Master's Theses   Graduate College

6-2000

Control and Data Acquisition for an Electron Spectrometer System

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CONTROL AND DATA ACQUISITION FOR AN
ELECTRON SPECTROMETER SYSTEM

by

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A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Physics

Western Michigan University
Kalamazoo, Michigan
June 2000

ACKNOWLEDGMENTS

CONTROL AND DATA ACQUISITION FOR AN ELECTRON SPECTROMETER SYSTEM

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Western Michigan University, 2000

An electron spectrometer system, installed on one of the beam lines in the WMU Van de Graaff accelerator laboratory, consists of two 45^0 parallel-plate electrostatic analyzers, a decelerating grid, and a channeltron. It allows the energy analysis, angular analysis, and the detection of continuum electrons ejected following the bombardment of a target with accelerated ions or electrons. First, the principles of operation of the spectrometer itself are discussed with emphasis on the energy analysis. Next, the electronics and computer interfacing required for control of the spectrometer functions and for acquisition of data are described. Finally, the control and data acquisition program created for complete system operation is described.

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ELECTRON SPECTROMETER

Overview

An electron spectrometer system, installed on one of the beam lines in the WMU Van de Graaff accelerator laboratory, is designed to detect continuum electrons ejected following the bombardment of a target with accelerated ions or electrons. A schematic of the spectrometer is shown in Figure 1. The system allows energy and angular analysis of continuum electrons emitted at 0^0, or within a range of angles from about 20 to 160 degrees.

The spectrometer itself is made from two 45^0 plane-mirror analyzers (PMA) that each deflects electrons through 90^0 into a channeltron. The energy of the deflected electrons depends on the voltages applied to the spectrometer plates. Only electrons with a particular energy can make it through the analyzers and into the channeltron. Each of the PMAs is thus a filter accepting electrons only within a small energy range determined by the voltages on the plates. The bombarding ions are nearly unaffected by the voltages due to their relatively large mass and high energy and pass through a hole in the lower PMA into a Faraday cup. Hence, an energy spectrum of the ejected electrons can be obtained by incrementing the voltages on the spectrometer plates and counting pulses from the channeltron for each set of plate voltages.

Channeltron

Electrons

Upper Spectrometer

Plates

Lower Spectrometer

Faraday Cup

Incoming Beam
+ electrons

Ion Beam
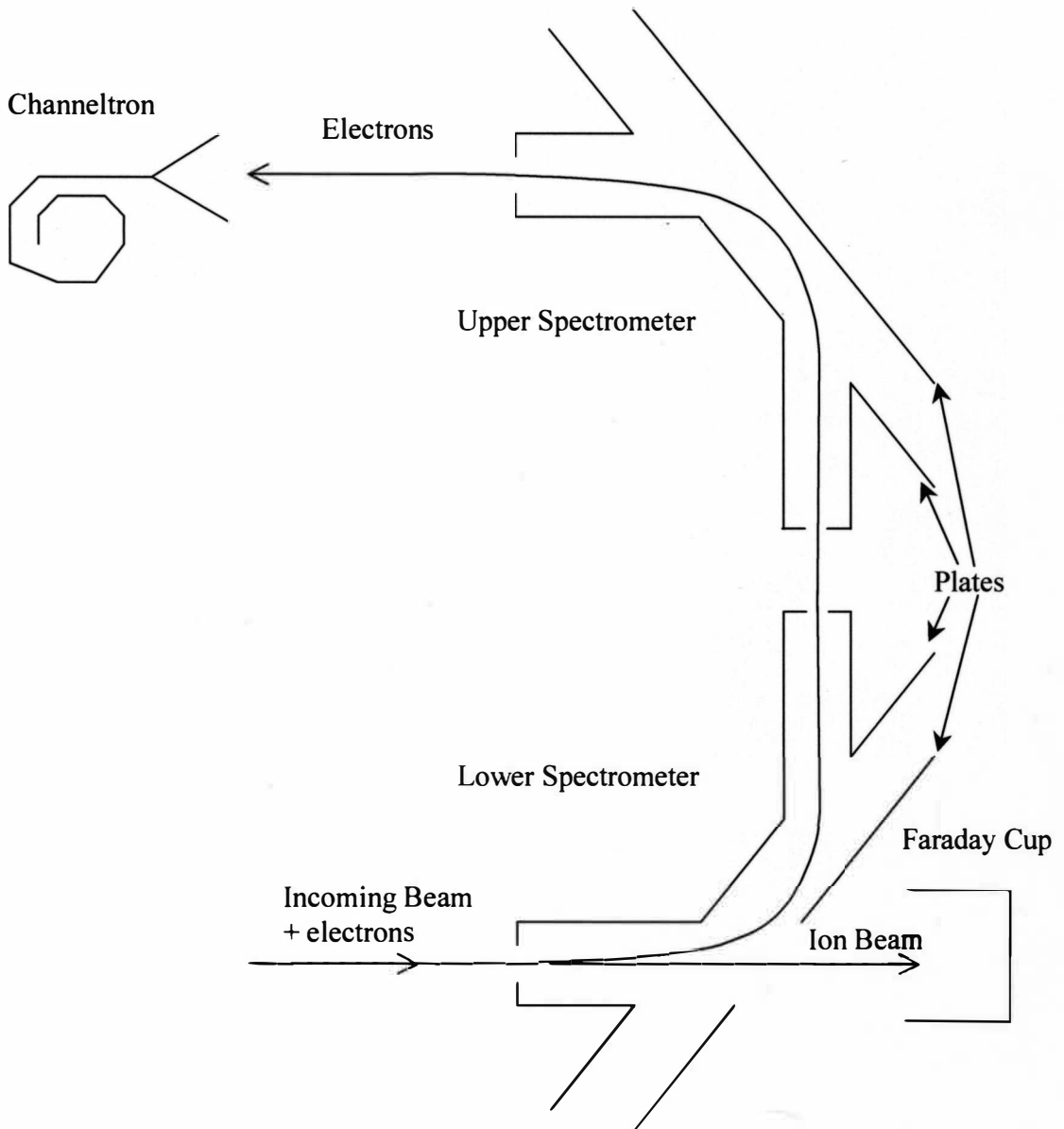
Figure 1.   Schematic of the Electron Spectrometer.

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The passage energy E of the detected electrons is related to the voltage V between the plates as follows:

$$E = \frac{Ve}{k},$$

where e is the electron charge, and k is the spectrometer constant. For the PMAs used in this setup the spectrometer constant has a nominal value of 0.60. The energy resolution of the spectrometer, ΔE, is the energy spread of the transmitted electrons. The ratio of the resolution to the passage energy, $\Delta E/E$ is a constant, which depends on the design. For the spectrometers used $\Delta E/E$ is ~ 0.03.

Spectrometer Modes

The spectrometer can be operated in several different modes depending on whether the experimenter is interested in detecting electrons with high or low energy, high or low resolution, or constant or variable passage energy through the second (upper) PMA. Energies higher than 100 eV are considered high.

The absolute accuracy of the power supplies used is ±1V when reading the voltage (there is a voltage monitor output on the supplies) and ±0.25V when setting the voltage. When measuring low energy electrons the accuracy can be improved by using voltage settings that are larger than needed, and then using voltage dividers to obtain the desired voltage values. In this case, the accuracy is increased by a factor equal to the division factor.

The six modes that are used are: (1) low resolution, high energy (normal mode); (2) low resolution, low energy; (3) high resolution, high energy, constant upper electron energy; (4) high resolution, low energy, constant upper electron energy; (5) high resolution, high energy, constant deceleration factor; (6) high resolution, low energy, constant deceleration factor.

Low-Resolution, High-Energy Mode

This is the normal setup. A schematic is shown in Figure 2. In this mode the PMAs are equivalent. So, the energy E_0 with which electrons leave the lower PMA is the same as the energy with which the electrons leave the upper PMA.

Low-Resolution, Low-Energy Mode

A schematic of this mode is shown in Figure 3, where d_1 and d_2 are division factors characteristic of the dividers, typical values being 5 or 10.

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Electrons

E_0

Upper Spectrometer

$V_2 = k_u E_0/e$

E_0

E_0

Lower Spectrometer

$V_1 = k_l E_0/e$

E_0

Figure 2.   Low-Resolution, High-Energy Mode.
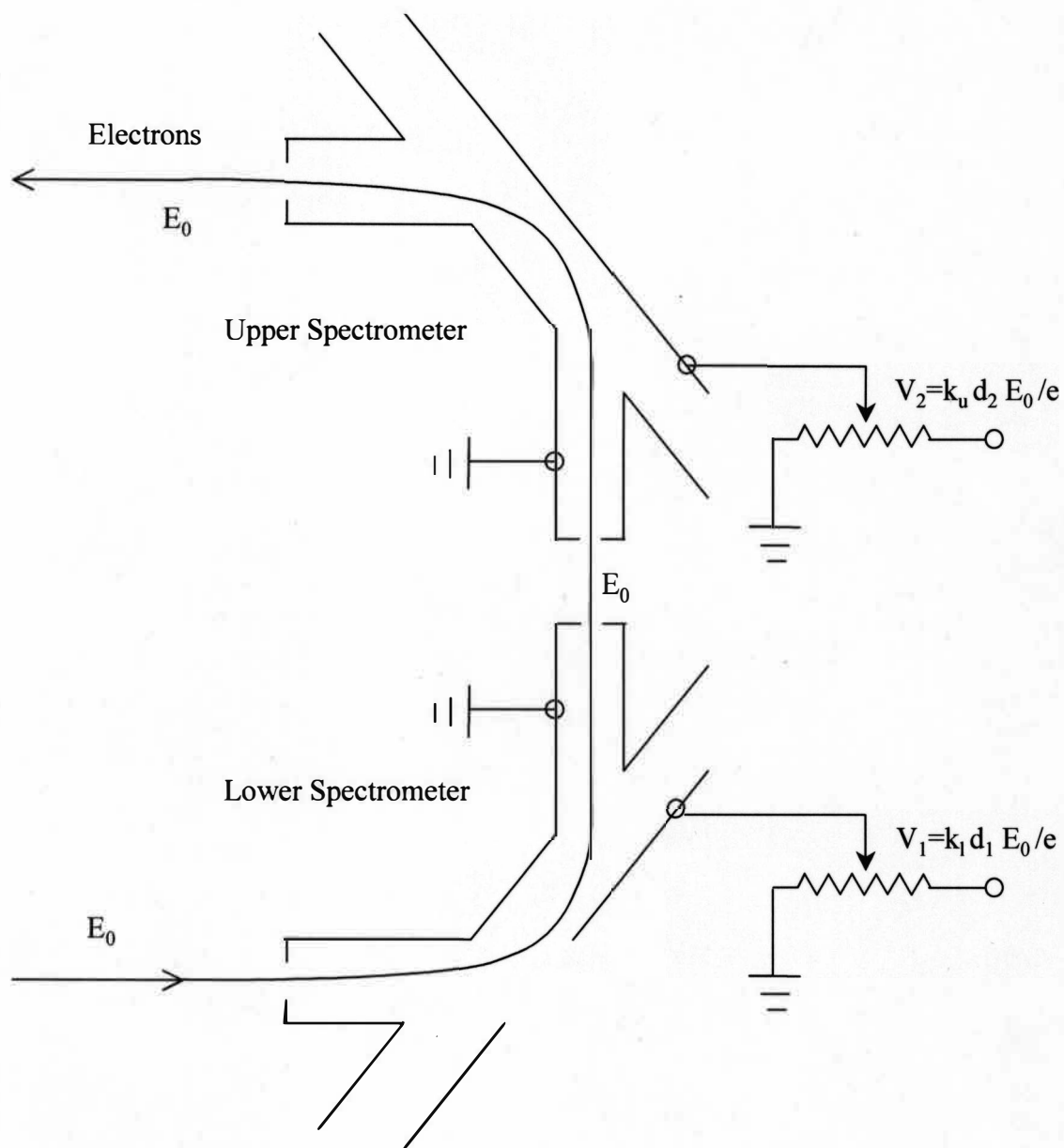
Figure 3. Low-Resolution, Low-Energy Mode.

