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Goniometer Control System for Coherent Bremsstrahlung Production

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0.0 Abstract

Goniometer Control System for Coherent Bremsstrahlung Production. Victor Acosta (Augsburg College, Minneapolis, MN 55454) Perry Anthony (Stanford Linear Accelerator, Menlo Park, CA)

A system for the generation of a high-intensity, quasi-monochromatic photon beam is discussed, The theory behind coherent bremsstrahlung photon beam production is analyzed and developed. The mechanics of a goniometer control system are presented. The software developed for remote control of the goniometer is also discussed. Finally, the results from various performance measurements are included.

1.0 Introduction

Upcoming experiments at SLAC are interested in the formation and propagation of J/Ψ (charm-anticharm particles) through nuclear matter. J/Ψ production is used as an indicator of the formation of the so-called quark-gluon plasma in heavy ion collisions. An understanding of how J/Ψ interacts with the surrounding nuclear medium is essential if the J/Ψ particles are to be used to extract information about the quark-gluon plasma (size, temperature, etc.). One way to study J/Ψ – nuclear matter interactions is to study the A-dependence of the J/Ψ particles (E160). For this experiment, a photon beam will be used to form J/Ψ particles. The particles will travel through atoms with varying number of nucleons in order to see how this variable (A-dependence) affects both the energy and angular distribution of J/Ψ particles resulting from the collisions. This information will be used by heavy ion experiments in Brookhaven, NY and Western Europe in order to control for the interaction between J/Ψ particles and nuclear matter (Griffioen 2000).

In order to perform these high-energy experiments, a photon beam with high intensity at a nearly mono-energetic wavelength is necessary. This beam is desirable because having a large spectrum of photon wavelengths would introduce an unwanted variable into these experiments.

One particularly efficient way of producing this beam is called coherent bremsstrahlung. In this emethod, a compact crystalline structure is bombarded with a steady electron beam (at SLAC this will be about 10^10 electrons/pulse with a pulse frequency of 120 Hz). Interactions between the electrons and the atoms in the crystal produce photons. If the crystal is oriented at certain quantized angles with respect to the electron beam, the photons emitted by the collisions will have nearly the same energy. For these experiments a diamond will be the crystal of choice because it has a short distance between lattices and can withstand high temperatures.

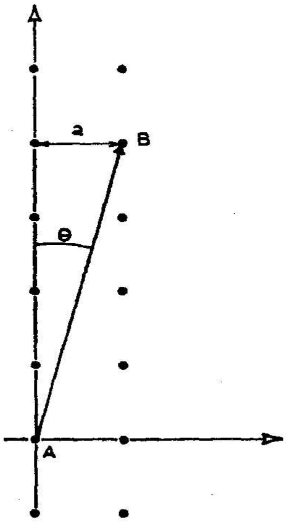
2.0 Theoretical Considerations

Previous experiments and a number of theoretical arguments have shown that the truly coherent bremsstrahlung can only be produced at high energy when the lattices of the crystalline structure are aligned in such a way that successive collisions between the same electron and atoms in parallel lattice planes have a phase shift that will produce constructive interference. This constructive interference is governed by the equation:

Eq. 1) $2\pi n/a = \delta/\theta$,

where n is an integer, a is the lattice spacing, and θ is the angle of electron deflection (see figure 1).

***Figure 1**: Electron path (A to B) between first and second collisions with atoms in parallel diamond lattice planes of distance, a (Palazzi, 1968).*



The variable δ comes from the equation for minimum momentum transfer:

Eq. 2) $\delta = K/(2E^2(1-K/E))$,

where K is the photon energy and E is the electron's primary energy (Palazzi 1968).

Eq.'s 1 and 2 tell us that the entire process of obtaining monochromatic photons of energy K (the definition of ideal coherent bremsstrahlung production) is controlled only by θ, the diamond's angular orientation. This is because the lattice spacing, a, and electron energy, E, are fixed, leaving only θ as the independent variable and K as the dependent variable. In fact these crystal positions are already known. The primary peak (n=1) is in the reciprocal lattice plane, (0,2,2). Since only certain finite angles relate to this plane (if all the molecules in the diamond are assumed to be monolayered and perfectly fitted), the diamond must be aligned very precisely and held still in order to create a steady coherent bremsstrahlung beam. In fact experimenters at SLAC found that the process of alignment was more complicated than even this theory predicted. D. Luckey and R. F. Schwitters reported that not only are there two axes of rotation from which to obtain the diamond's displacement angle, but there is another offset angle, α, that corresponds to the angle that the diamond is rotated about the beam axis due to slight misalignment. This value can only be determined experimentally (Luckey and Schwitters 1969). There are also other procedures necessary to refine the beam in order to maximize its coherence, such as collimation, but this work was primarily concerned with diamond positioning.

