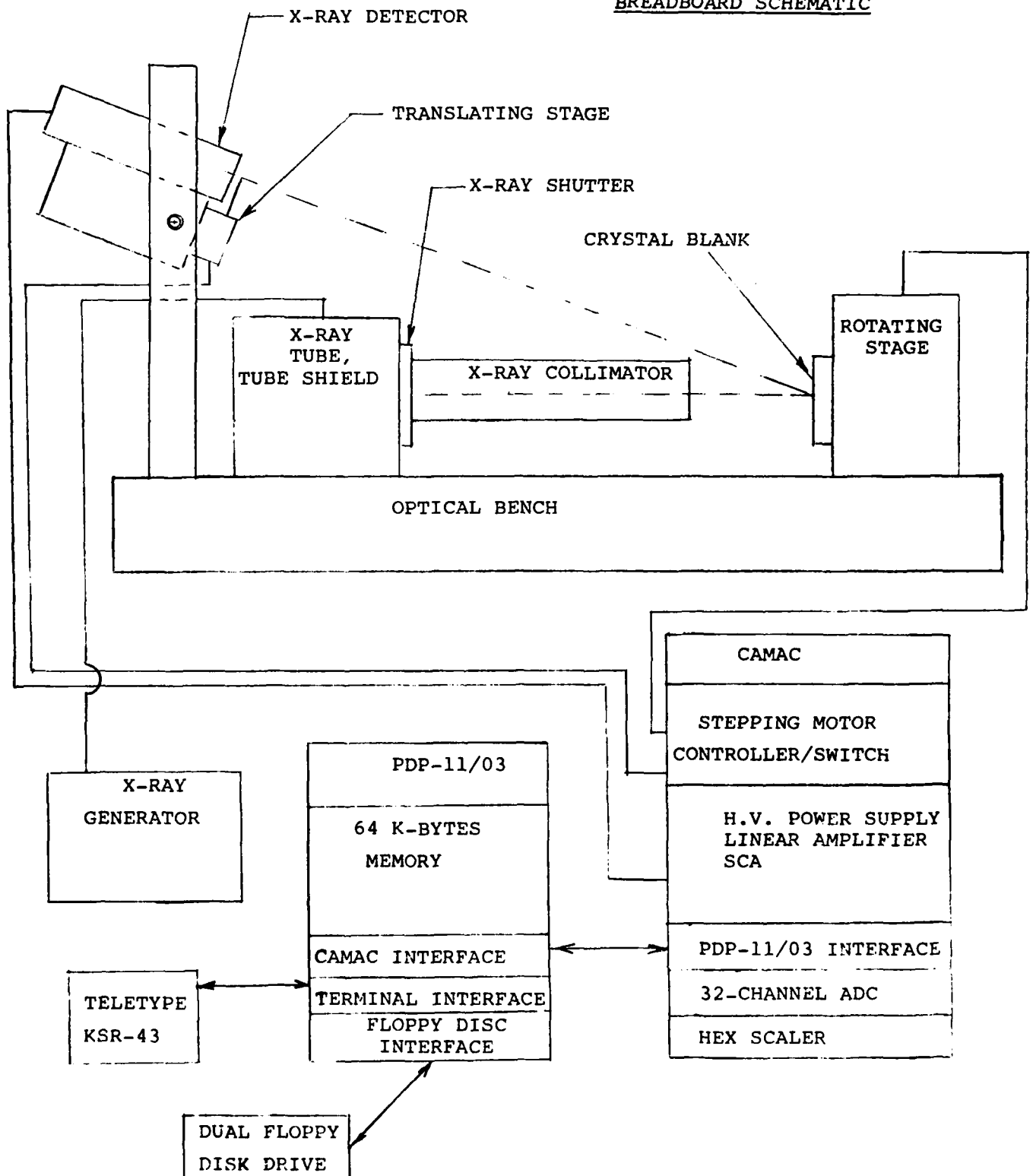


Figure 3.