High Resolution, High Energy, Constant Upper Electron Energy Mode

In this mode the electrons enter and leave the upper PMA with an energy, E_{pass}, that is lower than the analyzed energy E_0 in the lower PMA. This is accomplished by decelerating the electrons prior to entering the upper analyzer as shown in Figure 4. This mode is characterized by constant absolute resolution ($\Delta E/E_{pass}$=const), because the second PMA has constant passage energy E_{pass} independent of the energy E_0 with which electrons exit the lower PMA. Thus, a small E_{pass} provides high resolution.

High-Resolution, Low-Energy, Constant Upper Electron Energy Mode

This mode, shown in Figure 5, is similar to the previous one but is made applicable for low energies by using the voltage dividers mentioned above for the low resolution, low energy mode.

High-Resolution, High-Energy, Constant Deceleration Factor Mode

In this mode the ratio between E_0 and E_{pass} remains constant throughout the range of scanned energies. The mode is shown in Figure 6, where $c=E_0/E_{pass}$ is the deceleration factor. Such a scheme provides for constant transmission efficiency between the two PMAs, meaning that the energy dispersion of the electrons between the two PMAs is constant.

$V_2 = (E_0 - (1-k_u)E_{pass})/e$ $V_3 = (E_0 - E_{pass})/e$ $V_1 = k_1 E_0/e$

Electrons

E_0

E_{pass}

Upper Spectrometer

E_{pass}

E_0

Lower Spectrometer

E_0

E_0
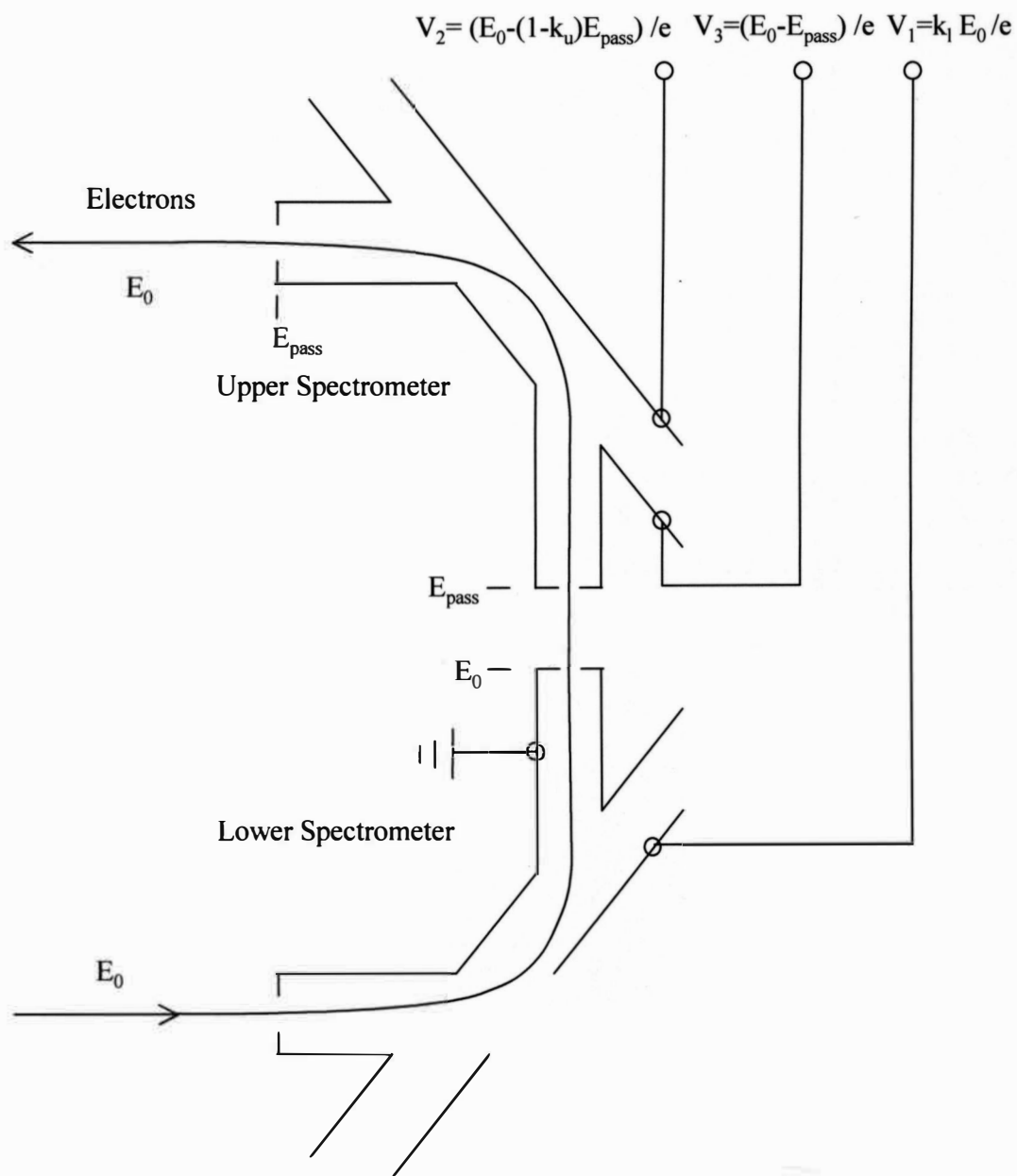
Figure 4. High-Resolution, High-Energy, Constant Upper Electron Energy Mode.

$$V_2 = d_2(E_0-(1-k_u)E_{pass})\,/e \quad V_3 = d_3(E_0-E_{pass})\,/e \quad V_1 = d_1\,k_1\,E_0\,/e$$
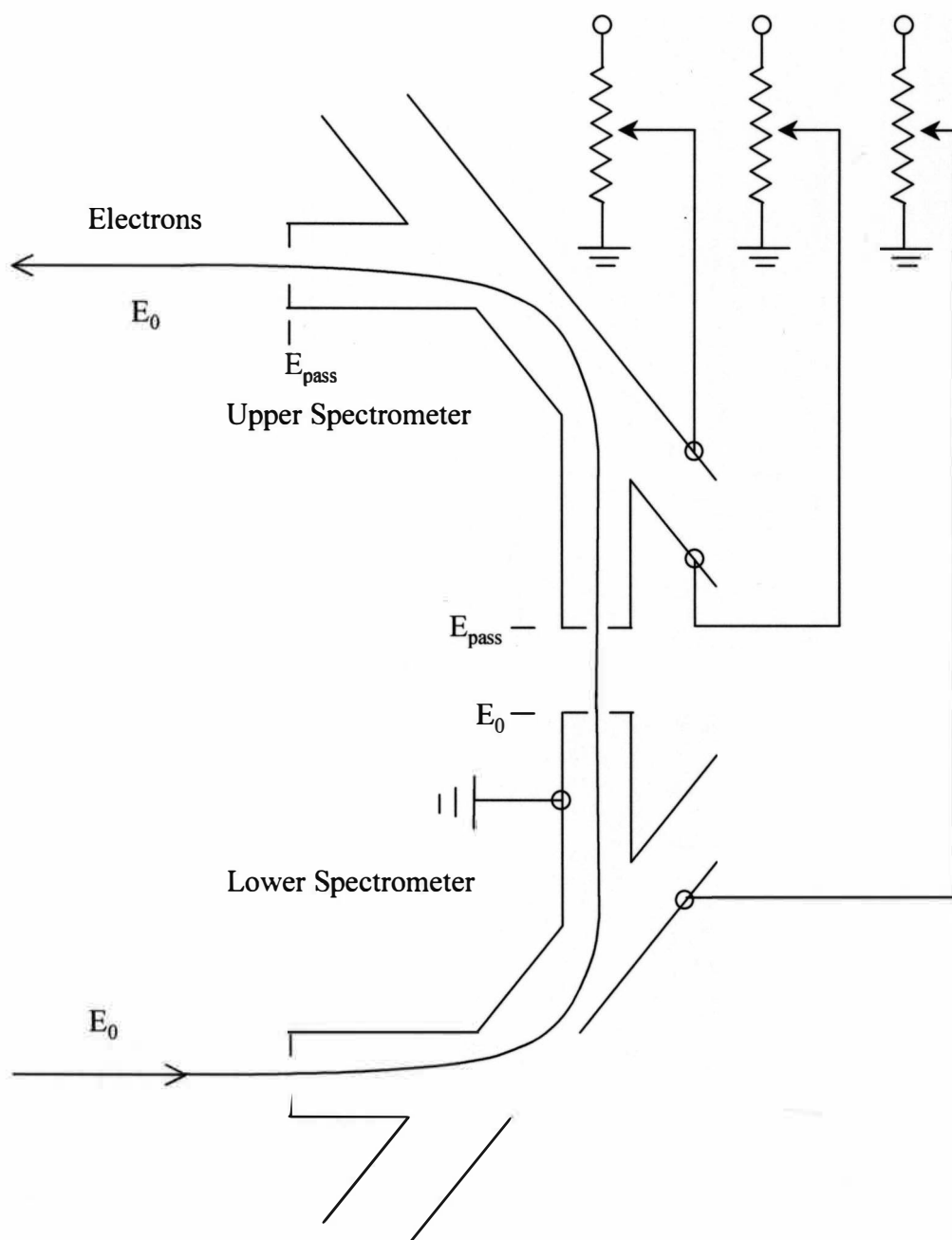
Figure 5. High-Resolution, Low-Energy, Constant Upper Electron Energy Mode.

$$V_2=(E_0-(1-k_u) E_0/c)/e \quad V_3=(E_0-E_0/c)/e \quad V_1=k_l E_0/e$$

Electrons

E_0

E_{pass}

Upper Spectrometer

E_{pass} —

E_0 —

Lower Spectrometer

E_0

E_0
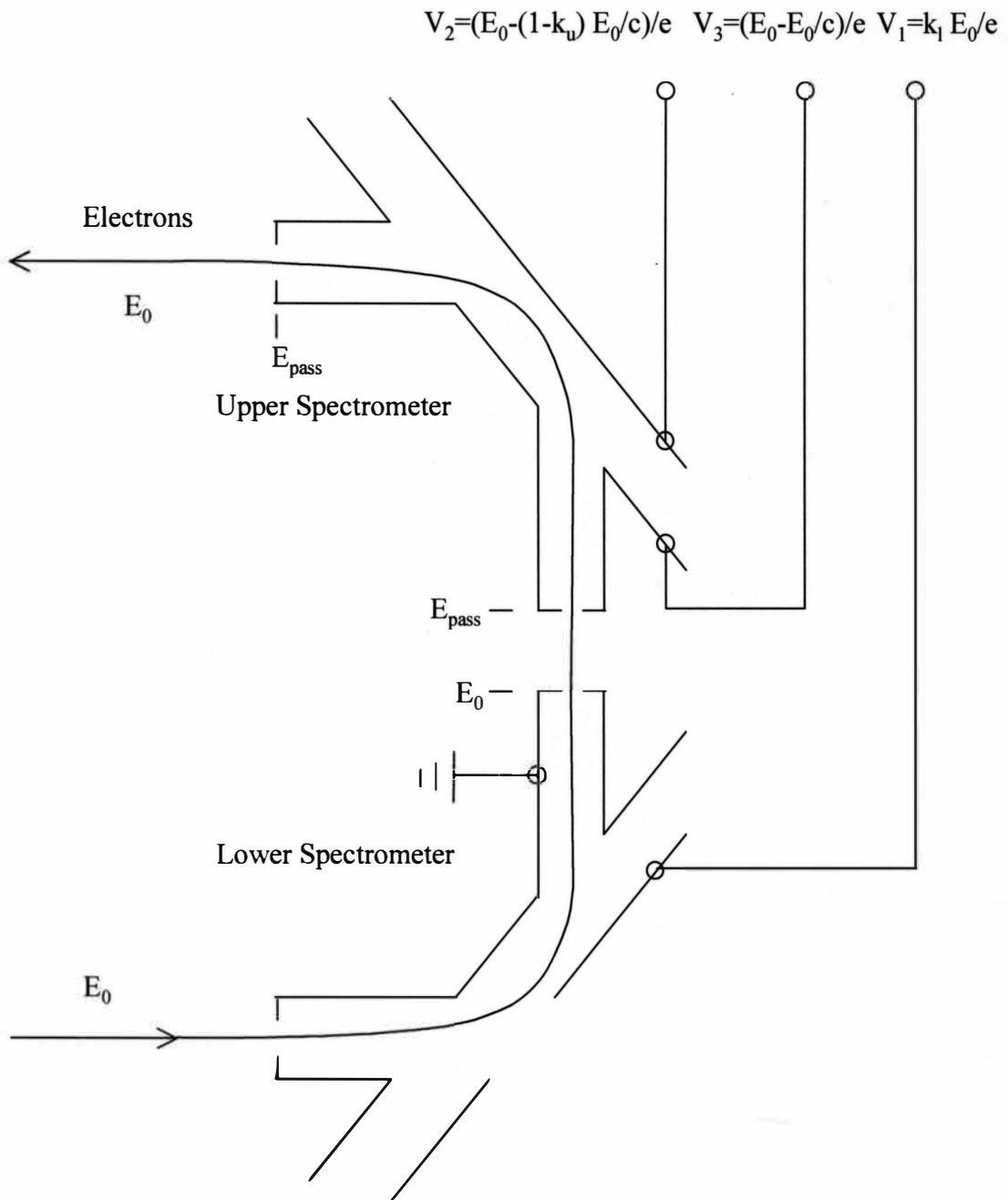
Figure 6.   High-Resolution, High-Energy, Constant Deceleration Factor Mode.

