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THE DESIGN, INSTALLATION, AND
OPERATION OF AN AUTOMATIC
NEUTRON DIFFRACTION SYSTEM

by

D. J. Dahm and R. A. Jacobson

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TABLE OF CONTENTS

	Page
ABSTRACT	iv
INTRODUCTION	iv
DESIGN OF MONOCHROMATING SYSTEM	1
ALIGNMENT OF MONOCHROMATING CRYSTAL	6
INTENSITY OF DIFFRACTED BEAM	8
BEAM UNIFORMITY AND DIVERGENCE	8
DETERMINATION OF HIGHER ORDER CONTAMINATION	9
DESIGN OF ORIENTATION SYSTEM	11
DETECTOR SYSTEM	13
OPTICAL ALIGNMENT OF INSTRUMENT	14
ALIGNMENT OF INSTRUMENT USING NEUTRONS	15
THE INTERFACE	19
ACKNOWLEDGMENTS	27
REFERENCES	28

THE DESIGN, INSTALLATION, AND OPERATION OF AN AUTOMATIC NEUTRON DIFFRACTION SYSTEM

D. J. Dahm and R. A. Jacobson

ABSTRACT

A Hilger-Watts four circle neutron diffractometer operates under the control of an SDS 910 computer. The interfacing and programming for the system are of local origin. A neutron beam forming an angle of 90° with the incident beam is taken from the beryllium monochromating crystal located inside the reactor face. Alignment of the diffractometer, both optically and with neutrons, the neutron detection devices, and other aspects of the system are discussed in some detail.

INTRODUCTION

An automatic neutron diffraction system has been made operational at the Ames Laboratory Research Reactor. The system consists of several parts: a monochromating system, a diffractometer, an interface, a teletype, neutron counting devices, and a computer.

The monochromating system uses a beryllium crystal and yields a beam with virtually no higher order contamination. The diffractometer is a Hilger-Watts (model 4230-1) four circle device which operates under computer control.¹ The computer used is an SDS 910 with 16K words of core storage. Auxiliary storage of five million words is provided by two magnetic disks. High speed access to auxiliary storage

is provided by an IBM-1401 computer, which handles the flow of information between the main computer and the disks.

Programs for this computer system are written in the "TASK" language,^{2, 3} which is an "ALGOL" based language with several modifications to permit real time usage of the computer. The interaction between the computer and the diffractometer is through an interface, which carries out computer commands and relays information from the experiment to the computer, as well as handling flow of information between the computer and the teletype. The teletype is the only means of communication a user has with the computer.

DESIGN OF MONOCHROMATING SYSTEM

The neutrons in the core of the reactor are of a wide energy range but in general have higher than optimum energy for use in neutron diffraction. To increase the number of useful neutrons, the average energy of the neutron beam must be reduced before one energy is selected by the monochromating crystal. The design of the system used to moderate and monochromate the neutron beam which comes from the reactor core is illustrated in Fig. 1.

The beam tube for the main beam is a circular opening 6 in. in diameter in the reactor wall running from the reactor core toward a cavity just inside the reactor face. Each end of the beam tube is covered with a 1/16 in. aluminum plate to make the tube air tight. Next to the interior aluminum plate is a 2 in. layer of graphite moderator through which all neutrons must travel. Through the remainder of the beam

Fig. 1. Moderating and Monochromating System.

tube there is a 1 in. square opening through which neutrons traveling in a straight line from the reactor core to the monochromating crystal can pass freely. The small opening is surrounded for the first 22 in. by graphite, which "funnels" some additional neutrons into the opening. For the next 24 in. the opening is surrounded by stainless steel and concrete, which serve as a collimator for the main beam.