GLANCING-ANGLE
GEOMETRY

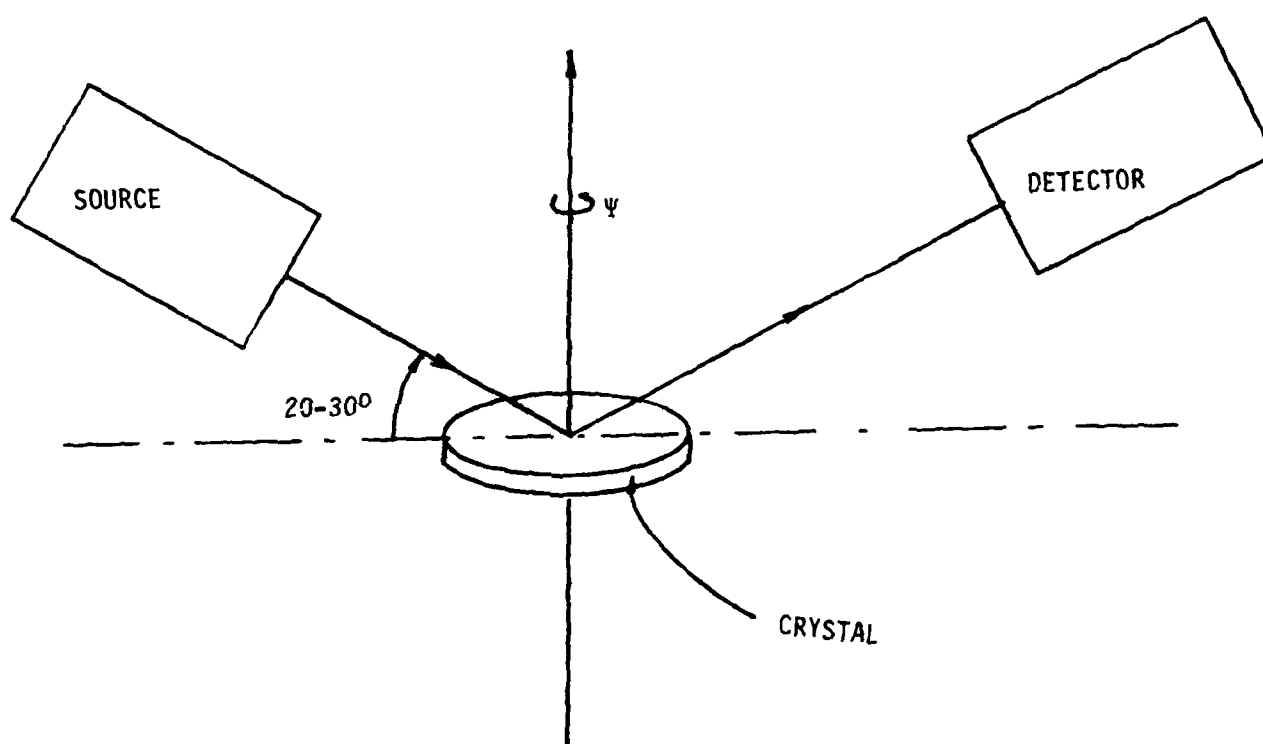


Figure 4.
SC PATTERN
HKL_{max} = 2

SC CUT, PSI=218.12 8.25.80

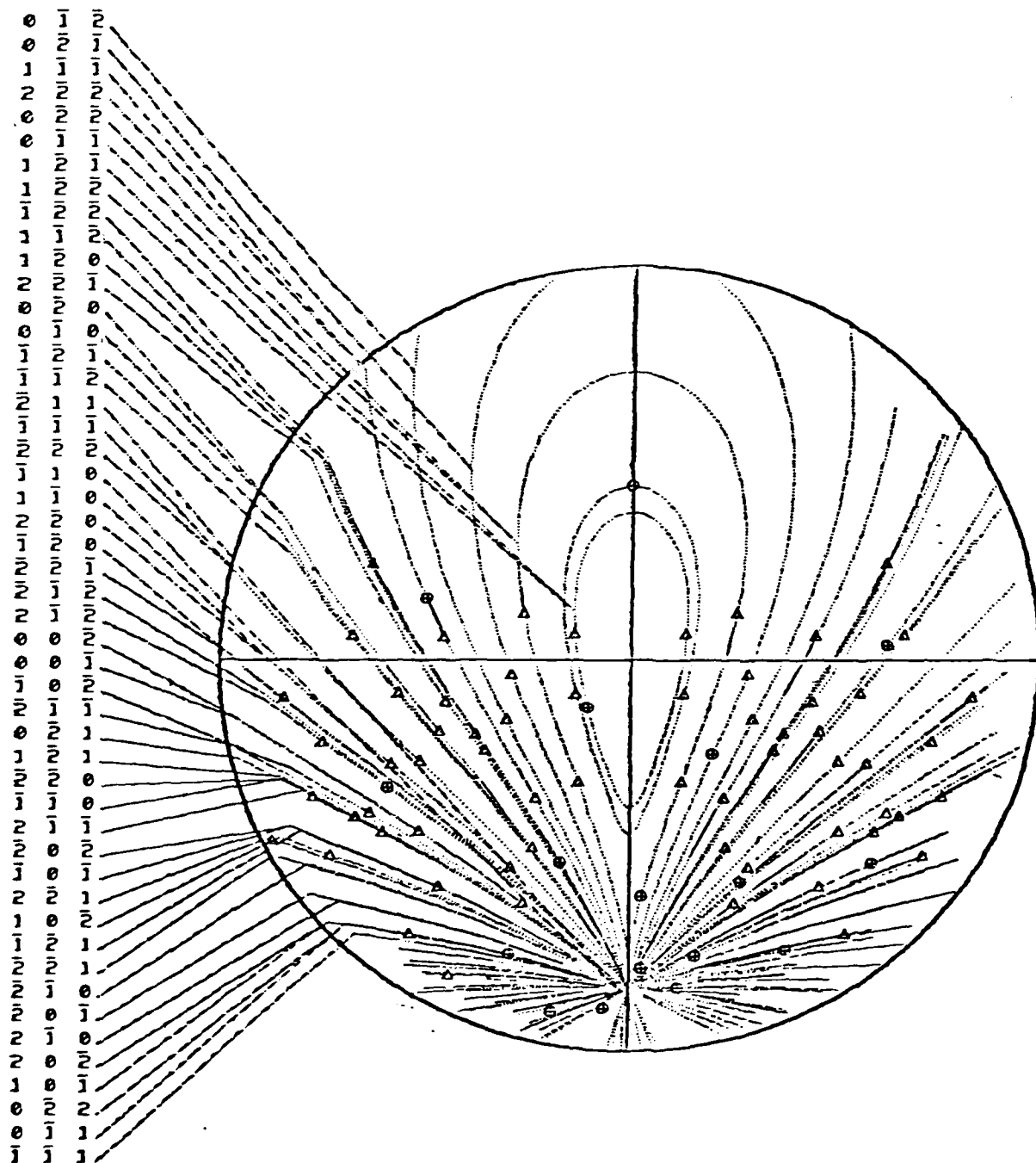