High-Resolution, Low-Energy, Constant Deceleration Factor Mode

This mode, shown in Figure 7, is the same, as the previous one but is made applicable for low energies by using the voltage dividers, described above.

$$V_2 = d_2(E_0 - (1-k_u) E_0/c)/e \quad V_3 = d_3(E_0 - E_0/c)/e \quad V_1 = d_1 k_l E_0/e$$

Electrons

E_0

E_{pass}

Upper Spectrometer

E_{pass} —

E_0 —

Lower Spectrometer

E_0
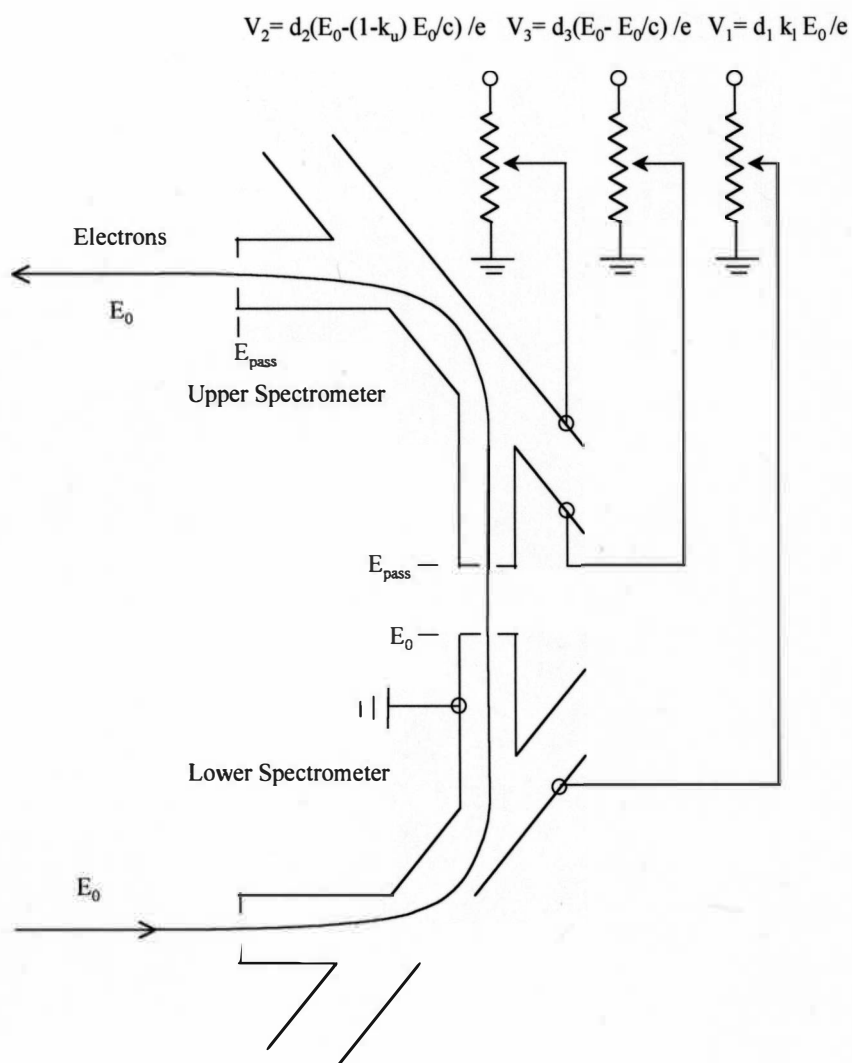
Figure 7.   High-Resolution, Low-Energy, Constant Deceleration Factor Mode.

ELECTRONICS FOR CONTROL AND DATA ACQUISITION

To enable the spectrometer to work as described in the previous chapter, means must be provided to control the plate voltages and the angular position of the spectrometer. Additionally, the number of detected electrons must be counted and normalized to the incident beam intensity. To provide experimenters with the tools for control and data acquisition the equipment and electronics shown in Figure 8 are used. The essential components are as follows:

1. A <u>Bi Ra Systems 6700-SCB Power Computer Automated Measurement and Control (CAMAC) Crate</u> is used to host most of the control and data acquisition equipment. The only exceptions are the General Purpose Interface Bus (GPIB) instruments, namely, the digital multimeters (DMMs) and the electrometer.

2. A <u>Highland Technology M210 CAMAC Serial Crate Controller</u> is used for data exchange between a personal computer (PC) and the other instruments in the system. It is connected to the PC via the RS-232 port.

3. Three <u>LeCroy 2415 High Voltage Power Supplies</u> are used to provide the necessary voltages V_1, V_2, and V_3 to the spectrometer plates.

4. Two channels of a <u>LeCroy 2551 Scaler</u> are used. One of them is used to count electrons registered by the channeltron. The other is used to count pulses proportional to the main beam current in order to normalize the electron counts from the channeltron to the incident beam intensity.

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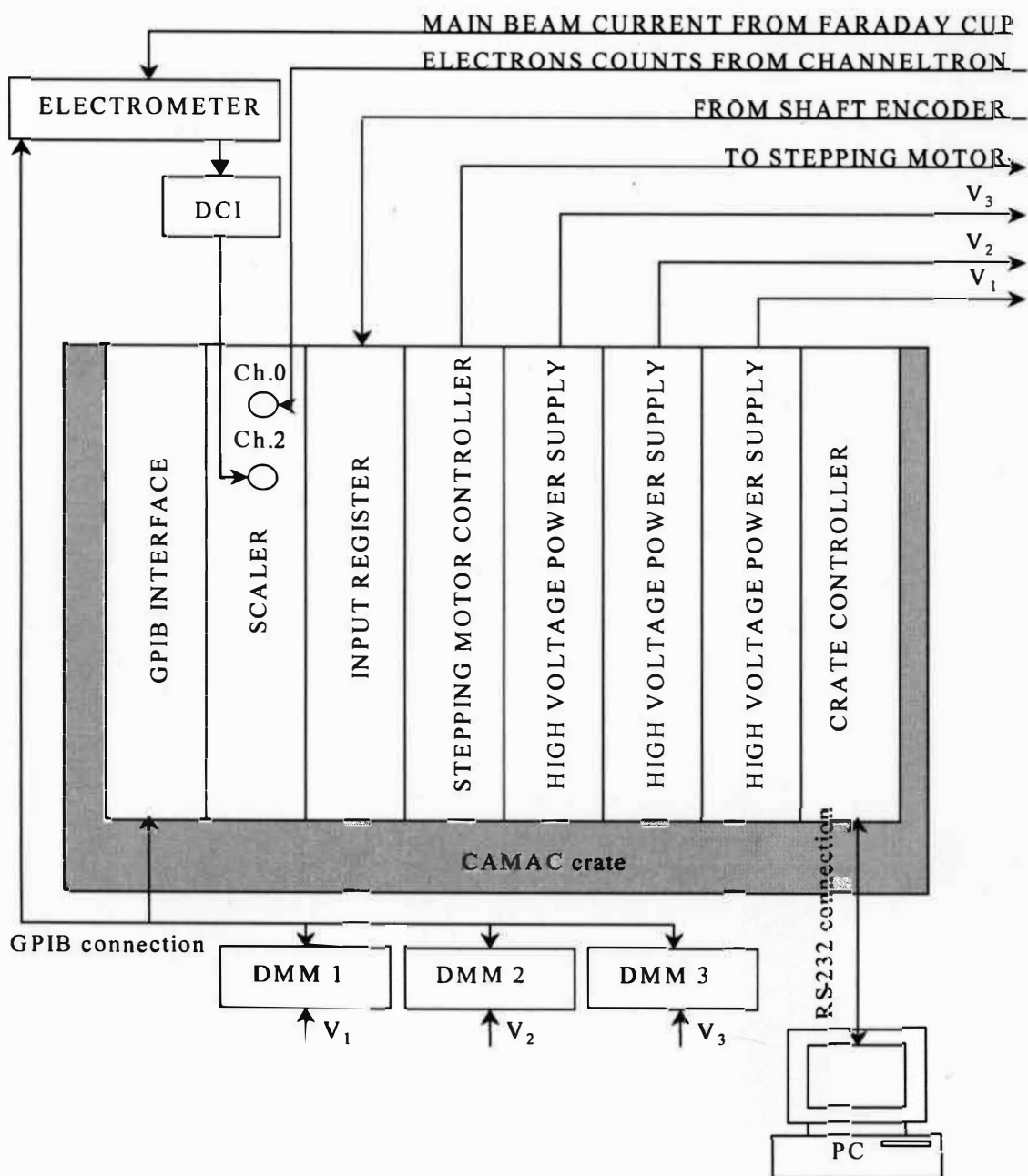
Figure 8. Electronics for Control and Data Acquisition.

5. A <u>Joerger SMC-R Stepping Motor Controller</u> is used to control the stepping motor that changes the angular position of the spectrometer with respect to the incident beam direction.

6. A <u>Joerger CS-5 Optically Isolated Input Register</u> is used to read the actual angular position of the spectrometer from a shaft encoder. This provides verification that the spectrometer is really at the position that was requested to be set by the stepping control program.

7. A <u>Kinetic Systems 3388 GPIB Interface</u> makes possible the control and monitoring of the GPIB instruments (three digital multimeters and an electrometer) via the same crate controller that is used to communicate with the other devices.

8. Three <u>Keithley 197A Autoranging Microvolt Digital Multimeters</u> are used to verify the voltage settings V_1, V_2, and V_3 of the high voltage power supplies. These DMMs give more accurate readings than the monitor outputs (not shown) of the power supplies. The use of these DMMs is optional and they do not affect the operation of the control program.

9. A <u>Keithley 617 Programmable Electrometer</u> is used to measure the main beam current that is collected in the Faraday cup. The output of the electrometer is sent to a digital current integrator (DCI) to digitize the beam current so that it can be counted by the LeCroy scaler (see Figure 8).

THE CONTROL AND DATA ACQUISITION PROGRAM

A PC is used for both sending commands to the system and acquiring data from it. The PC runs under the Microsoft® Windows® 95 operating system. The control and data acquisition program is written and run using the National Instruments™ LabVIEW™ package. The program checks accessibility of the equipment, collects user input regarding the mode and parameters of the experiment, and then executes the experiment by programmatically setting and changing the voltages on the spectrometer plates, counting the detected electrons for each set of voltages, normalizing the counts to the beam intensity, and continuously displaying the collected data on graphs. After the experiment is finished the program records the collected data into log files if requested.