3.0 Background on the Goniometer

***Figure 2**: Goniometer in Beam Pipe*

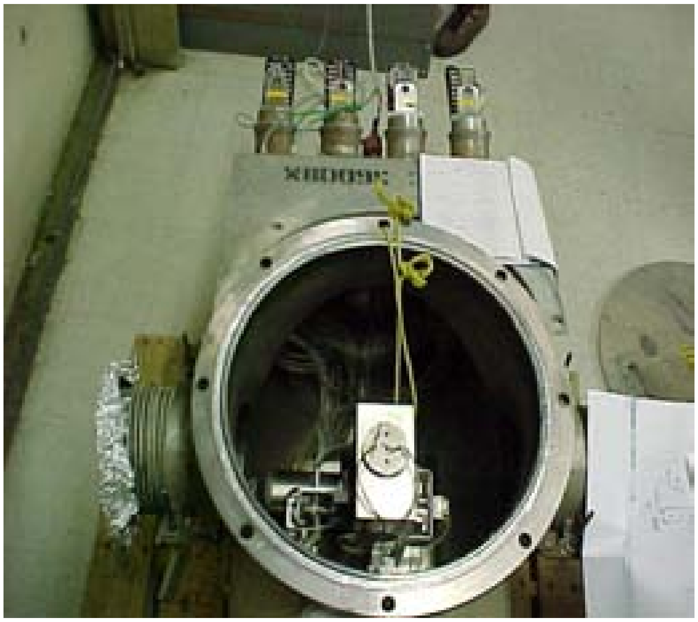


***Figure 3**: Goniometer with Diamond*

In the early 1970s, a device known as a goniometer was used to hold and manipulate the position of the diamonds. The control system for this apparatus was, unfortunately, outdated and missing several pieces so upcoming experiments required that a new system be assembled. The purpose of this work was to create and fine-tune the control system for this device. A LabView program that controls two stepping motors runs the goniometer. The stepping motors turns at a resolution of 200 steps/revolution. Each of these steps move the diamond approximately 25 μradians in one of two angular axes such that if the electron beam were the z-axis, the diamond would rotate around the x- and y- axes. In addition to being able to move the diamond into position, an electrical system called a "Micro-Syn" will monitor the exact positioning of the diamond so that the position creating the most desirable beam can be reproduced. The Micro-Syn works by turning the armature of a transformer's secondary in correlation with the goniometer's motion such that when a reference voltage, is entered into the Micro-Syn's input, the output will read zero if that voltage directly corresponds to the diamond's position.

In order to justify the need to use a step size as small as 25 μrad., calculations were done to show the scale of the displacement angles needed to theoretically set the diamond to its primary peak position. Table #1 illustrates a theoretical calculation, using eq.'s 1 and 2, of the angles corresponding to the settings of photon and electron energies that will be used in the upcoming experiment E160. Of course, these calculations do not take into account the breakdown of this displacement into two angular axes or the misalignment factor, α, because these variables must be determined experimentally (Luckey and Schwitters 1969).

***Table 1**: Theoretical First-Order Diamond Angular Displacements for E160 (Bosted 2002)*

Electron energy, E (GeV)	Photon Energy, K (GeV)	Diamond Angular Displacement, θ (μrad.)
48.3	35.2	1587
48.3	35	1543
45	25	894
45	26.5	888
45	14.8	305
26.7	15	1360

While these calculations are for first order, n=1, it is easy to show that n is inversely proportional to the displacement angle. Therefore, eq. 3, below, shows how to calculate second order and beyond angles:

Eq. 3) $\theta_{n+1} = \theta_n(n/(n+1))$

Table #1 clearly illustrates the need for fine adjustment of the diamond's position on the order of 25 μrad. Therefore, this goniometer is a sufficient instrument to create and manipulate the coherent bremsstrahlung photon beam for upcoming experiments.