Figure 5.
SC PATTERN

SC CUT, PSI=218.12, HKL MAX=3 8/25

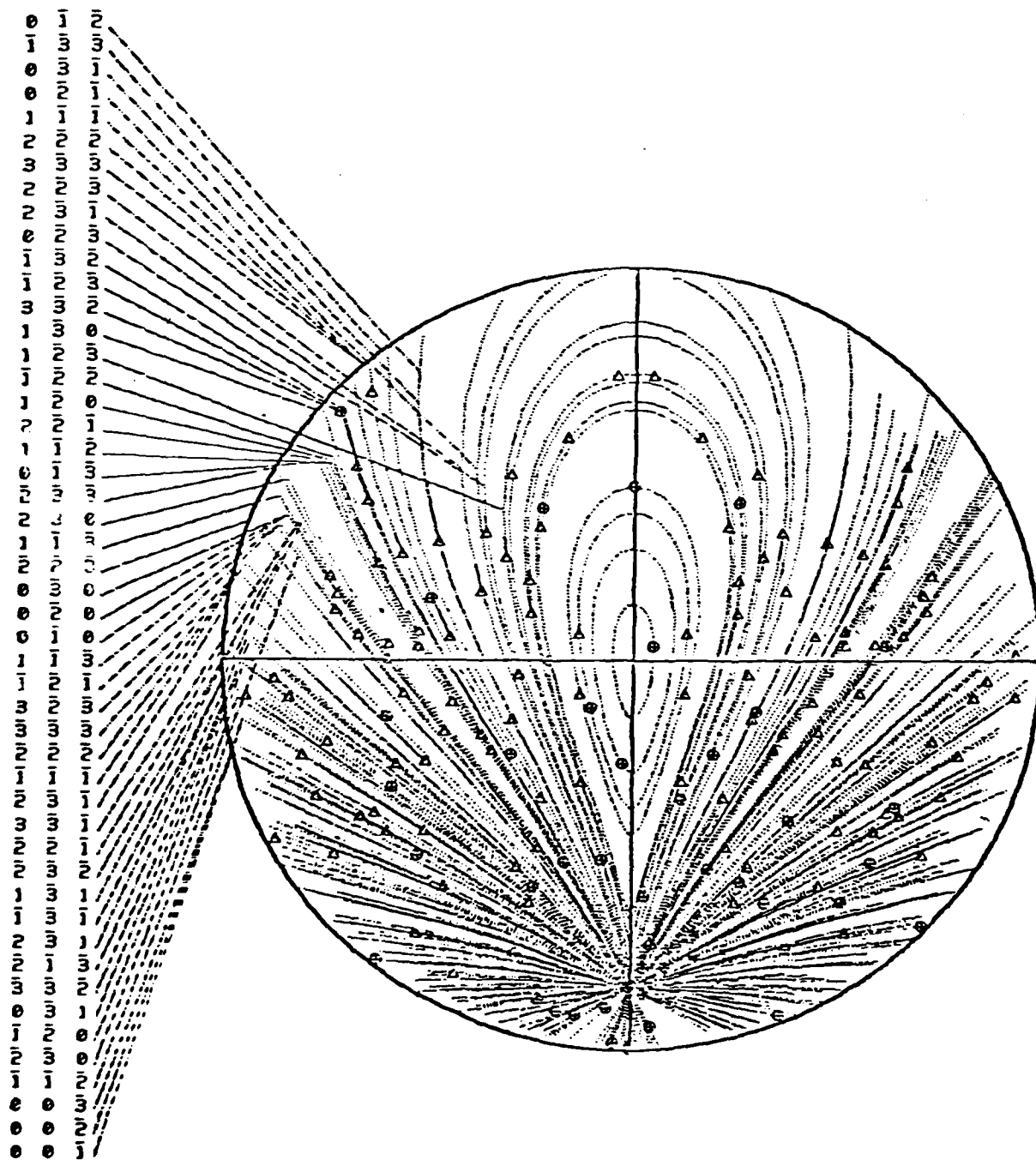


Figure 6.
AT PATTERN
 $HKL_{\max} = 2$