The position of the monochromating crystal is somewhat different than in many other systems. A common arrangement is to allow the main beam to impinge on a monochromating crystal external to the reactor face. This necessitates that considerable shielding be put up around the monochromating crystal and therefore takes up much floor space. It has an advantage in that it permits the angle between the beam incident to and diffracted from the monochromating crystal to be readily changed; consequently the wavelength being used can be optimized for a particular experiment. Our monochromating crystal, however, is located inside the reactor face, as illustrated in Fig. 1. This arrangement requires almost no shielding on the reactor floor but restricts the angle between the diffracted and incident beams to approximately 90° . We will refer to this angle as the "take-off angle." Our take-off angle is large compared to that in many systems, but this is advantageous for data taking. All reflections from the sample crystal which occur at an angle less than the take-off angle have the same peak shape as the reflection from the monochromating crystal, but reflections which occur at angles higher than the take-off angle have a half-width greater than the half-width of the peak from the monochromating crystal.

Our large take-off angle was an important factor in choosing beryllium for our monochromating crystal. Beryllium not only has a high scattering cross section but also has a large Debye temperature and therefore the decrease of intensity due to thermal motion as a function of the take-off angle is smaller for beryllium than other metals. This is especially important at our large take-off angle.

All reflections of beryllium for which $h-k=3n$ and $l = 2n$ have all atoms scattering in phase. Thus any one of these will have maximum intensity, so the only criterion for picking one is that θ be 90° for a wave length of approximately $1 \text{ \AA}$. The $\bar{1}2\bar{1}4$ reflections satisfy this condition and is the one currently being used.

The original specifications for the monochromating crystal called for a Be single crystal $1.5 \times 1 \times 0.5$ in., cut with the 1.5×1 in. face parallel to the 0001 plane. A 1×0.5 in. face was cut parallel to the $10\bar{1}0$ plane. The $\bar{1}2\bar{1}4$ plane forms an angle of about 25° with the 0001 plane; this Fankuchen cut would result in a decrease in the divergence of the beam. The crystal actually being used has a volume nearly twice that specified but is irregularly shaped so that its minimum dimensions are slightly smaller than specified. The face of the crystal being struck by the incident neutron beam is the 0001 plane, and the $10\bar{1}0$ plane is placed horizontally.

The monochromating crystal is positioned on a mount inside the reactor face. This mount can be rotated 5° , tilted 10° and moved up to 1 in. in two horizontal directions by dials on the reactor face. The base beneath the mount can be similarly rotated by as much as 90° .

The collimator through which the neutrons pass from the monochromating crystal to the reactor face is housed in a concrete lined steel tube about 6 in. in diameter. The collimator itself is a cadmium plated steel tube 1 cm square and 61 cm long. The collimator can be driven by a motor from one side of the large tube to the other in a 3° arc which centers on the monochromating crystal. Because this system was designed exclusively for single crystal structure studies, fine collimation of the neutron beam is not necessary. However some additional collimation is provided by a moveable cadmium-filled brass plate with a 1 cm square opening. This plate slides over the end of the steel tube just at the reactor face.

The exact placement of the collimator is actually rather arbitrary but the angle it makes with the incident beam does determine the exact wave length of the neutrons which enter the collimator. The line following the center of the collimator will be the "reference line" for the entire system. The monochromating crystal, the sample crystal, and the center of the instrument must lie on this line. The collimator was placed horizontally and was centered on the approximate center of the monochromating crystal table. In order to facilitate later optical alignment of the orienter, two scribe marks identifying the reference line were made with the aid of a transit, one on a wall at the height of the collimator and a second on the floor near the reactor face directly below the reference line.

There is a small, cadmium-plated shutter which, when activated by a selenoid, stops about 90% of the monochromatic neutron beam. Complete cessation of the beam is accomplished by means of a large rotary shutter which can be closed to prevent the main beam from hitting the monochromating crystal. This large shutter, however, is not under computer control.

ALIGNMENT OF MONOCHROMATING CRYSTAL

In order to properly position the monochromating crystal, a BF_3 neutron detection system was placed on the reference line. The monochromating crystal was aligned by successively maximizing the intensity of the neutron beam with respect to the above mentioned adjustments of the monochromating crystal mount in a cyclic fashion until an absolute maximum was attained. Then the moveable plate was placed over the end of the steel tube. It was positioned optically so that the neutron intensity emerging from the opening was maximized.