Tests, Procedures, and Analysis

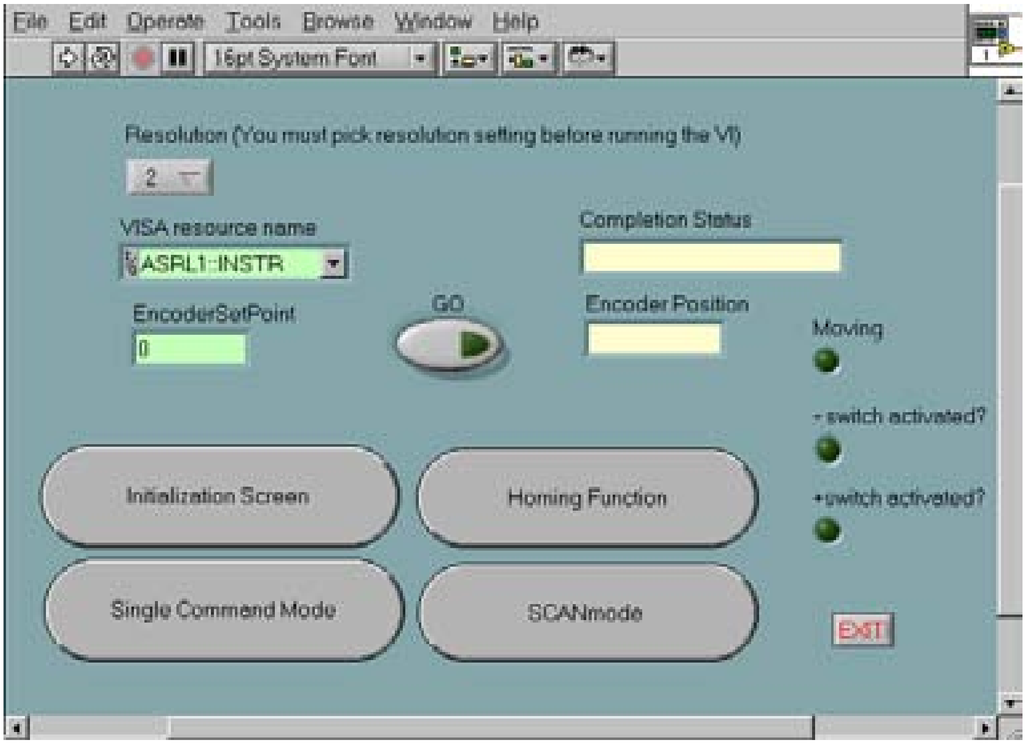
4.1 *Running the Goniometer with LabView*

The goniometer was hooked up to a LabView control program called GoniometerControl.vi. This program communicates with a control box, which then communicates with two stepper motors that move the goniometer in each angular axis, θ_h and θ_v.

***Figure 4**: Simple Flow Diagram of Goniometer Control System*

It was verified that GoniometerControl.vi is able to manipulate the stepping motors to move the goniometer in two angular axes (each motor corresponds to a different axis, θ_v and θ_h).