AT CUT, $\Psi = 180^\circ$. 8.25.80

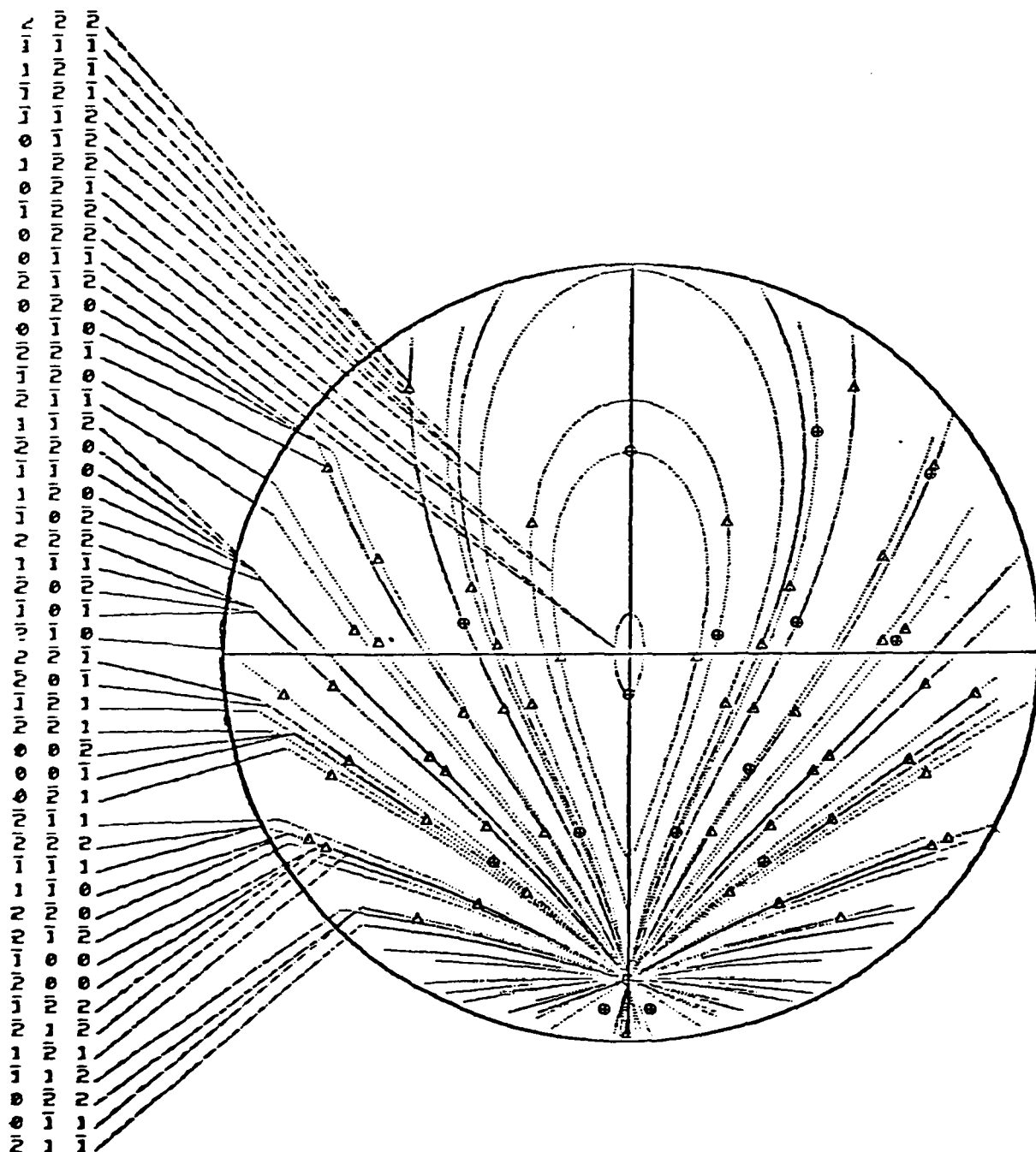


Figure 7.
AT PATTERN

AT CUT PSI=180 HMAX=3

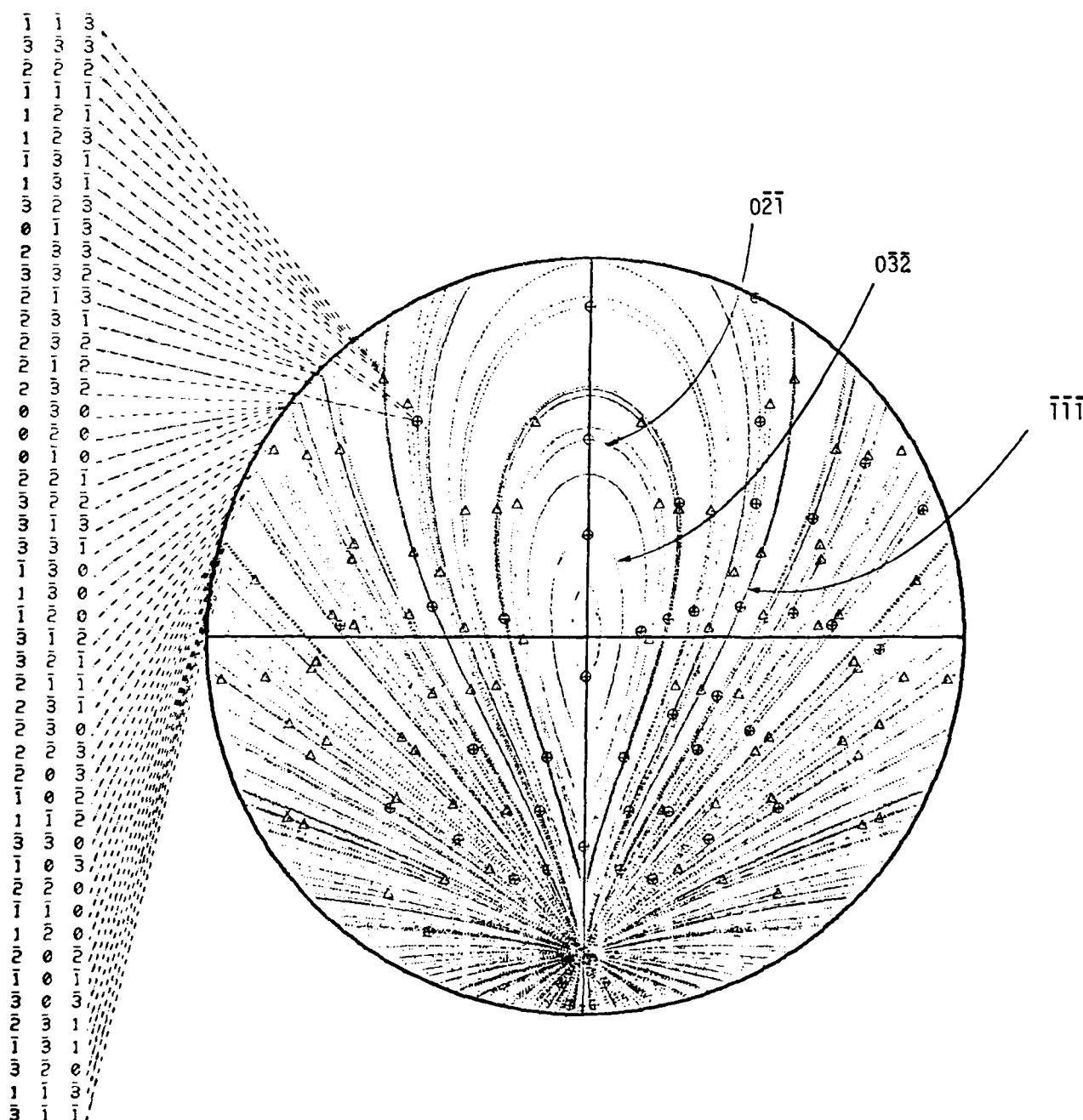


Figure 8.