After alignment is obtained, the rotation adjustment rotates the crystal about an axis perpendicular to the plane defined by the main beam and the diffracted beam. A curve obtained by measuring the intensity of the diffracted beam as a function of rotation indicates the mosaic spread of the monochromating crystal. The curve obtained for our beryllium crystal (Fig. 2) shows the mosaic spread to be 0.41° .

Fig. 2. Rocking Curve of Beryllium Crystal.

INTENSITY OF DIFFRACTED BEAM

While relative numbers of neutrons are easy to measure with uncalibrated BF_3 counters, exact intensities are not because BF_3 tubes are in general less than 100% efficient. In order to determine the exact intensity of our beam and to get an idea of the efficiency of our BF_3 tube, a circular piece of gold foil 1 cm in diameter was placed in the diffracted beam. After irradiation for 19 1/2 h with reactor power at 5 MW the radioactivity of the gold was measured and the neutron flux was calculated. The result, 9.3×10^4 neutrons/cm² sec, was very close to that which we measured with our BF_3 counter, indicating that our BF_3 tube is nearly 100% efficient.

BEAM UNIFORMITY AND DIVERGENCE

The beam uniformity and divergence were recorded photographically. The intensifying screen was removed from a conventional Polaroid x-ray attachment and was replaced by a screen which emits light when struck by a neutron. The camera was placed next to the moveable plate, just outside the reactor face. As expected, the exposed portion of film was 1 cm square. An exposure was also made at a distance of 116 cm from the plate. Here the exposed portion measured 2.3 cm square indicating that the beam intensity falls off as the square of the distance plus 90 cm from the plate. In our present setup the crystal is 125 cm from the plate. From pictures made with several different exposure times, it was evident that the beam is quite uniform except at the extreme edges.

DETERMINATION OF HIGHER ORDER CONTAMINATION

Ideally, the beam leaving the collimator should be one and only one wave length. This is usually impossible to obtain because of second or higher order contamination. If a set of h , k , l planes of the monochromating crystal are in position to diffract neutrons of wave length λ into the collimator, the nh , nk , nl planes will be in position to diffract neutrons of wave length $\frac{\lambda}{n}$ in the same direction, and higher order contamination will result. One could reduce the problem by choosing a reflection which has an extinct second order reflection, but this is impossible for beryllium if one desires a first order reflection of highest intensity.

The amount of higher order contamination was determined by a time of flight analysis of the diffracted beam. A chopper which allows neutrons to pass intermittently was placed in the beam at the collimator, with a BF_3 detector positioned 43.53 m from the chopper. The length of time which the chopper was open was short enough to give adequate resolution and the time it was closed is long compared to the time it takes a 1 Å neutron to travel from chopper to detector. When the chopper was open, a pulse was generated and t seconds later the counting system was turned on for 0.04 milliseconds. For each value of t , this process was repeated for 100 sec. A plot of the number of counts as a function of flight time is shown in Fig. 3. From this it can be seen that the amount of higher order contamination is less than 1%.

Fig. 3. Wavelength Analysis of Beam.

DESIGN OF ORIENTATION SYSTEM

The table on which the diffractometer sets has translations in two perpendicular horizontal directions and a height adjustment. The table was bolted to the reactor floor so that its center was very close to the reference line and so that one of the translational adjustments on the table was perpendicular to the reference line.

The instrument itself is a device for positioning a crystal in any orientation. A crystal can be mounted on a standard goniometer head which can be affixed onto the instrument by means of a screw fitting. The crystal can then be rotated about any of three axes, designated as phi, chi, and omega. The detector arm rotates about an axis designated as the theta axis.

When all axes are at their zero positions, the theta, omega, and phi axes are vertical, and the chi axis is horizontal and parallel with the reference line. The direction of positive rotation is counterclockwise, looking down in the case of theta, omega, and phi, and toward the monochromating crystal for chi, when all other axes are at their zero positions.