Starting the Program

The program is started by opening the main file, SPECTROMETER CONTROL.VI. Usually, just double clicking on the file name accomplishes this. The file is set to run upon opening, so LabVIEW will run the file instead of opening it for editing.

Following the LabVIEW logo and some messages concerning loading the program files into memory, the user is presented with the main screen as shown in

Figure 9. The program was developed to run at 1024x768 resolution. Not all of the graphical display information is visible simultaneously on the main screen. Two

Figure 9. The Main Screen of the Program.

additional graphs, shown in Figure 10, can be seen by scrolling down.

After the program is started it is not yet ready to interact with the user as indicated by the disabled **Run** button (see Figure 9). Before the program is able to accept user input and begin the experiment, it needs to complete the process of initialization, which includes reading the configuration file CONFIG.INI described

below and initialize all the devices in the system. This initialization process is reflected by messages appearing in the status line just below the first graph.
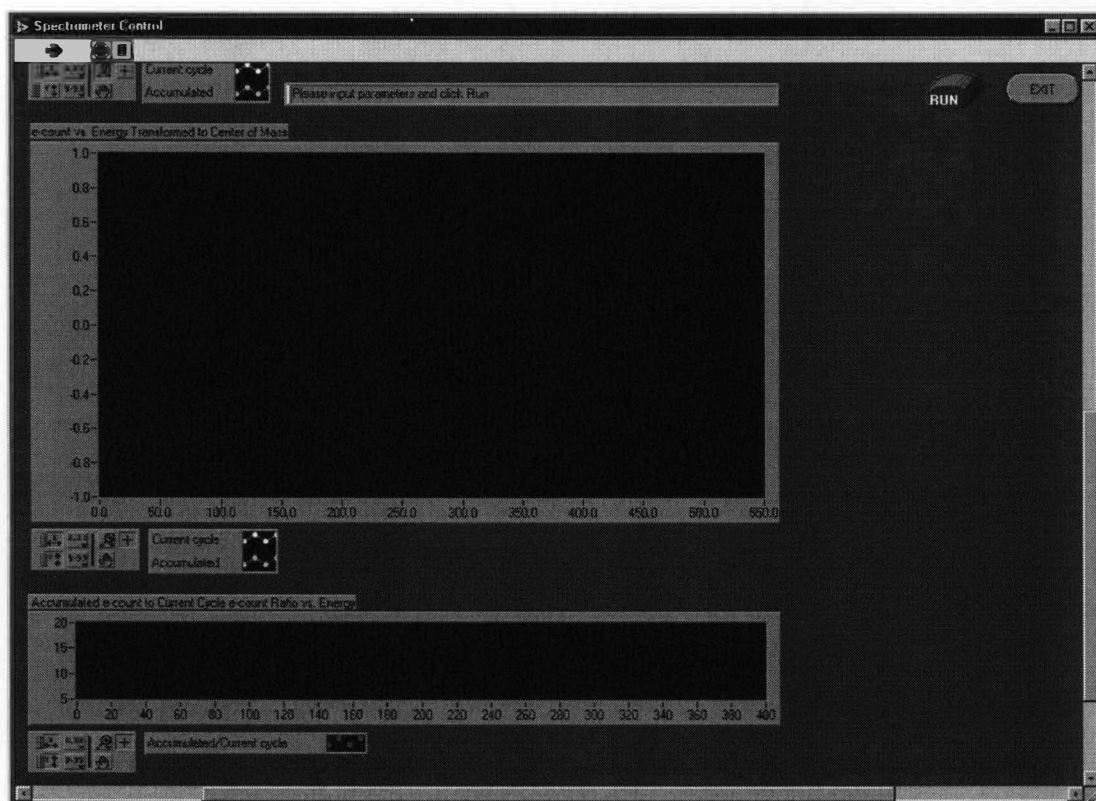
Figure 10. The Lower Part of the Main Screen of the Program.

If the program fails to initialize a device it reports an error, disables the controls and indicators for that device and, depending on the role of the device, may or may not allow user to run the experiment. The devices that are absolutely necessary for the program to be able to run the experiment are (a) the CAMAC crate itself, (b) the crate controller, (c) the power supplies, (d) and the scaler. If the program fails to initialize

any of these devices, it will not allow the experiment to begin, and the **Run** button will remain disabled. If the initialization process succeeds, the status line displays the message "Please input parameters and click Run" (see Figure 9), which means the program is ready to accept user input and begin the experiment.

Configuration File

The first thing that the program does upon starting is to read the configuration file, CONFIG.INI, which is expected to reside in the same directory as the other program files. This file is a plain text file. A sample listing is shown in Figure 11. As can be seen, the structure of the file is similar in format to standard Windows initialization (.INI) files. The file is divided into sections, denoted by names enclosed in brackets. Each section in the file has a unique name. Each section contains key-value pairs. Keys are named parameters that are used by the program. For example the line in the configuration file Baud_Rate=56000 means that the key parameter Baud_Rate is assigned a value 56000. Each key within a section has a unique name.

If the configuration file cannot be found the program will recreate it. However, in this case, the values for all the keys will be set to their default values, which may not match the actual configuration of the system. This may lead to an incompatibility, causing the program not to run until the discrepancies are resolved.

```
[COM_Port_settings]
COM_Port_#=0
Baud_Rate=56000
[Configuration]
HVPS_1_station_#=9
HVPS_2_station_#=11
HVPS_3_station_#=13
Scaler_Lecroy_2551_station_#=18
Scaler_Main_Beam_Channel=2
Scaler_e_channel=0
IEEE_Interface_station_#=3
IEEE_Interface_Address=1
Voltmeter_1_IEEE_Address=21
Voltmeter_2_IEEE_Address=20
Voltmeter_3_IEEE_Address=23
Electrometer_IEEE_Address=22
Step_Motor_Controller_Station_#=22
Input_Register_Station_#=21
Step_Motor_Channel_in_use=1
[Last_Run_Parameters]
Mode=0
Minimum_Energy=800.000000
Maximum_Energy=1200.000000
Energy_Step=2.000000
Maximum_Beam_Count=100
Number_of_Cycles=1
Pass_Energy=100.000000
Deceleration_Factor=0.000000
Upper_Spectrometer_Constant_Ku=0.600000
Lower_Spectrometer_Constant_Kl=0.600000
Division_Factor_D1=10.000000
Division_Factor_D2=10.000000
Division_Factor_D3=10.000000
Log_File="C:\\Rumega\\Spectrometer data\\exprun1.dat"
Logging=TRUE
Stop_Count_When=TRUE
Max_Time=1.000000
Cusp_Energy=543.000000
[Last_Run_Global_Settings]
Electrometer_Function=1
Electrometer_Range=7
Position_Offset=7876
Shaft_Encoder_Rollovers=0
Spectrometer_Angle=109.375000
```

Figure 11.   A Sample Listing of the Configuration File CONFIG.INI.

COM Port settings Section

Since all communications with the electron spectrometer system are done via a serial (RS-232) connection between the PC and the CAMAC crate controller, it is important that the port settings are set correctly on both devices. The COM_Port_# determines which PC serial port is used to communicate with the crate controller. A value of "0" means PC serial (communication) port number 1 (COM1), while a value of "1" means serial port number 2 (COM2), etc.

The serial port settings for the crate (number of data and stop bits, etc.) are nearly the same as those of the PC serial port default settings that are initialized by LabVIEW. So, the only possible discrepancy can be the speed of communication (i.e., the baud rate). The communication speed for the crate controller is set by entering a binary code in sections 1 to 4 of Dual In-Line Package (DIP) switch 1 on the controller itself. Hence, for the communication to be successful the Baud_Rate key must have the same value as that set on the crate controller. Then the program will initialize the PC port to the correct baud rate value.

Configuration Section

Every command sent to a device in a CAMAC crate must contain a station number, i.e., the slot number in the crate where the device resides. The Configuration section has entries corresponding to all the devices that are installed and used in the crate. All the keys storing station numbers have "…station_#" as a part of their names. If a CAMAC device becomes inaccessible the first thing to do is to check if

the device really is in the slot in which the program thinks it is located based on the number stored in the corresponding "…station_#" key.

Since the LeCroy 2551 scaler has several channels, the program needs to know which channels are used and for what purpose. The values of the keys Scaler_e_channel and Scaler_Main_Beam_Channel determine which channels are used for counting electrons registered by the channeltron and pulses proportional to the main beam current, respectively.

Each device on a GPIB (IEEE-488) bus must have a distinct address. The Configuration section contains entries storing addresses for each of the GPIB devices used including the GPIB to CAMAC interface. The names of the keys storing the address information end with "…_Address".

Since the stepping motor controller used is a dual channel device, the program needs to know which of the two channels is used, 0 or 1. This information is stored in the Step_Motor_Channel_in_use key.

Last Run Parameters Section

Since the program has a large number of input parameters that can be requested from the user, the program is designed to "remember" most of the user input between runs. The purpose of the entries in the Last_Run_Parameters section is exactly that: to store the parameter values that the user set the last time the program was used. It is never required to edit the values in this section manually, since the program takes care of them automatically.

Last Run Global Settings Section

The entries in this section also store parameters from the previous run. The parameters stored in this section exist in the program as global variables rather than controls on the main screen. Just as for the previous section, manual editing is not needed.

User Input

Most of the controls (except **Run** and **Exit** buttons) are concentrated in the upper part of the main screen (Figure 9). The purpose of each control is clearly reflected in its name. Nevertheless, if Ctrl-H is pressed the program will display short descriptions of the various controls and indicators as the mouse pointer hovers over them. The actual set of the controls displayed changes dynamically depending on values some of them acquire.

Run and Exit Buttons

If the program is able to initialize the minimal set of hardware the **Run** button starts the experiment with the parameters entered. The **Exit** button terminates the program and records the last set of parameters into the configuration file.

Logging the Results

Depending on the state of the **Logging** button in the upper left corner of the main screen the results of the run may or may not be recorded into two text files.

Both files contain the parameters set for the given run. However the main purpose of the log files is to store the data collected during the experiment. The first file stores the recorded data in the laboratory system of coordinates, while the second stores the data in the center of mass system of coordinates. The data from the log files can be easily loaded for later analysis into a specialized package such as Microcal™ Origin®. Two log file sample listings are given in Figures 12 and 13.

The Log File for Data in the Laboratory System of Coordinates

This log file is a plain text file (see Figure 12). Its header includes information about the time and date of the experiment, the mode, and other parameters of the run. The main part of the file is a table containing the recorded dependence of the number of electrons registered versus their laboratory energies. The first column contains the values of the energies. Depending on the number of measurement cycles there can be one or more columns that contain the electron counts for the particular cycles. During each cycle the entire range of voltages corresponding to the energy range being investigated is scanned on each PMA. The last column in the table contains the counts for the particular energies summed over all the cycles.