SC PATTERN

$\pm 1.7^\circ$ Central Aperture

$HKL_{\max} = 6$

SC CUT, CENTRAL APERTURE

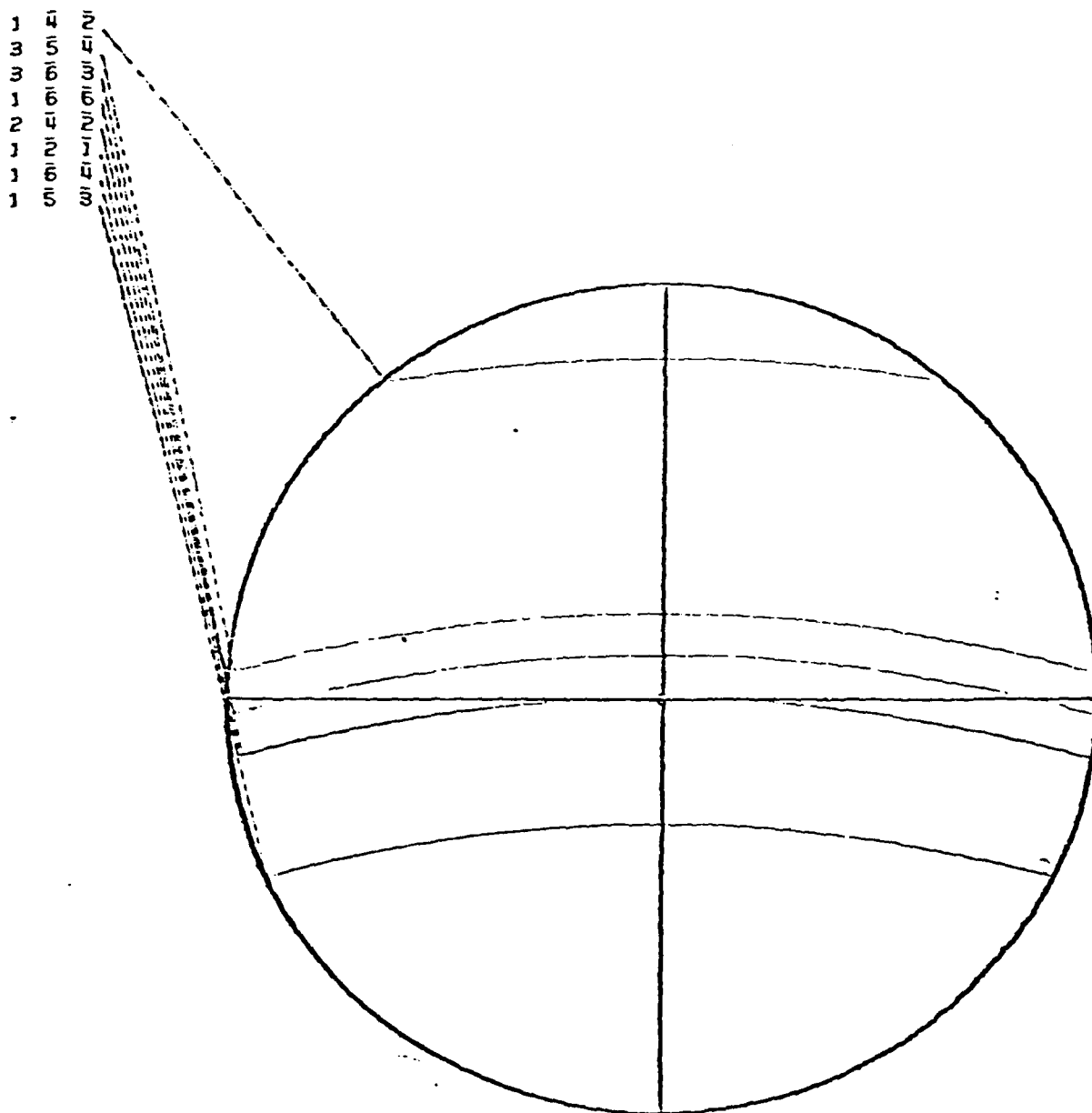


Figure 9.
 SC PATTERN
 ± 1.70 "Outboard"
 $HKL_{max} = 6$