***Figure 5**: GoniometerControl Front Panel*



Resolution (You must pick resolution setting before running the VI): 2

VISA resource name: ASRL1::INSTR

EncoderSetPoint: 0

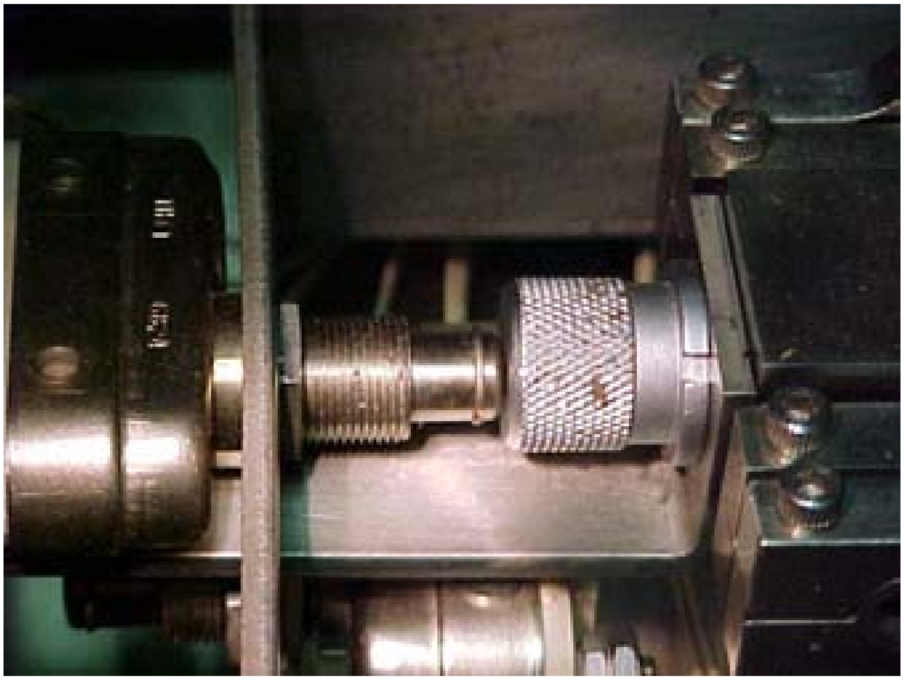
4.2 *Testing Range of Motion*

When the goniometer has reached its mechanical limits it triggers limit switches. These limit switches were connected to the Stepper Motor controller and the LabVIEW programs such that motion is stopped immediately when the limit switches are triggered. Then the total range of motion was tested from one limit switch to another. The purpose of this procedure was to calculate the range of motion that the stepper motors can go through, for programming and operational purposes, and also to verify that the switches work.

***Table 2**: Directional limits of Goniometer in Relative Axes [Resolution = 2 steps/revolution]*

Axis	Negative Limit (# of revolutions from arbitrary 0)	Positive Limit (# of revolutions from arbitrary 0)	Total Range of Motion (revolutions)
θ_h	-21 +/- .5	+14 +/- 1	35 +/- 1.5
θ_v	-21.5 +/- 1	+1 +/- .5	22.5 +/- 1.5

***Figure 6**: Negative Limit Switch for θ_h*



The Limit Switches DO work, but the errors indicate that the switches trigger at different points possibly due to corrosion/dirt.

4.3 *Testing Micro-Syn Transformer Readout*

The purpose of this procedure was to determine the response of the MicroSyn transformer to manipulation of the stepping motors. This information can then be used to calibrate the MicroSyn, when the final circuitry is available, so that the reference voltage entered will correspond to the diamond's position. A 5.0 kHz, 3.0Vrms signal was generated and applied to the primary. The stepping motor's position was then varied and the secondary's output was recorded in Vrms.

***Table 3**: Micro-Syn Transformer Dependence on θ_v Motor Position [Resolution = 2 steps/revolution]*

Motor Position (# of revolutions from arbitrary 0)	Secondary Output (Vrms)
+1 (limit switch triggered)	3.12
0	2.92
-2.5	2.49
-5	2.06
-7.5	1.56
-10	1.08
-12.5	.593
-15	.117
-15.5	.023
-15.625	.003*
-15.75	.024*
-16	.073*
-17.5	.353*
-20	.814*
-20.5 (limit switch triggered)	.903*

*Note: A minimum was reached at –15.625 revolutions. From +1 revolutions to –15.625 revolutions, the secondary was in phase with the input signal. From –15.625 revolutions to –20.5 revolutions, the secondary was 180º out of phase.

***Table 4**: Micro-Syn Transformer Dependence on θ_h Motor Position [Resolution = 2 steps/revolution]*

Motor Position (# of revolutions from arbitrary 0)	Secondary Output (Vrms)
13.5 (limit switch triggered)	2.07
13	1.99
12.5	1.91
10	1.47
5	.620
1.5	.017
1.425	.003
1.4	.003*
1.375	.007*
1.25	.028*
1	.071*
0	.243*
-5	1.10*
-10	1.96*
-15	2.75*
-20	3.41*
-21 (limit switch triggered)	3.47*

*There is a minimum between 1.4 and 1.425 revolutions. From +13.5 revolutions to +1.425 revolutions, the secondary is in phase with the input signal. From 1.4 revolutions to –21 revolutions, the secondary is 180º out of phase.

The Micro-Syn circuit is designed to be able to account for the phase shifts and this was verified via computer simulations.

4.4 *Testing Dip Switches 7 and 8*

Dip Switches 7 and 8 are for manipulating resolution. In other words, the conversion from steps to motor revolutions can be altered using the following state table.