In the following discussion, the term "axis" will be reserved for the axis about which the crystal is rotated. The term "shaft" will refer to the mechanical assembly which moves when rotation about an axis occurs. The symbols, χ , ω , and Φ will be reserved to indicate the number of degrees the corresponding shaft has been rotated from its zero position. The symbol θ will represent one-half the number of

degrees the detector arm has been rotated from its zero position. The term "value" of a shaft will have the same meaning as the Greek symbols.

The shafts are positioned by a moiré fringe method. To accomplish this, each shaft has a radial transmission grating which generates fringes as it passes over a fixed grating on a pick-up head which also contains a lamp and photocells. Movements of the fringes produce pulses which can be counted by the computer so that in the ideal case shaft position is known to 0.01° . This method of pulse counting necessitates an absolute datum point or external reference for shaft position. In order to prevent the accumulation of errors, the shafts must periodically be returned to their datum points. The location of a datum point to within 0.01° is facilitated by a reference mark on each shaft's grating which is detected by a separate pick-up head. In order to find its datum point, a shaft can be operated in a "datum seek" mode. When the datum point of a shaft moving in datum seek mode passes the second pick-up head, the shaft stops moving and a pulse (interrupt) is produced.

Exact positioning of shafts when the instrument is operated manually has been found to be extremely difficult. The instrument can be effectively operated manually in the datum seek mode, however.

Each shaft except phi has limit switches to protect the instrument from damage. Over 360° rotation is provided for omega, just under 360° for chi, and about 210° rotation for the detector.

The detector shielding provided by the instrument's manufacturer was found to be inadequate. Therefore a new receiving collimator and the surrounding detector shielding were constructed.

DETECTOR SYSTEM

If relative intensities of reflections from a sample crystal are to be measured, it is important that there be the same number of neutrons in the beam incident to the crystal while all reflections are being measured. Since the neutron flux from the reactor is not steady over long periods of time, it is not sufficient to make each measurement for the same length of time. For this reason, the beam passes through a fission chamber just before it gets to the sample crystal. This chamber contains a thin layer of U^{235} . About 1 neutron in 1000 causes a U^{235} atom to split, which generates an electronic pulse. This pulse is amplified by a preamplifier and sent into the interface for recording as described later. The number of these pulses is directly proportional to the beam flux so that instead of measurements being made for a fixed length of time as in x-ray diffraction, they are made for a fixed number of monitor counts.

The intensities are recorded by means of a BF_3 tube inserted into the receiving collimator. When a neutron is captured in the tube a pulse is generated which is amplified by a preamplifier, sent through an amplifier-discriminator and then into the interface.

Under current operating conditions a voltage of 2650 V is placed on the BF_3 tube, and 500 V on the fission chamber. The gain of the preamps is about 3×10^{12} V/Coulomb with a noise level of less than 0.25 V. The pulse leaving the integrating preamplifier caused by a typical neutron in the fission chamber is 1 V. In the BF_3 tube, the corresponding pulse is also 1 V, while a gamma-ray gives a pulse of less than 0.3 V. The amplifier-discriminator sends out a 10 V pulse for every pulse over 0.4 V which it receives.

OPTICAL ALIGNMENT OF INSTRUMENT

In order to facilitate optical alignment of the diffractometer, a round lead shot was mounted on a goniometer. The ball was placed on the phi axis of rotation by adjusting the translations on the goniometer. It was placed on the chi axis of rotation by using the height adjustment of the orienter. The shot was assumed to be on an axis if displacement of the center of the shot as the axis was rotated was not detectable through a transit. If the diffractometer has been constructed correctly, after the above operations, the center of the shot would also be on the omega axis. However, when the omega axis was rotated 180° , the center of the lead shot moved noticeably. The phi axis was moved by loosening the four screws which hold the phi carriage to the chi carriage and, while pushing it in the proper direction, retightening them. After several attempts at this, the ball was put in a place where, to the accuracy of our observation, the position of its center was independent of

the phi, chi or omega rotations. The center of the ball was then at what shall be termed the "instrument center".