SC CUT, OUTSIDE APERTURE

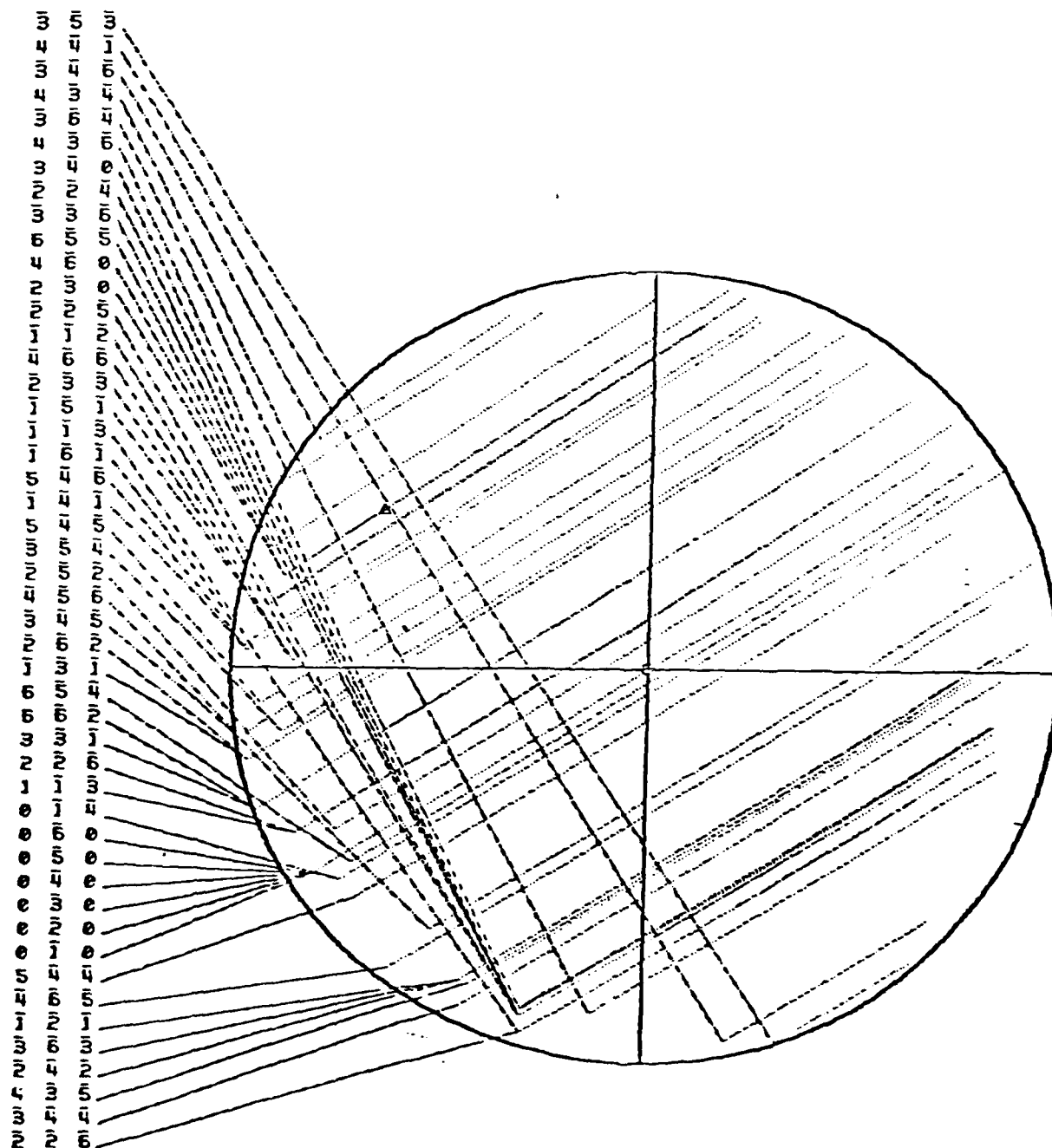


Figure 10.

SAW CUT#1, PSI=24.33

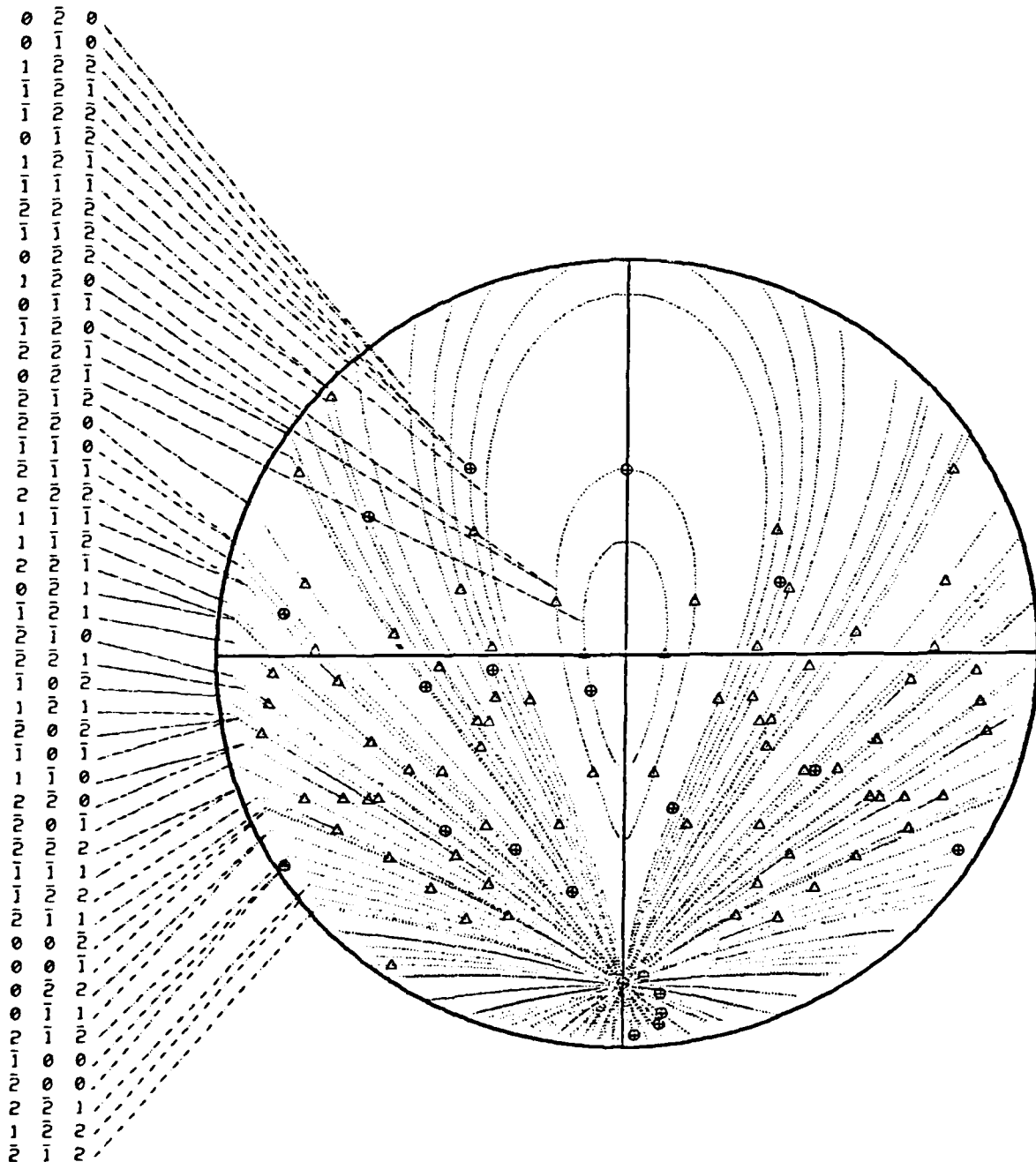
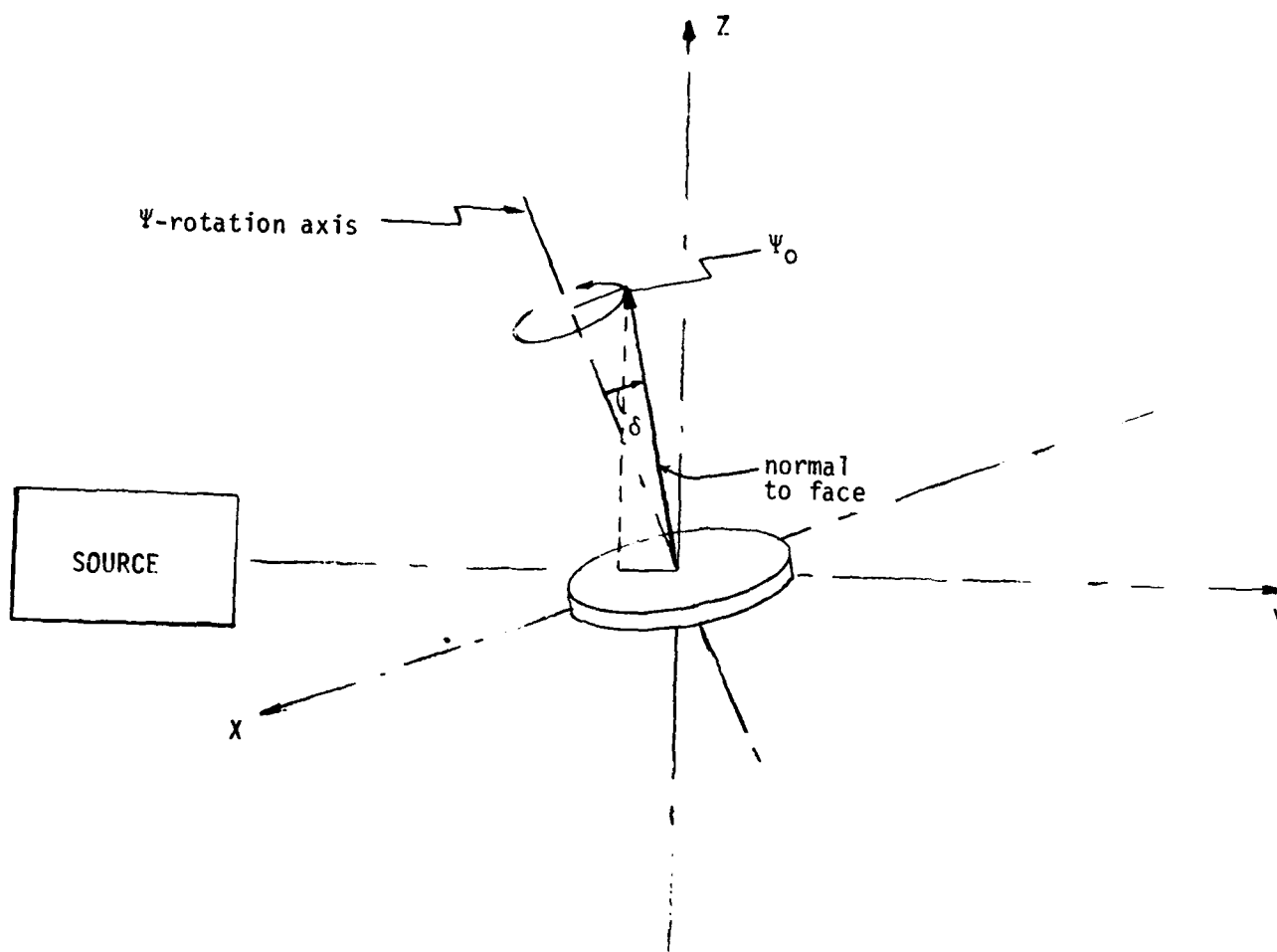