***Table 5**: Resolution Manipulation using Dip Switches 7 and 8*

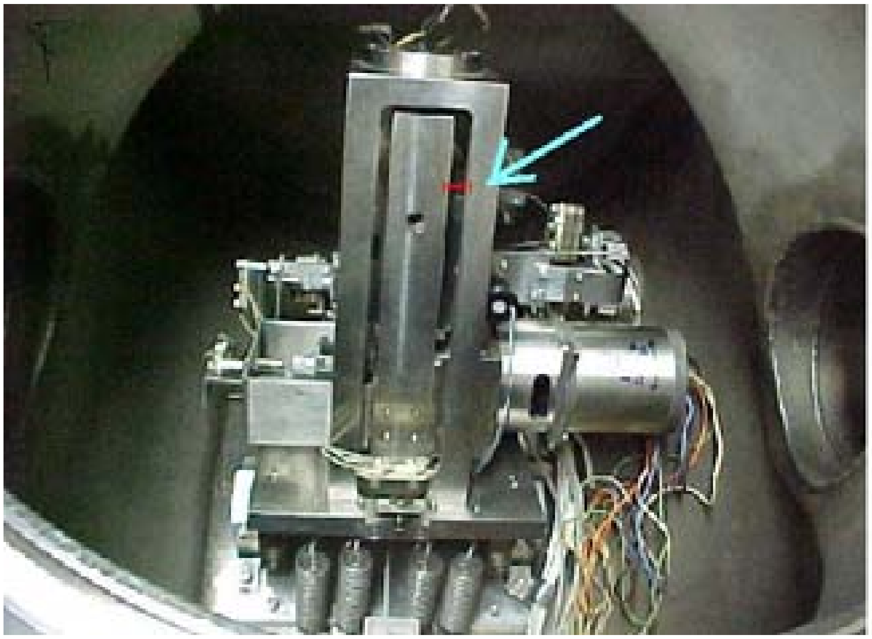
Switch #7	Switch #8	Resolution (steps/revolution)
0	0	2
1	0	10
0	1	25
1	1	100

This table was verified using Micro-Syn transformer readouts. It was also verified that a resolution of 200 is possible by entering ½ step increments when resolution = 100.

4.5 *Measuring Actual Angular Shift/Step of Diamond*

Two methods were used for calculating the angular shift and they were taken at two different locations on the goniometer. They both involved a linear approximation of motion (since the arc of motion is so slight, a linear approximation involves a very small error). Digital micrometers were used to make measurements and simple calculations were done via calculator.

***Figure 7:** Measuring Diamond Angular Shift*



Note: The distance marked in red was recorded at each limit of the goniometer's motion to obtain the calculations in table #6.

***Table 6**: Diamond angular shift/step at highest resolution*

Method #	Trial #	Resolution = 200 steps /revolution
method 1:	1	25.4 μrad.
"	2	21.4 μrad.
method 2:	1	22.9 μrad.
"	2	23.1 μrad.
	Average	23.2 μrad.

The average of 23.2 μrad./step at resolution = 200 steps/revolution is slightly smaller than the 25 μrad. suggested by previous experimenters (Bosted 2001). This error is understandable because both methods involved approximating the slight arc as a linear motion that would have added to the angular shift (see figure 4). Having verified that the angular shift/step is on the order of 25 μrad., and using the information from Tables #2 and #3, it is easy to calculate the total diamond range of motion as shown in Table #7.

***Table 7**: Directional Limits of the Goniometer (assuming 25 μrad./step)*

Axis	Stepping Motor Range of Motion	Diamond Range of Motion
θ_h	35 revolutions	.175 rad. = 10 deg.
θ_v	22.5 revolutions	.113 rad. = 6.5 deg.

The small angular shifts/step at the highest resolution appear to be big enough for the Micro-Syn to distinguish. The difference between every 5 revolutions was taken and proved to be all of similar magnitude. Therefore, the voltage versus position data was treated as a linear relationship (as the prototypical circuitry predicted), and the voltage differences were simply averaged and converted into a relationship between 1/200 revolution and voltage. Using this method, it can be estimated that the Micro Syn readout varies about .86 mVrms/step at the highest resolution (200 steps/revolution) when a 3Vrms signal is sent into the primary. This corresponds to approximately 34.4 mVrms/mrad, using the

25μrad./step calculation done by previous experimenters. When using a 5kHz, 3Vrms input and read by an oscilloscope, the Micro-Syn appears to be accurate to 1 mVrms so this rate of change, without the distortion of a scope, should be within the Micro-Syn's capabilities.