By making use of the transit and the aforementioned scribe marks, the translational and height adjustments of the instrument table were set so that the instrument center lay on the reference line. By sighting along the reference line, the receiving collimator was placed so that its center line fell on the reference line. This was accomplished by moving the theta shaft and adjusting setscrews provided on the detector base. Optical alignment of the instrument was then complete.

ALIGNMENT OF INSTRUMENT USING NEUTRONS

Final alignment of the instrument was accomplished after automation was complete by finding the exact peak positions of a few reflections from a zinc crystal. The crystal was mounted so that a prominent reflection was in position to diffract when chi was at 90° . If the reciprocal axis of a crystal is parallel with the phi axis of our instrument, the reflection on this axis is independent of a phi rotation when chi is at 90° .

The settings of the four shafts which maximized the intensity of the reflection in the detector were found by a "half peak" method. In this method, the four shafts are set so that their placement is approximately correct to have the reflection strike the detector. In a cyclic, iterative process the settings of the omega, theta, and chi shafts are found which maximize the peak in the detector relative to the positions of the other shafts.

The process of maximizing with respect to one shaft is started by taking a count somewhere near the peak maximum. The two settings (one on each side of the peak) of the shaft which give $1/2$ of this count are located to the nearest 0.01° . The shaft is set at the average of these two settings and the next shaft is maximized in the same manner. In practice, two cycles of the three shafts give convergence.

If both the instrument and crystal are centered and if the interplanar spacings are such that the Bragg angle is θ , the reflection should be centered at the instrument settings shown in Table I.

The exact shaft positions which center the peak near these settings are determined. The deviations of the exact settings from those in the table are due to errors in arc and translational adjustments on the goniometer, crystal height, or misalignment of the instrument.

In order to minimize the effect of errors in crystal alignment, the settings are averaged in the following manner. The a and b positions of each setting are averaged to give a new theta, omega, and chi which are independent of goniometer setting errors.

Next the theta and chi positions of pairs 1 and 5, 2 and 6, 3 and 7, and 4 and 8 are averaged. The omega positions of these are also averaged after subtracting 180° from the omega settings in 5, 6, 7, and 8. The resultant values are independent of errors in crystal height and will be termed the $+++$, $++-$, $--+$, and $---$ solutions, respectively.

The chi values from the $+++$ and $--+$ solutions are averaged, as are those from the $++-$ and $---$. We will term these values χ^+ and χ^- ,

Table I
Equivalent Instrument Settings

POSITION	THETA	OMEGA	CHI	PHI ^a
1a	θ	θ	90	p
1b	θ	θ	90	180+p
2a	θ	θ	-90	p
2b	θ	θ	-90	180+p
3a	$-\theta$	$-\theta$	90	p
3b	$-\theta$	$-\theta$	90	180+p
4a	$-\theta$	$-\theta$	-90	p
4b	$-\theta$	$-\theta$	-90	180+p
5a	θ	180+ θ	90	p
5b	θ	180+ θ	90	180+p
6a	θ	180+ θ	-90	p
6b	θ	180+ θ	-90	180+p
7a	$-\theta$	180- θ	90	p
7b	$-\theta$	180- θ	90	180+p
8a	$-\theta$	180- θ	-90	p
8b	$-\theta$	180- θ	-90	180+p

^a The value of phi is arbitrary.

respectively. The average of χ^+ and χ^- is the instrument setting of the chi shaft which corresponds to the true zero position of the shaft. The chi values for all four solutions can then be corrected for errors in the zero position. If the average height of the neutron sensitive portion of the detector is correct, all values of chi should have a magnitude of 90° . If the detector is too low, the magnitudes for chi for the +++ and --- solutions are greater than 90° and for the --+ and ++- solutions are less than 90° . If the detector is too high, the opposite effect is observed.

The theta and omega values of the +++ and --+ solutions can be averaged to give the instrument settings which correspond to the true zero positions of the theta and omega shafts. The same can be done for the ++- and --- solutions. If the omega zero position obtained from this averaging is different than that obtained from the first, it would indicate that the four instrument axes do not have a common point.