The Log File for Data in the Center of Mass System of Coordinates

This log file is also a text file (see Figure 13). The header information is the same as that for the laboratory system of coordinates file. This file, however, contains the number of electron counts versus center of mass energies.

```
1/17/00 12:22:06 PM
Mode:Low Resolution, High Energy
MIN ENERGY=300 eV
MAX ENERGY=2400 eV
ENERGY STEP=50 eV
Spectrometer Constants
Kl=0.6
Ku=0.6
# of Cycles=1
Max Beam Count=200
Cusp Energy=545 eV
Spectrometer Angle=0 degrees
e-count_lab vs. Energy_lab table
Energy_lab   e-count_lab
300.000      26.000         26.000
350.000      44.000         44.000
400.000      30.000         30.000
450.000      36.000         36.000
500.000      42.000         42.000
550.000      47.000         47.000
600.000      39.000         39.000
650.000      40.000         40.000
700.000      29.000         29.000
750.000      28.000         28.000
800.000      33.000         33.000
850.000      19.000         19.000
900.000      28.000         28.000
950.000      21.000         21.000
1000.000     16.000         16.000
1050.000     13.000         13.000
1100.000     12.000         12.000
1150.000     21.000         21.000
1200.000     27.000         27.000
1250.000     15.000         15.000
1300.000     19.000         19.000
1350.000     23.000         23.000
1400.000     19.000         19.000
1450.000     15.000         15.000
1500.000     21.000         21.000
1550.000     14.000         14.000
1600.000     15.000         15.000
1650.000     30.000         30.000
```

Figure 12.   A Sample Listing of a Log File for Energies in the Laboratory System of
             Coordinates (truncated to fit the page).

```
1/17/00 12:22:06 PM
Mode:Low Resolution, High Energy
MIN ENERGY=300 eV
MAX ENERGY=2400 eV
ENERGY STEP=50 eV
Spectrometer Constants
Kl=0.6
Ku=0.6
# of Cycles=1
Max Beam Count=200
Cusp Energy=545 eV
e-count_cm vs. Energy_cm table
Energy_cm    e-count_cm
36.220       215.351
21.442       718.226
11.148       1076.461
4.518        3585.500
0.957        21949.615
0.013        2014797.375
1.337        17507.885
4.650        5591.902
9.726        2087.121
16.381       1281.989
24.458       1079.419
33.825       477.454
44.371       567.933
55.999       356.255
68.624       233.154
82.172       166.114
96.579       136.676
111.785      216.040
127.740      253.640
144.397      129.850
161.715      152.738
179.655      172.831
198.183      134.219
217.269      100.106
236.884      132.977
257.000      84.436
```

Figure 13.   A Sample Listing of a Log File for Energies in the Center of Mass
System of Coordinates (truncated to fit the page).

These energies are calculated based on the data from the first log file as follows:

$$E_{cm} = E_{lab} + E_{cusp} - 2 \sqrt{E_{lab} \cdot E_{cusp}} \cos \theta,$$

where E_{cm} is the energy in the center of mass system of coordinates, E_{lab} is the energy in the laboratory system of coordinates, E_{cusp} is the energy of an electron that moves with the velocity of the projectile, and θ is the angle between the direction of the detected electrons and the incident beam direction. This file contains just two columns: energies and accumulated counts.

Choosing Files to Record the Results

If the Logging button is in the "On" position (see Figure 9) two additional elements appear on the main screen: the indicator, showing the file to be used for recording the data in the laboratory system of coordinates and the **Browse** button which allows the user to choose the file. When the **Browse** button is pressed the user is presented with a screen similar to the one shown in Figure 14.

The log files have the .DAT extension. The user chooses the name for the first log file only (the laboratory system of coordinates). The name for the second log file (containing the data in the center of mass system of coordinates) is created automatically by taking the name of the first log file and adding "_CM" to its main part (before the dot.)
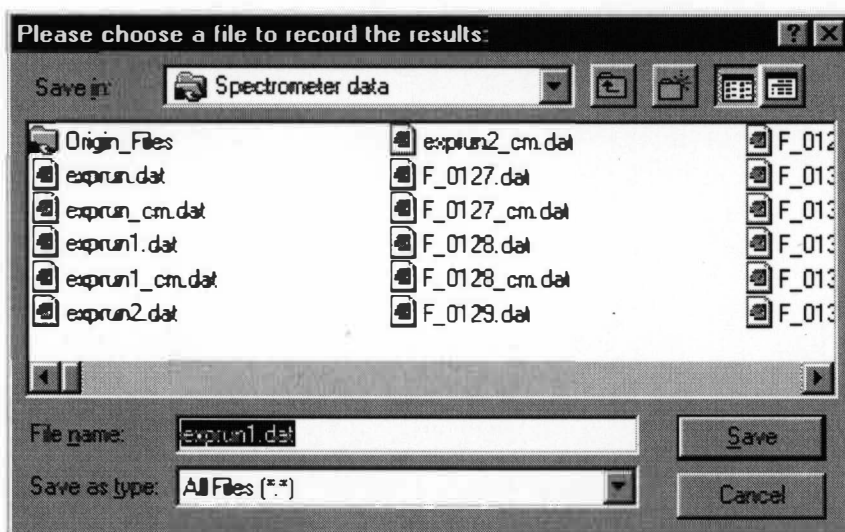
Figure 14. Choosing a File to Record the Results.

Main Screen Controls in Different Modes

The actual set of controls displayed on the main screen depends on the setting of the **Mode** control. The different possible sets of controls depending on the mode chosen are shown in Figures 15 through 20. Only those controls are displayed that are needed for a particular mode. Figure 16 also demonstrates how this part of the main screen looks when the **Logging** button is in the "Off" position.
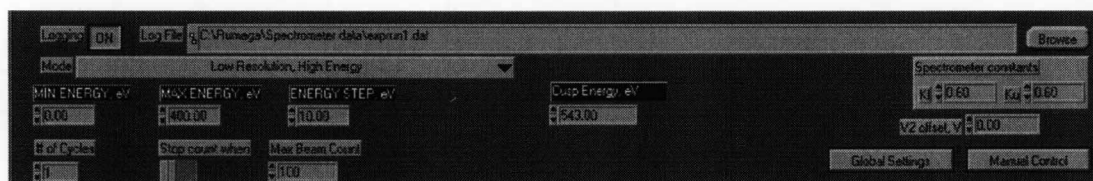

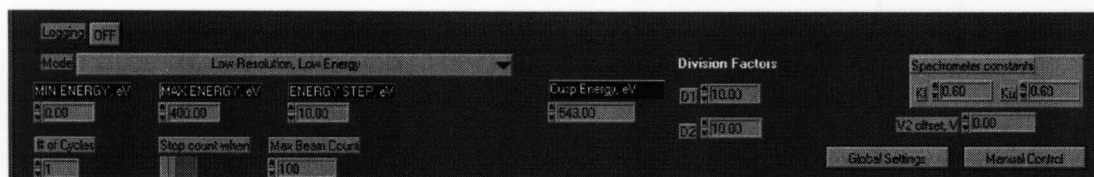Figure 15. Main Screen Controls in the Low Resolution, High Energy Mode.

Figure 16.   Main Screen Controls in the Low Resolution, Low Energy Mode.
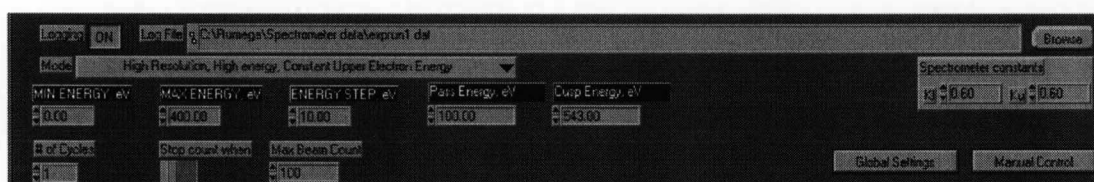

Figure 17.   Main Screen Controls in the High Resolution, High Energy, Constant
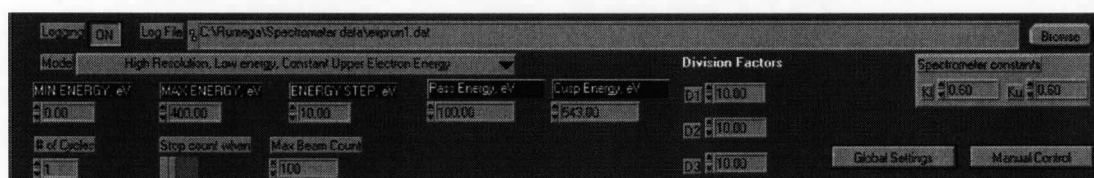   Upper Electron Energy Mode.

Figure 18.   Main Screen Controls in the High Resolution, Low Energy, Constant
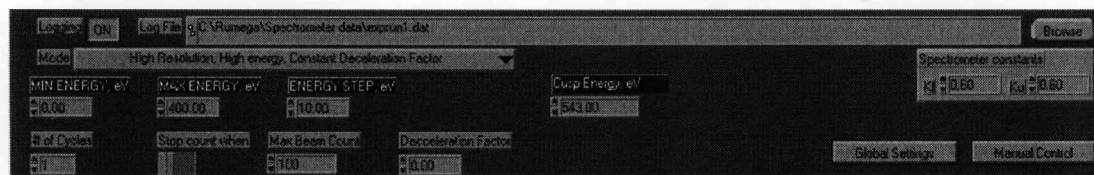   Upper Electron Energy Mode.

Figure 19.   Main Screen Controls in the High Resolution, High Energy, Constant
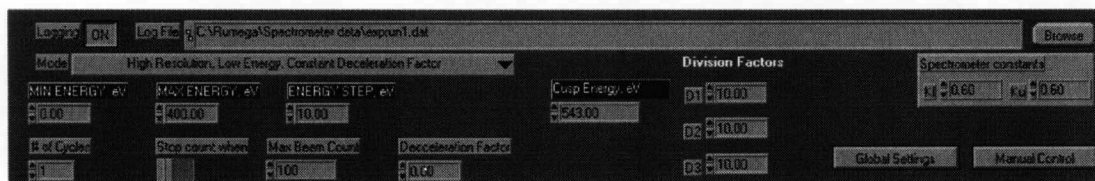   Deceleration Factor Mode.

Figure 20. Main Screen Controls in the High Resolution, Low Energy, Constant
Deceleration Factor Mode.

Counting Modes

When the program runs there are two possible options for normalizing the

electron counts for a given energy (voltage setting). Depending on the position of the

Stop Count When switch the program can stop counting when either the maximum

main beam count is reached or the selected time elapsed is reached. The upper part of

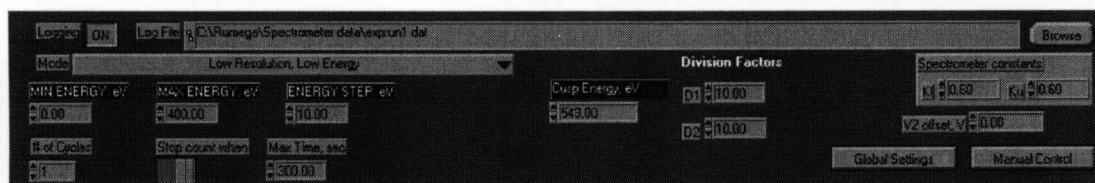the screen for the latter mode is shown in Figure 21.

Figure 21. Stop When Maximum Time Elapsed Counting Mode.

Global Settings

The configuration parameters of the system described in the Configuration File section above do not need to be set by editing the file. Instead, the **Global Settings** button on the main screen will bring up the screen shown in Figure 22. If a component of the system doesn't respond, this screen should be checked to verify that the software configuration settings match the actual system configuration.

Figure 22.   Accessing the Global Settings.

These are called "Global Settings" because these data are implemented as global variables in the program to make the configuration information accessible everywhere within the program without the need for passing the parameters as input to each of the modules separately. Clicking **OK** saves the changes in the corresponding key value pairs in the configuration file CONFIG.INI (see Figure 11) and exits the screen. **Cancel** just exits the screen without saving any changes made.