Figure 11.
GEOMETRY
USED FOR
TEARDROP
DERIVATION



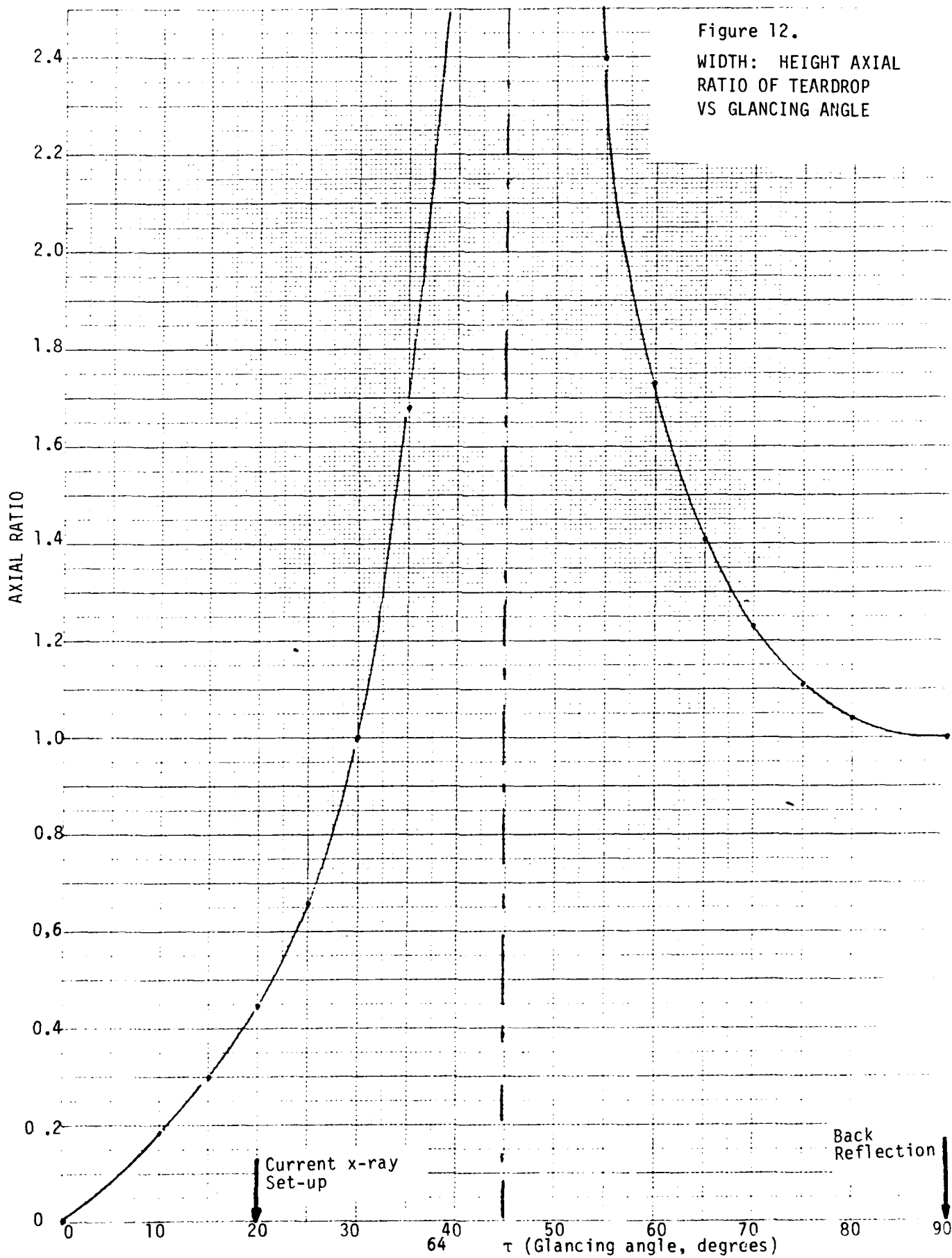
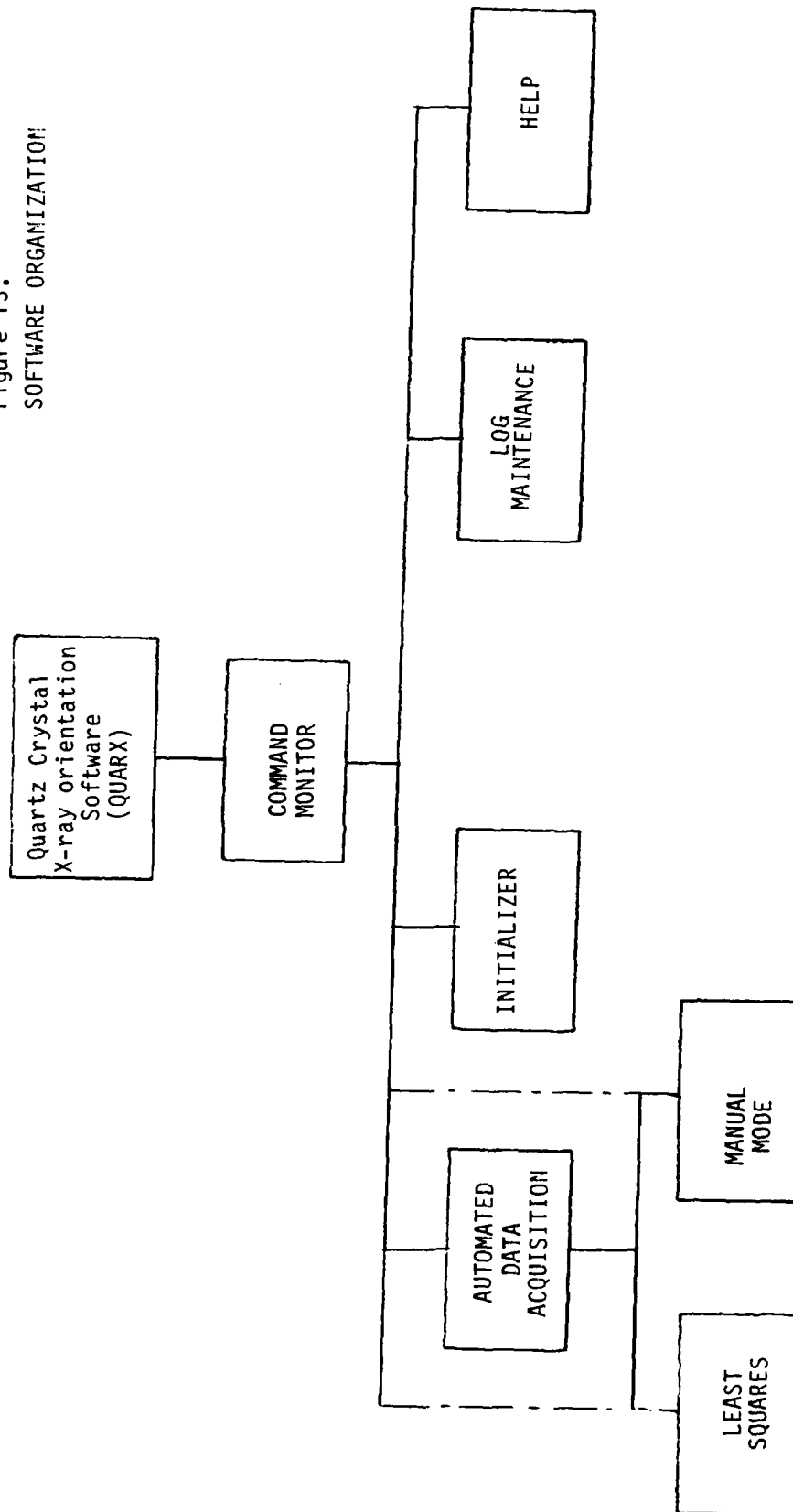