In practice, after these determinations are made, the corrections indicated are made and the process is performed again. From what has been said, it might not seem necessary to correct the crystal position but this is done as a precaution (lest crystal position errors might not be cancelled by the averaging process as they should be in theory) and because it is a great aid in determining whether a line passing lengthwise through the center of the detector intersects the four axes at the instrument center. When a crystal is at the instrument center and all shaft settings are such that the peak maximum is falling

on the detector, it should be falling on the center of the detector. This is easily confirmed by using the up-down and left-right beam splitters, which can be operated either manually or under computer control. When the detector is properly positioned, alignment of the instrument is complete.

THE INTERFACE

The interface has several 24-bit registers. These registers can be loaded or read by a program being executed in the computer. The TASK language statement which causes a register to be read is of the form:

.INPUT. (A, B);

where both A and B can be either a number or a program variable. After execution of this statement, register A will contain the value of B.

The registers in the interface of the experiment being described have been assigned numbers 64-73. There are more numbers than there are registers because two different numbers can refer to the same register.

The number whose binary representation is contained in a 24-bit word or register is the value of that word. Three of the interface registers are used for counting pulses and therefore have a value with intrinsic meaning. The values which represent the contents of the other registers are arbitrary and have only the meaning given them by

the design of the interface. For example, if a bit of a certain register is set equal to 1, the theta shaft will begin moving, or when a shaft hits a limit switch, a bit reserved for that shaft is set equal to 1. The meanings of all bits which a programmer or experimenter might need to know are summarized in Table II. Table III shows the action taken on all .INPUT. and .OUTPUT. statements which the computer would address to the interface of the experiment being discussed.

Another means of sending information to the computer is by 11 interrupt lines. Eight of them are special interrupt lines. These are used in keeping track of the position of the four axes. Each shaft has two special interrupt lines running to the computer. Every time a shaft moves 0.01° in the positive direction a pulse is sent on one of the two lines, the computer halts what it is doing, adds 1 to the value stored in the location reserved for the position of the shaft, and then the computer goes back to what it was doing. If a shaft moves 0.01° in the negative direction, a pulse is sent on the opposite line of the pair and 1 is subtracted from the value in the shaft location address. These are called special interrupts because the computer always responds to them in the same way as determined by hardware circuitry. These interrupts are handled the same way regardless of what program is operating the experiment or, in fact, whether or not any program is being executed at all. A program can use any of these reserved locations as one of its variables and thereby know or even change the value of these locations but cannot respond directly to the interrupts.

Table II
Register Meanings

REGISTER	BITS	MEANING
1	0	Phi is at datum
	1	Has no meaning
	2	Phi is in datum seek mode
	3	Phi is in positive drive
	4	Phi is in fast drive
	5	Phi is moving
	6	Chi is at datum
	7	Has no meaning
	8	Chi is in datum seek mode
	9	Chi is in positive drive
	10	Chi is in fast drive
	11	Chi is moving
	12	Omega is at datum
	13	Omega is in step-scan mode
	14	Omega is in datum seek mode
	15	Omega is in positive drive
	16	Omega is in fast drive
	17	Omega is moving
	18	Theta is at datum
	19	Theta is in step-scan mode
	20	Theta is in datum seek mode
	21	Theta is in positive drive
	22	Has no meaning
	23	Theta is moving
2	0-23	Binary representation of time pulse counter

Table II (Contd.)

REGISTER	BITS	MEANING
3	0-23	Binary representation of detector counter
4	0-23	Binary representation of monitor counter
5	0	Request for counting to begin
	1	Permits counters to restart during step-scan
	2	Counting will stop when monitor counter reaches zero
	3	Counting will stop when detector counter reaches zero
	4	Counting will stop when time pulse counter reaches zero
	5	Counters are operating
6	12	Set time pulse counter to zero
	13	Set detector counter to zero
	14	Set monitor counter to zero
	18	Set all counters to zero, stop all shafts, and disengage all beam splitters.
	19	Reset limit switch indicators
7	12	Has no meaning
	13	Has no meaning
	14	Phi has hit its limit switch
	15	Chi has hit its limit switch
	16	Omega has hit its limit switch
	17	Theta has hit its limit switch
	18	Has no meaning
	19	Right beam splitter is engaged

Table II (Contd.)