Manual Control

By clicking the **Manual Control** button on the main screen the user gets the screen shown in Figure 23. From this screen individual components of the system can be accessed. This screen also controls the angular position of the spectrometer.
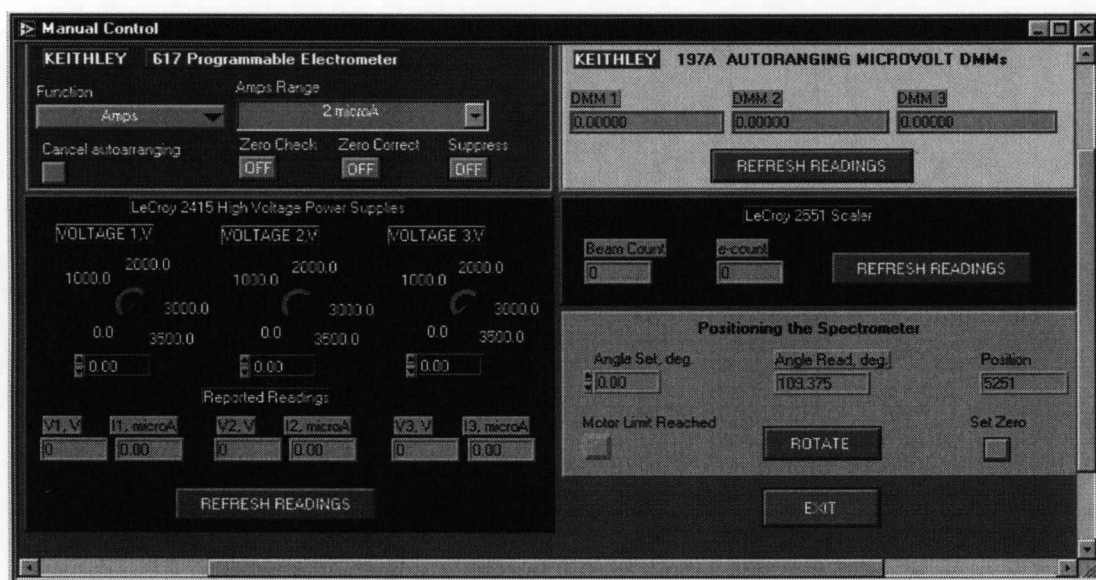

Figure 23. Manual Control Screen.

Electrometer and Power Supplies

As soon as the value of a control for the electrometer or the power supplies is changed the corresponding command is sent. Depending on the function (the value of the **Function** control) chosen for the electrometer different controls are displayed showing the applicable range values. For the power supplies the voltages and currents as reported by the power supplies themselves are read. However, since it takes some time (usually a few seconds) for the voltages to reach the requested values, it is recommended that the **Refresh Readings** button on the power supplies panel be clicked several times to obtain the settled values.

DMMs

Each click on **Refresh Readings** in the DMMs panel retrieves the voltage readings from the DMMs. Due to the nature of communicating with GPIB instruments via the crate controller and the GPIB to CAMAC interface, this can take up to several seconds.

Scaler

Each click on **Refresh Readings** in the scaler panel retrieves the data from the channels set as electrons count and main beam count channels in the configuration file.

Positioning the Spectrometer

To set the spectrometer to a particular angle with respect to the incident beam direction it is necessary to let the program know which absolute position reported by the shaft encoder, through the input register, should be considered the zero angle position. This is done by physically aligning the spectrometer (with a telescope) along the beam direction. Then the **Set Zero** button is pressed. The program will request a confirmation whether the user really wants the current position to become "zero". After this the spectrometer can be set to the desired angle by entering the angle into the **Angle Set** field and clicking on the **Rotate** button. The **Position** indicator reflects the progress of rotation. When the process of rotation is complete the **Angle Read** indicator reports the actual angle as calculated from the newly reported shaft encoder absolute position value. If the stepper motor reaches either of its physical limits while rotating, the **Motor Limit Reached** indicator becomes black.

Inaccessibility of Devices

During the initialization process, if the program discovers that some devices are inaccessible the controls and indicators for those devices become disabled as shown in Figure 24 where the electrometer and DMM2 were found inaccessible (compare to Figure 23.) This may not be a problem unless inaccessible devices belong to the set of equipment that is crucial for the experiment. As mentioned earlier, this set includes the power supplies and the scaler.
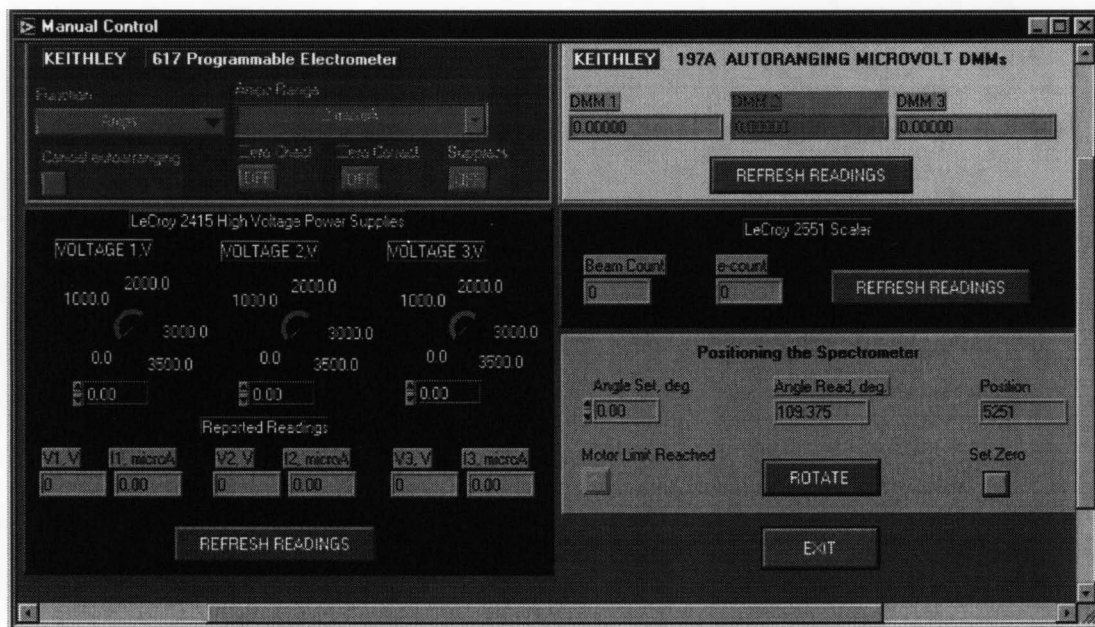
Figure 24.   Manual Control Screen With Inaccessible Devices.

The Program in Action. Running the Experiment

When the desired mode has been chosen and all the required parameters have been entered, the program can start to control the experiment, and collect and display the data. This is done by clicking on the Run button (see Figure 9).

What the Program Does During the Experiment

For each value of energy within the range between the values input into the **MIN ENERGY** and **MAX ENERGY** fields the program calculates the necessary set of voltages V_1, V_2, V_3, depending on the other parameters applicable for this mode. It then sets the power supplies to the calculated voltages, waits until the voltages settle

and starts counting electrons and main beam counts. Counting is done by repeatedly polling the scaler until either the maximum beam count is reached or the requested time elapses. When the counting for a given energy (voltage) setting finishes the program adds the value of the **ENERGY STEP** field to the energy and proceeds to the next energy value (voltage setting) until all the energies within the range have been processed. If the number of cycles is set to more than one, the program starts scanning the entire energy range again and continues for the number of cycles selected. After all the cycles are complete or when the **Stop** button is pressed, and if logging is on, the program requests confirmation of the value for the cusp energy which is needed to correctly calculate the data in the center of mass system of coordinates. Upon receiving confirmation the program records the collected data into the log files and is ready to run again.

The name of the log file suggested for the next run is changed by the program, which increments by one the number at the end of the current file name (before .DAT). For example, if the name of the first log file is EXPRUN14.DAT the name suggested for the next run will be EXPRUN15.DAT. If the file name is just EXPRUN.DAT the name suggested for the next run will be EXPRUN1.DAT.

Monitoring the Experiment

The progress of the experiment is monitored continuously with three graphs and the Current Parameters indicators as shown in Figure 25. The spectrometer

angular position as read from the input register is also displayed for reference below the Current Parameters panel.

Graphs

Every time counting for a given voltage setting is complete, the corresponding points are added to all three graphs. The first graph shows the number of electron counts registered for each laboratory energy value in the requested range with the requested step size for both the current cycle of measurement and for the accumulated

Figure 25.   The Main Screen of the Program During an Experiment.

data summed over all cycles as of the current time. The second graph (see Figure 10) shows the number of electron counts vs. energy calculated in the center of mass system of coordinates. The third graph is auxiliary, allowing for detecting unusual fluctuations by showing the ratio of the accumulated count to the current cycle count for every energy value. Ideally, this graph should be a straight line. A spike indicates a possible distortion of the data due to some spurious effect.

Each graph has a palette . The palette allows changing the graph characteristics while the program executes. One can scale the X or Y-axis, focus in on a specific area (zoom), and scroll the display area (pan).

Numeric Indicators

Numeric indicators displaying the current values of several parameters are located in the Current Parameters panel on the main screen. The **Cycle #** shows the current cycle out of the total number of cycles requested. **Beam Count** and **e-count** continuously display the current values of the corresponding counts as reported by the scaler. The user also has information concerning the current point number out of the total number of points investigated within the given energy range.

The Current Parameters panel has three columns of voltage indicators. The first column shows (or doesn't show, depending on the state of the **DMMs On/Off** button) the "true" voltages, as reported by the DMMs. However, since communication with the DMMs via the crate controller and then via the GPIB to

CAMAC interface takes a significant time compared to the time it takes to communicate with the power supplies and the scaler, the opportunity to turn off reading the DMMs is provided. The second column of voltages in the Current Parameters panel shows the voltages as reported by the power supplies themselves. The last column of voltages shows the set values of the voltages, i.e., as calculated from the current energy and other user input depending on the mode. Thus, the user can see how close the actual values of the voltages match those expected.

Interrupting the Data Acquisition Process

As soon as the **Run** button is pressed the **Run** and **Exit** buttons are replaced with **Skip the Cycle**, **Pause**, and **Stop** buttons. **Skip the Cycle** allows the user to delete the data for the current measurement cycle that may be contaminated by some unexpected event while still saving the data for the previous cycles that have been completed. The program then repeats the skipped cycle, starting with the lowest energy value within the requested energy range. The **Pause** button allows stopping the measurement cycle temporarily. When pressed, the **Pause** button changes its name to **Resume**. So, clicking on the button a second time resumes the process thus continuing with the same energy value that had not been completed at the moment the **Pause** button was pressed.

Some of other controls that are typically used while entering the desired parameters of the experiment remain accessible during the runs. For example, the

user can still change whether the results are to be logged, the total number of cycles

of measurement, and the cusp energy.

INTERNAL STRUCTURE OF THE SPECTROMETER CONTROL PROGRAM

The Development Environment

The Control and Data Acquisition Program was developed using LabVIEW. LabVIEW is a graphical software programming language developed by National Instruments, that provides a powerful and quick software development environment. Programming in LabVIEW is performed graphically. A developer is given a set of software building blocks. These blocks represent I/O ports, basic numerical functions (add, subtract, integrate, differentiate, amplify, compare), and several hundred other functions. All of the pieces are connected with simple "wiring tools". To build an interface the user has virtual buttons, knobs, switches, indicators, and even graphs, i.e., everything needed to control equipment and acquire data under computer control. Using LabVIEW only about one fourth of the time required for C code is needed to develop equivalent functional software.