4.6 *Testing Slowest Allowable Motor Speed*

In order to locate the diamond position resulting in optimal beam production, it is necessary to move the diamond in increments followed by a pause to read position with Micro-Syn. The purpose of this procedure was to establish a minimum speed and observe how the goniometer functions at slow speeds.

***Table 8**: the Slowest Allowable Speed at each Resolution*

Resolution (steps/revolution)	Slowest Possible Speed** (steps/second)	Recommended Minimum Speed (steps/second)	Time Between Diamond Motion Increments at Recommended Minimum Speed (seconds)
2	.01	.02	.5
10	.01	.02	2.5
25	.01	.02	6.25
100	.01	.02	25

**NOTE: The hardware functions in an erratic way as it approaches speeds of .01 steps/revolution at all resolutions. A jolt of perhaps more than 1/100 rev. was detected at different times for all resolutions.

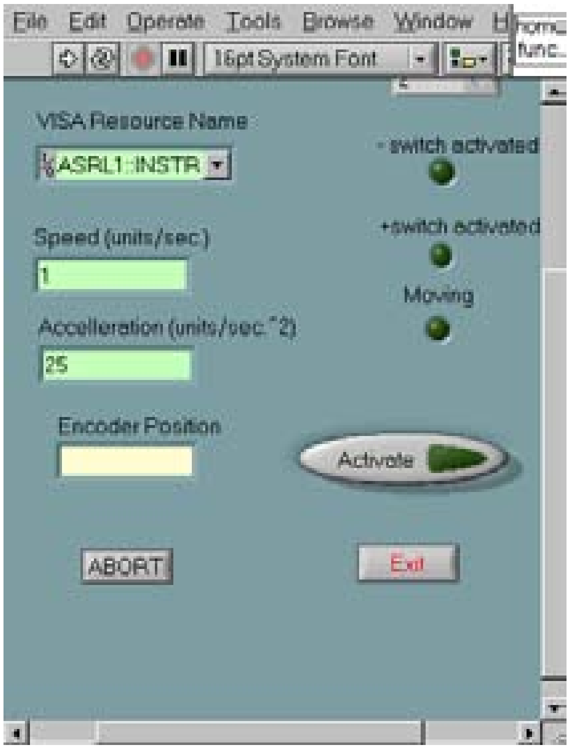
For predictable motion, the motor ought to be operated at speeds at or above .02 steps/second. Furthermore, speeds higher than 5 revolutions/second may cause the motor to mechanically jam up against a limit switch, so 5 revolutions/second ought to be the upper speed limit.

At all resolutions, the motor runs in intervals of 1/200 revolution. At the slowest allowable speed for a resolution of 100, each step occurs every 25 seconds, but the actual motor motion occurs only for a split second and is followed by 25 seconds of inactivity and then the next ½ step (1/200 revolution).

4.7 *Setting a Home for the Motors*

In order to establish a reproducable ‘0’ or ‘home’ position for the motors, a LabView subVI was created called homingfunction.vi. This VI tells the motors to move back to the negative limit switch at a fairly rapid speed. Then the motors are commanded to move a reasonable amount of revolutions away from the switch at the previous speed (in order to account for the fact that the deceleration is not infinity) and finally to move back to the switch at a slow speed so that when the switch is hit, the motor stops nearly right at the switch. This new position is entered as 0, and the motor is now at its electrical home. The homing function runs automatically when starting up the Goniometer control and can be called up later by pressing the homing function push button on the GoniometerControl front panel.

***Figure 8**: Homing Function Front Panel*



VISA Resource Name: ASRL1::INSTR

Speed (units/sec): 1

Accelleration (units/sec.^2): 25

Encoder Position:

The following table displays the speeds and steps for the homing function (note: speed and distance ‘away’ refers to the portion of homing where the motor is moving away from the switch before moving back again).