REGISTER	BITS	MEANING
	20	Left beam splitter is engaged
	21	Bottom beam splitter is engaged
	22	Top beam splitter is engaged
	23	Shutter is open

Table III
TASK Statements Which Address the Interface

STATEMENT	BITS	EXPERIMENT REGISTER	OPERATION
.INPUT. (64, T);	0-24	1	The bits listed of program variable T will be given the configuration of the corresponding bits in the Experiment Register listed.
.INPUT. (68, T);	0-24	2	
.INPUT. (69, T);	0-24	3	
.INPUT. (70, T);	0-24	4	
.INPUT. (71, T);	0-5	5	
.INPUT. (73, T);	18-23	7	
.INPUT. (65, T);			Operation is not defined; no action is taken.
.INPUT. (66, T);			
.INPUT. (67, T);			
.INPUT. (72, T);			
.OUTPUT. (64, T);	19-23	1	The indicated bits of the Experiment Register shown will be given the configuration of the corresponding bits in the value of T.
.OUTPUT. (65, T);	13-17	1	
.OUTPUT. (66, T);	8-11	1	
.OUTPUT. (67, T);	2-5	1	
.OUTPUT. (68, T);	0-24	2	
.OUTPUT. (69, T);	0-24	3	
.OUTPUT. (70, T);	0-24	4	
.OUTPUT. (71, T);	0-4	5	
.OUTPUT. (72, T);	12-14, 18-19	6	
.OUTPUT. (73, T);	12-23	7	

The non-special interrupts, on the other hand, depend entirely on user programs for action to be taken when they occur. In the TASK language a program can ask to be informed of a particular interrupt and then take the necessary action. If an interrupt occurs of which no program has asked to be informed, it is ignored. These non-special interrupts occur to indicate that a shaft is at its datum positions, to indicate that a shaft has hit its limit switch, or that some phase of neutron counting has ended.

To better illustrate the interaction of computer and experiment, two examples of typical processes are presented. In these samples, the underlined arguments of the .INPUT. and .OUTPUT. statements are given as binary numbers. In reality, if numbers such as these are put into TASK language programs they would be given octal or decimal representations in the source language coding but upon execution would have binary representations in core. The only bits which are loaded into a register are those between the arrows.

Let us assume that ω is 50° and that a datum check of the omega shaft is desired. The first statement executed could be:

.OUTPUT. (65, 000000000000000000011000000);

As can be seen by looking at Table III, this would load bits 13-17 of register 1 with the values 0, 0, 0, 1, and 1, respectively. As shown by Table II, the omega shaft would then begin moving fast in the negative direction. The program could then check periodically to see

if ω was getting close to zero. When ω was found to be less than 5° , the program could execute the statement:

.OUTPUT. (65, 000000000000000001001000000);

and ask to be informed when the shaft reached its datum point. The execution of this statement would cause omega to move at slow speed in the negative direction in the datum seek mode. When omega reached its datum point, it would stop and an interrupt would be sent to the computer. Since the program has asked to be informed when this interrupt occurs, the program could go on to a subsequent task knowing that the omega is at its datum point.

As a second example, assume a detector count is desired for 1000 monitor counts. The following statements could be executed:

.OUTPUT. (72, 0000000000000000000100000);

.OUTPUT. (70, -1000);

.OUTPUT. (71, 101000000000000000000000);

and the program could ask to be informed when the counting was complete. The first of these statements would cause the value of all three counters to be set to zero. The second statement would load the binary representation of a -1000 in register 4. The third statement would cause counting to begin when all three counters were ready, and counting would stop when 1000 counts had been accumulated in the monitor counter and its value became zero. When counting stops, an interrupt

is sent to the computer and the program is informed that counting has been completed. The program could then execute the statement:

.INPUT. (69, A);

and the value of the program variable A would then be the number of detector counts accumulated while the counters were operating.

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