The Program Hierarchy

The calling hierarchy of the program is shown in Figure 26. Each module is a separate file with the extension ".VI" for "virtual instrument". Calls are made from files positioned higher in the hierarchy to files that are lower along lines connecting the blocks. All the files are assumed to reside in the same directory. The various files used in the program are described below.
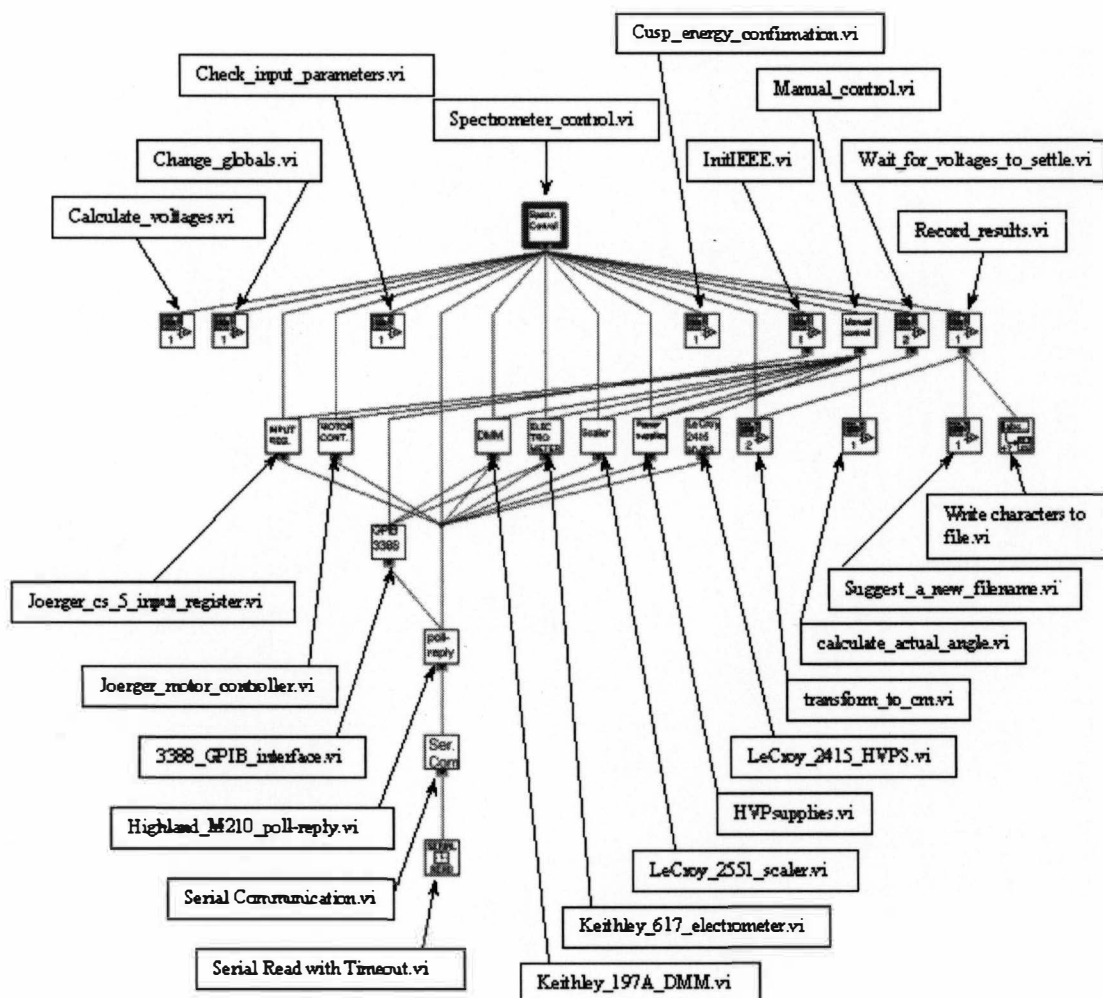
Figure 26. Calling Hierarchy of the Program Modules.

1. SPECTROMETER_CONTROL.VI is the top of the hierarchy (the main file). This file handles (a) loading the configuration data from the file CONFIG.INI, (b) accepting user input data, (c) running the experiment, and (d) displaying the progress of the experiment on the main screen (Figure 27.)
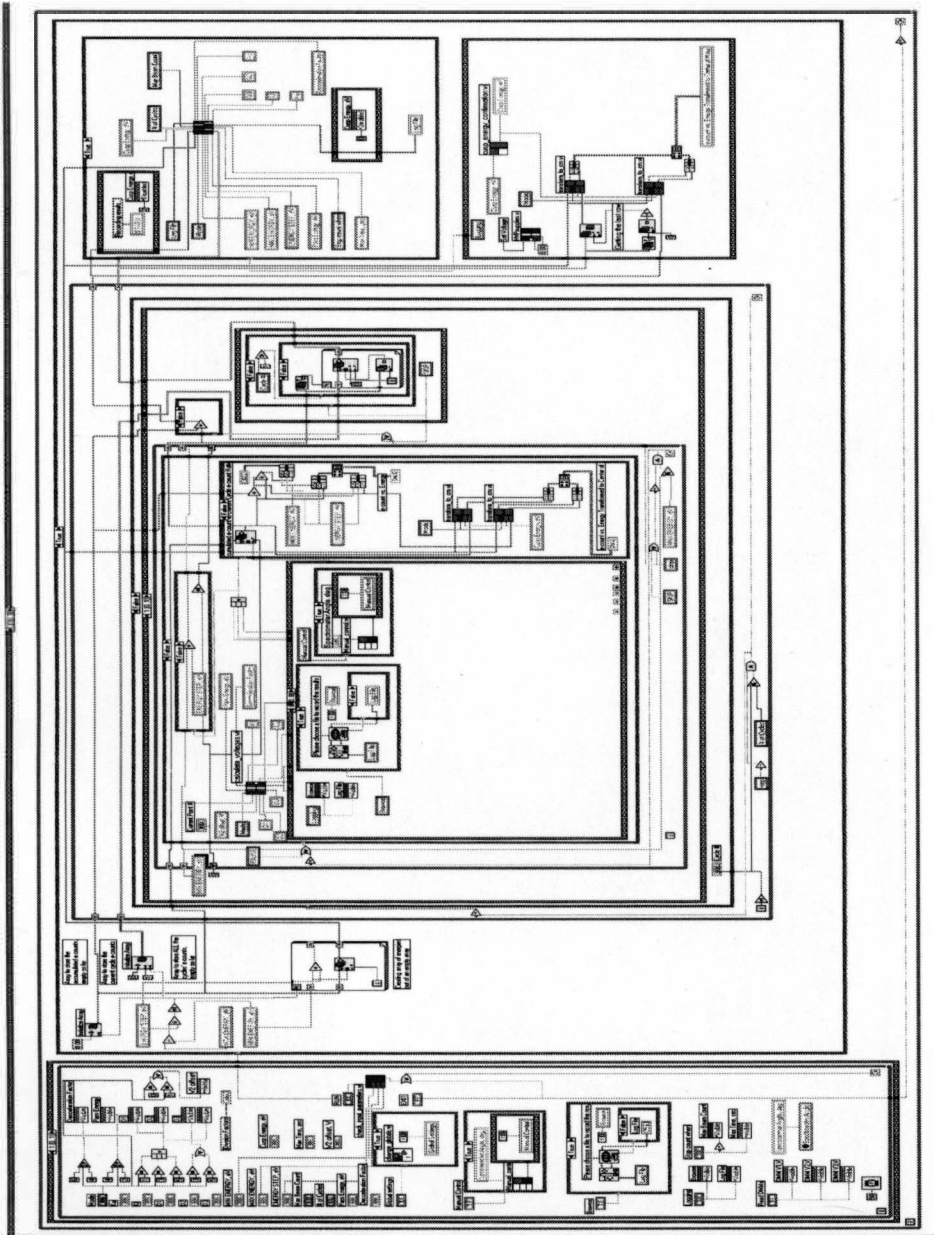
Figure 27.   The SPECTROMETER_CONTROL.VI Module.

2. CALCULATE_VOLTAGES.VI calculates the voltages V_1, V_2, and V_3, to be set to detect electrons with a particular energy depending on the mode and other user input (Figure 28.)
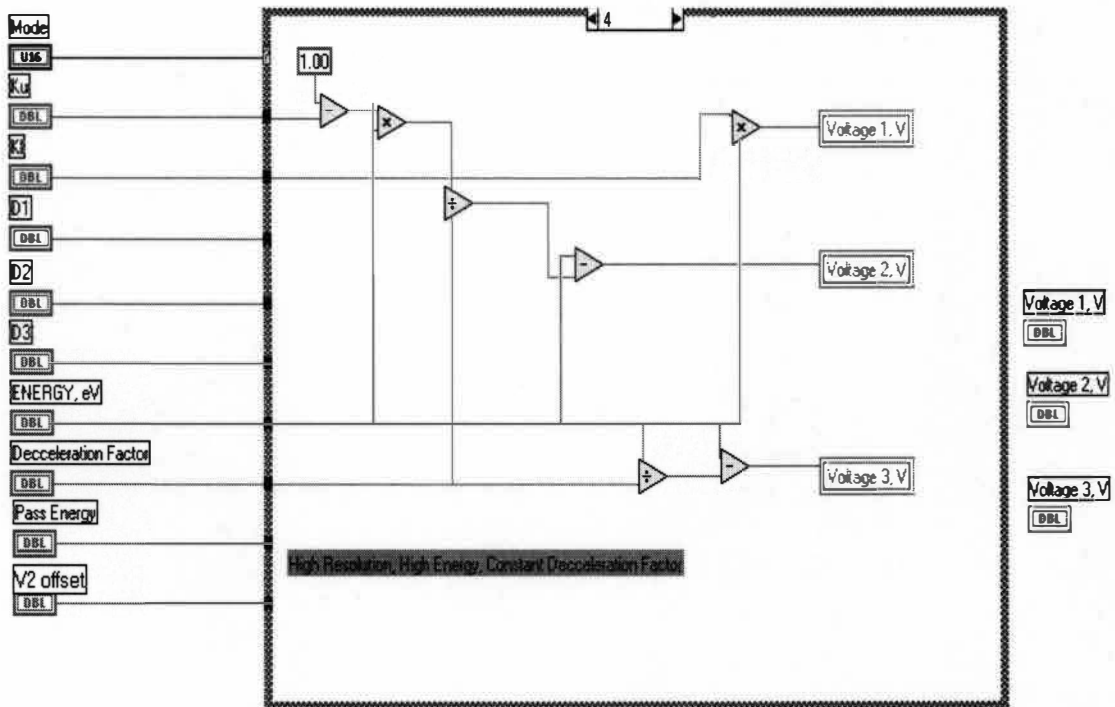
Figure 28.   The CALCULATE_VOLTAGES.VI Module.

3. CHANGE_GLOBALS.VI presents the Global Setting screen to the user allowing the changing of settings in the configuration file without manual editing of the file (Figure 29.)

4. CHECK_INPUT_PARAMETERS.VI ensures that the user enters valid input parameters.   For example, **MAX ENERGY** must be larger than **MIN ENERGY** (Figure 30.)