***Table 9**: Homing Function Specifications*

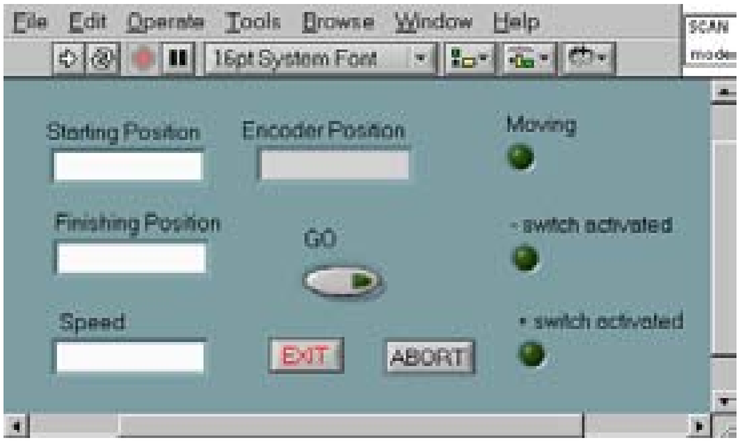
Resolution (steps/rev.)	Acceleration (steps/sec.^{2})	Speed Home and Away (steps/sec.)	Distance Away (steps)	Speed Back (steps/sec.)	Maximum Time (sec.)*
2	50	4	5	.5	28.75
10	200	20	25	2	31.25
25	500	50	50	5	28.5
100	2000	200	50	1	67.75

*Note: The homing function can take up to 67.75 seconds to complete. If it is not needed, the homing function can be skipped if and only if the skip homing function button is pressed prior to running the GoniometerControl VI.

4.8 *Establishing a ScanMode*

The ScanMode SubVI runs the motors from one specified position to another at a given speed. The motors will move to the specified initial position at the speeds given in table #7, column 3 (speed home and away). The motor will then move from the initial position to the specified finishing position at the speed specified by the user.

Figure 9: *ScanMode Front Panel*



The default settings for the ScanMode are posted when the user pushes the ScanMode button (located on the GoniometerControl front panel) and the ScanMode front panel pops up. They are given in the following table:

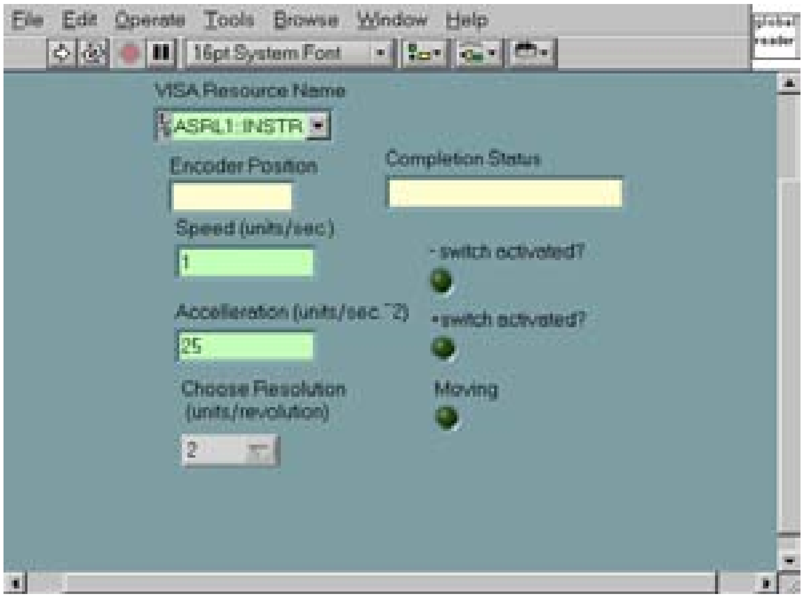
Table 10: *ScanMode Default*

Starting Position	Finishing Position	Speed
current position	current position + 10 rev.	current speed

4.9 *Establishing A Simple Indicator Panel*

The LabView SubVI, Global Indicators will be run simultaneously with the Goniometer Controls. This SubVI will constantly update and display the current settings for speed, acceleration, position, acceleration, resolution, VISA reference, completion status, both limit switches, and whether the motors are moving or not.

***Figure 10**: Global Indicators Front Panel*



VISA Resource Name: ASRL1::INSTR

Encoder Position

Completion Status

Speed (units/sec): 1

- switch activated? ●

Accelleration (units/sec ^2): 25

+switch activated? ●

Choose Resolution (units/revolution): 2

Moving ●

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