Figure 13.
SOFTWARE ORGANIZATION!



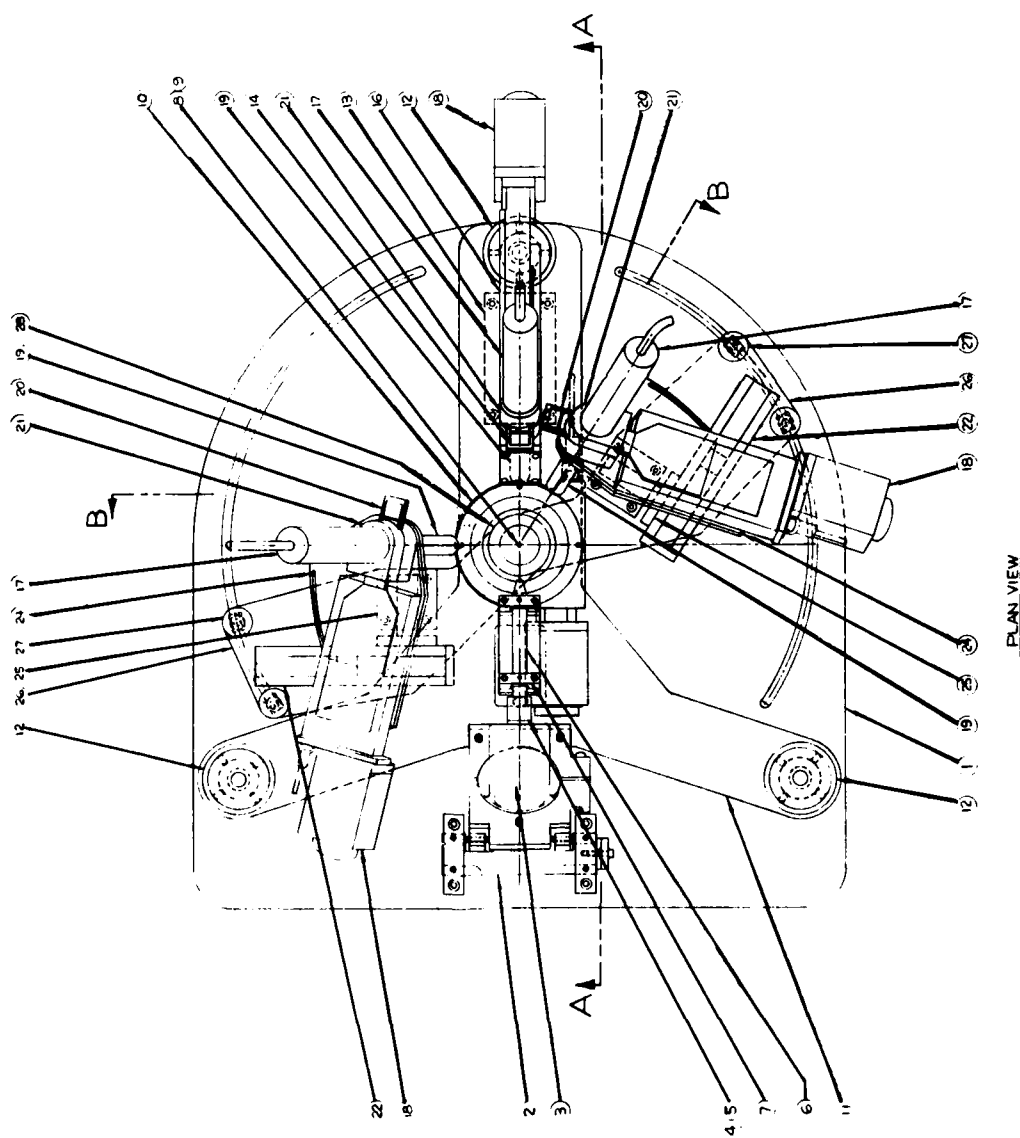


Figure 14.
AXROS Layout - Plan View

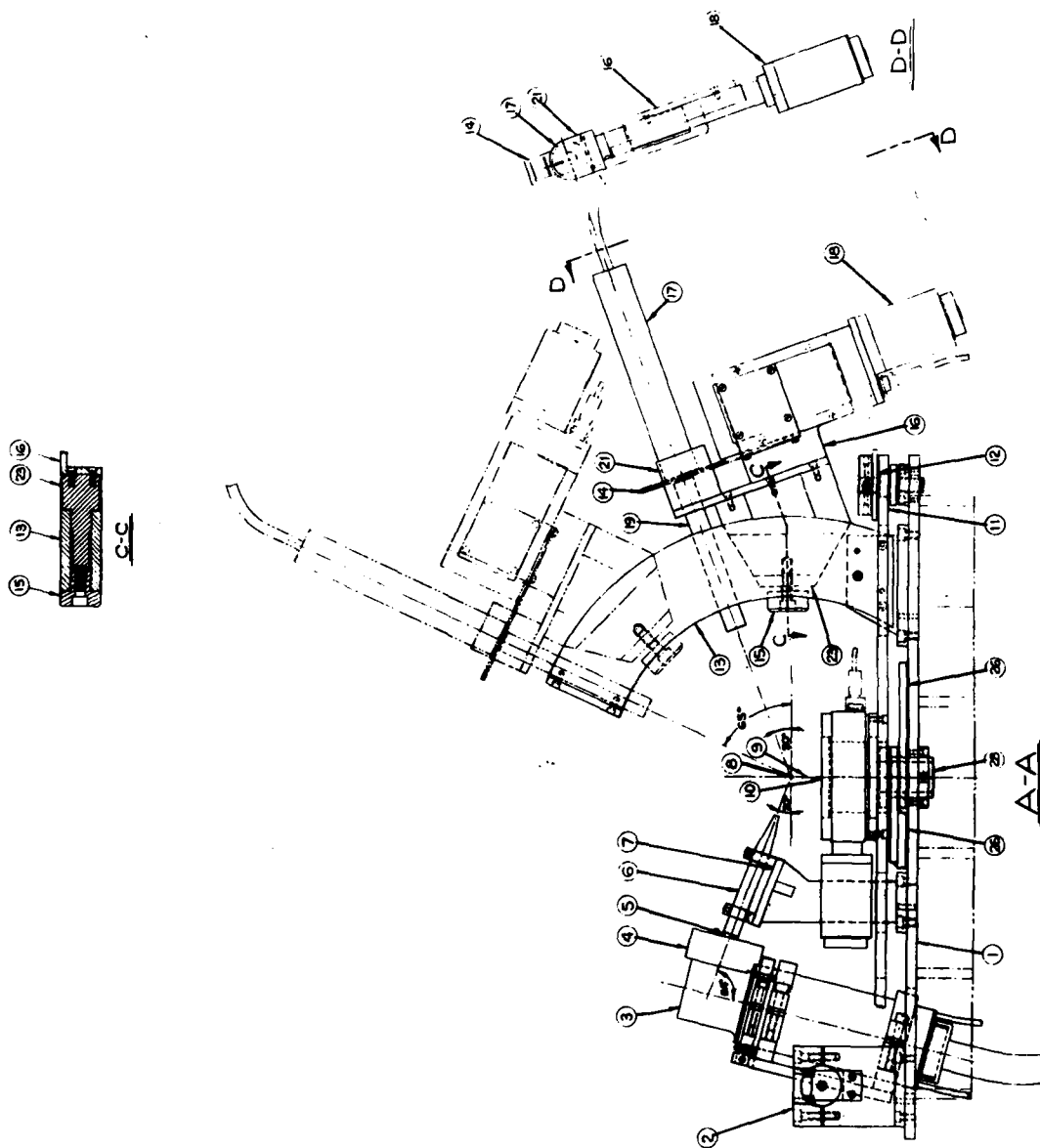


Figure 15.
AXROS Layout - Elevation View (Center Detector Stage)

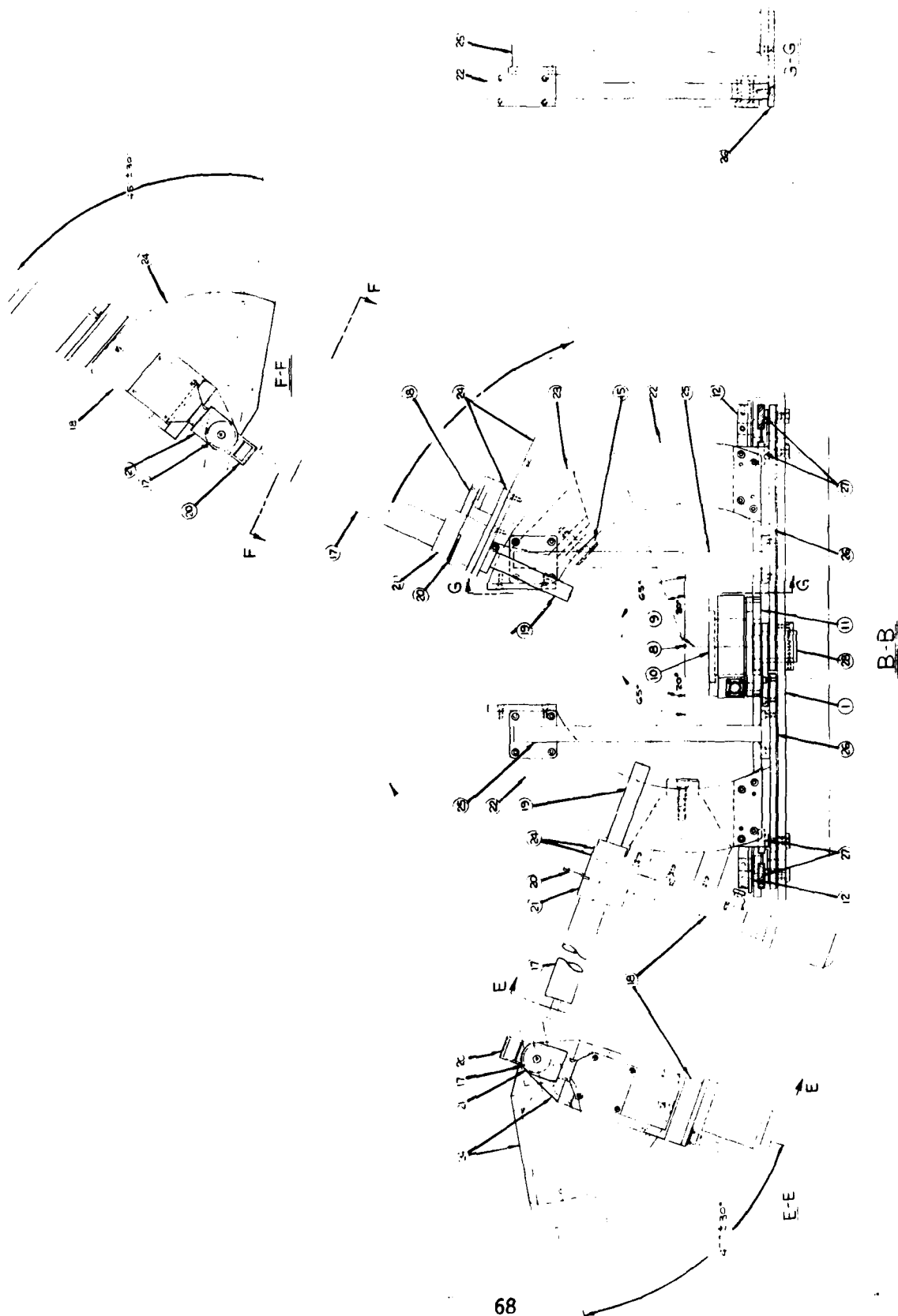


Figure 16.
AXROS Layout - Elevation View (Outboard Detector Stage)