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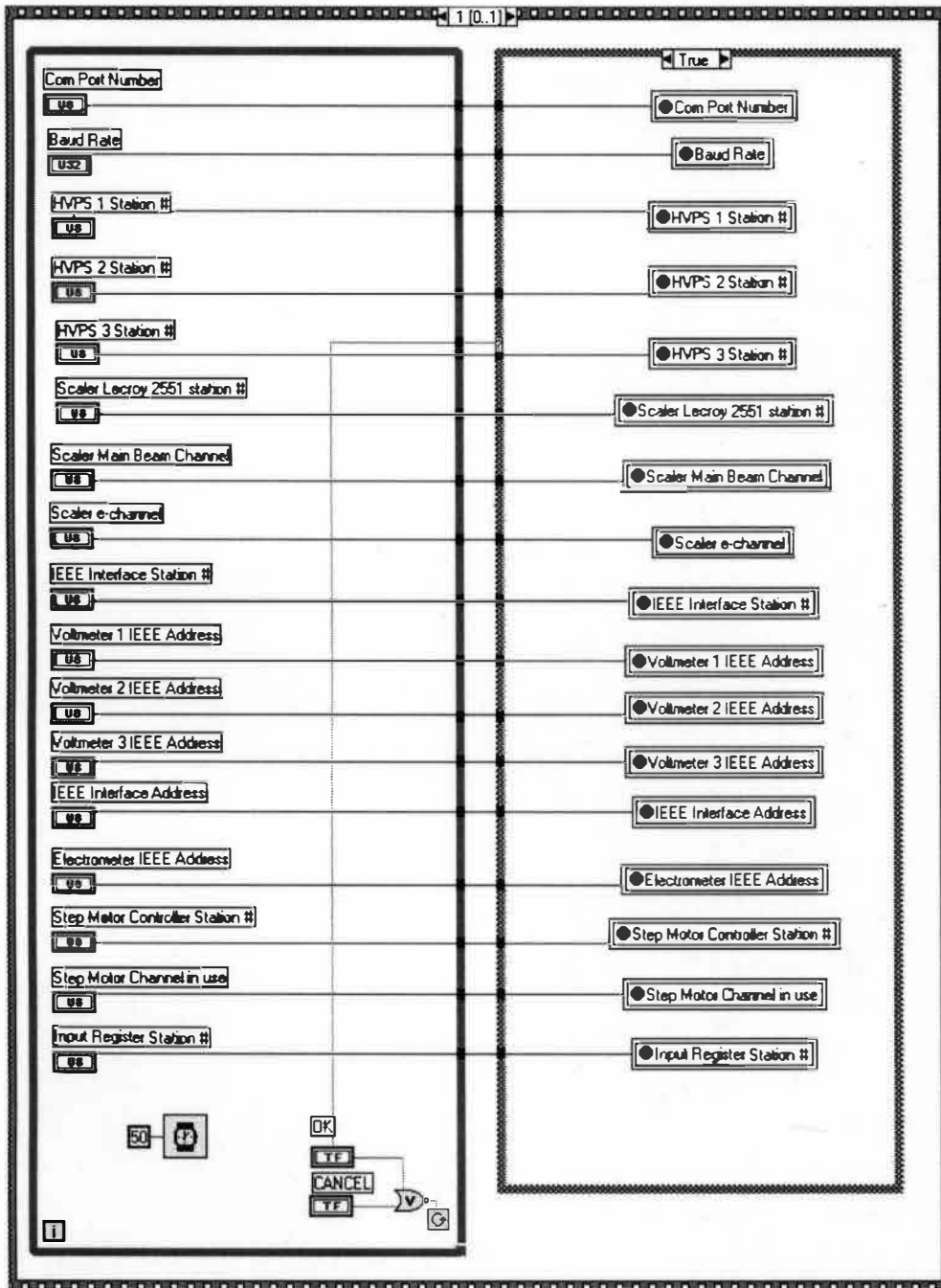
Figure 29.   The CHANGE_GLOBALS.VI Module.
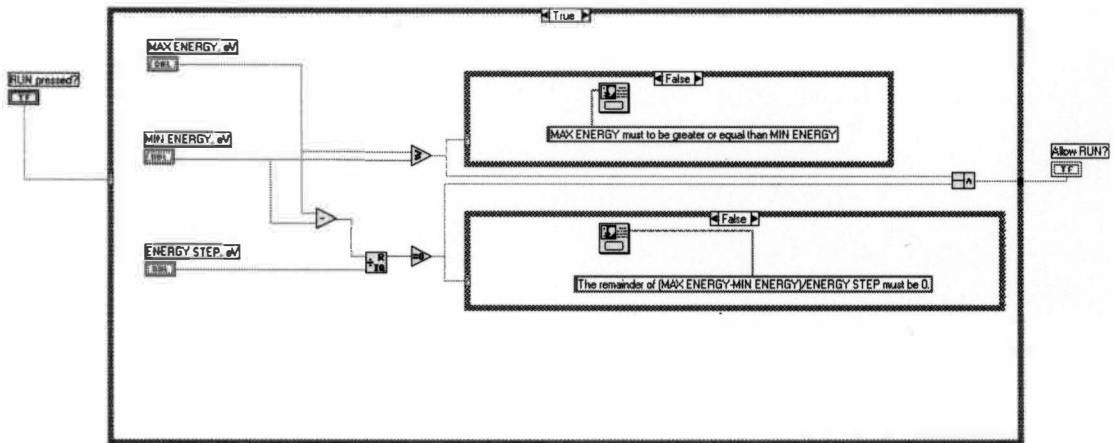
Figure 30. The CHECK_INPUT_PARAMETERS.VI Module.

5. CUSP_ENERGY_CONFIRMATION.VI gives the user a final chance to change the cusp energy before recording into the log file the data calculated in the center of mass system.

6. INITIEEE.VI runs a series of GPIB commands on the GPIB to CAMAC Interface to initialize it (Figure 31.)
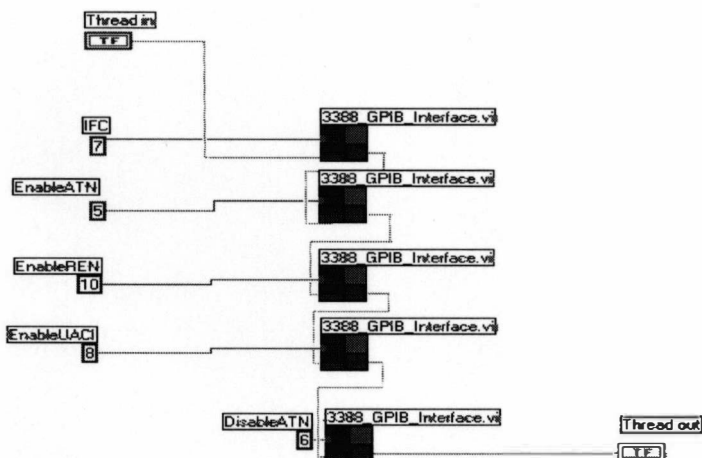

Figure 31. The INITIEEE.VI Module.

7. MANUAL_CONTROL.VI presents the Manual Control screen to the user. This module allows the control and reading of data from individual components of the system, e.g., the electrometer, the power supplies, the DMMs, and the scaler. This file also provides an interface for the control of the angular position of the spectrometer (Figure 32.)
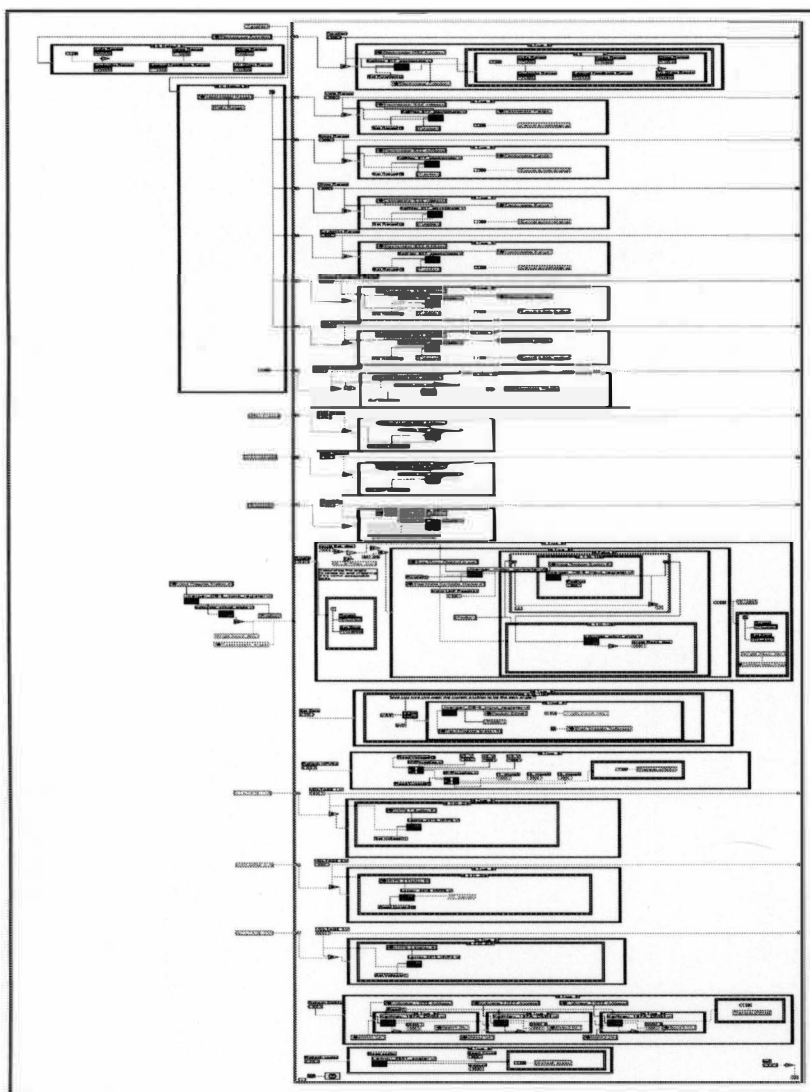

Figure 32. The MANUAL_CONTROL.VI Module.

8. WAIT_FOR_VOLTAGES_TO_SETTLE.VI ensures that the power supply voltages have settled before the program starts counting (it takes some time for the voltages to reach the set values after a command has been sent to the power supply). This is done by reading and storing four consecutive readings until the difference between the first and the last is no larger than 1 V, which is the uncertainty in the power supply voltage readings (Figure 33.)
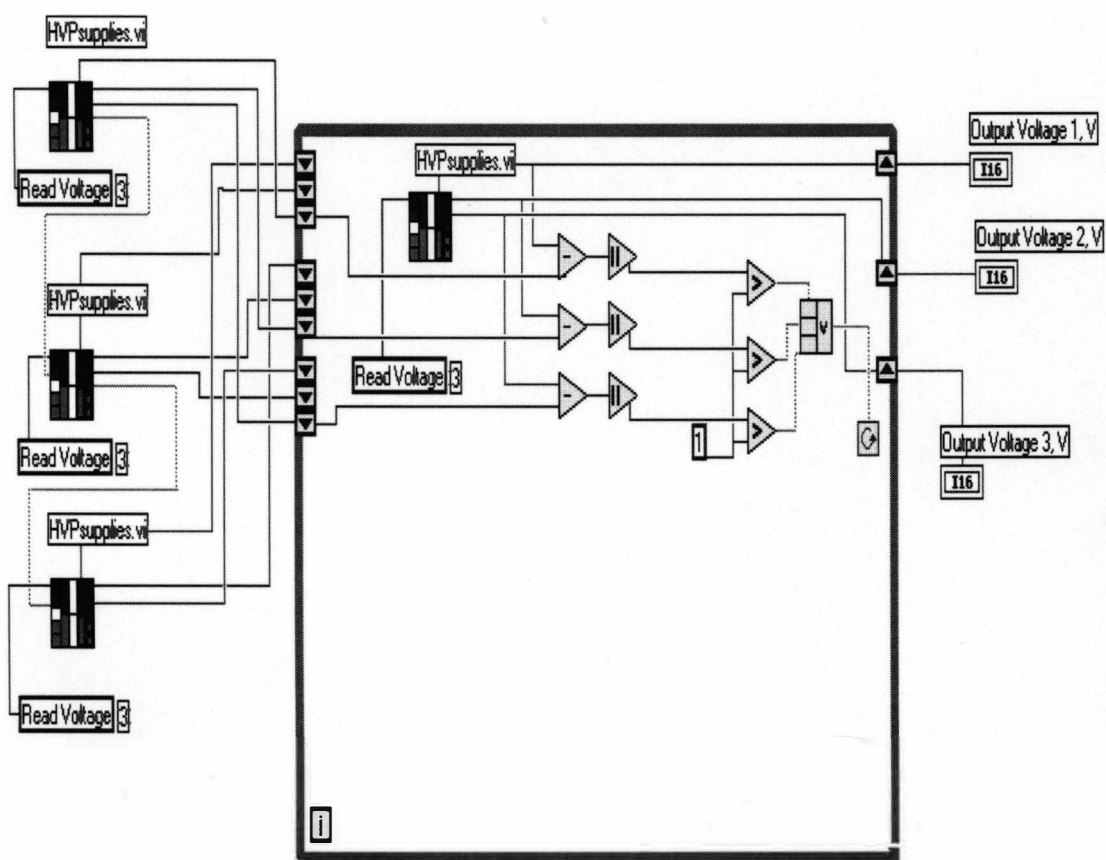

Figure 33.   The WAIT_FOR_VOLTAGES_TO_SETTLE Module.

9. RECORD_RESULTS.VI handles the recording of the results of the experiment into the two log files (laboratory and center of mass coordinates) chosen if logging is on (Figure 34.)
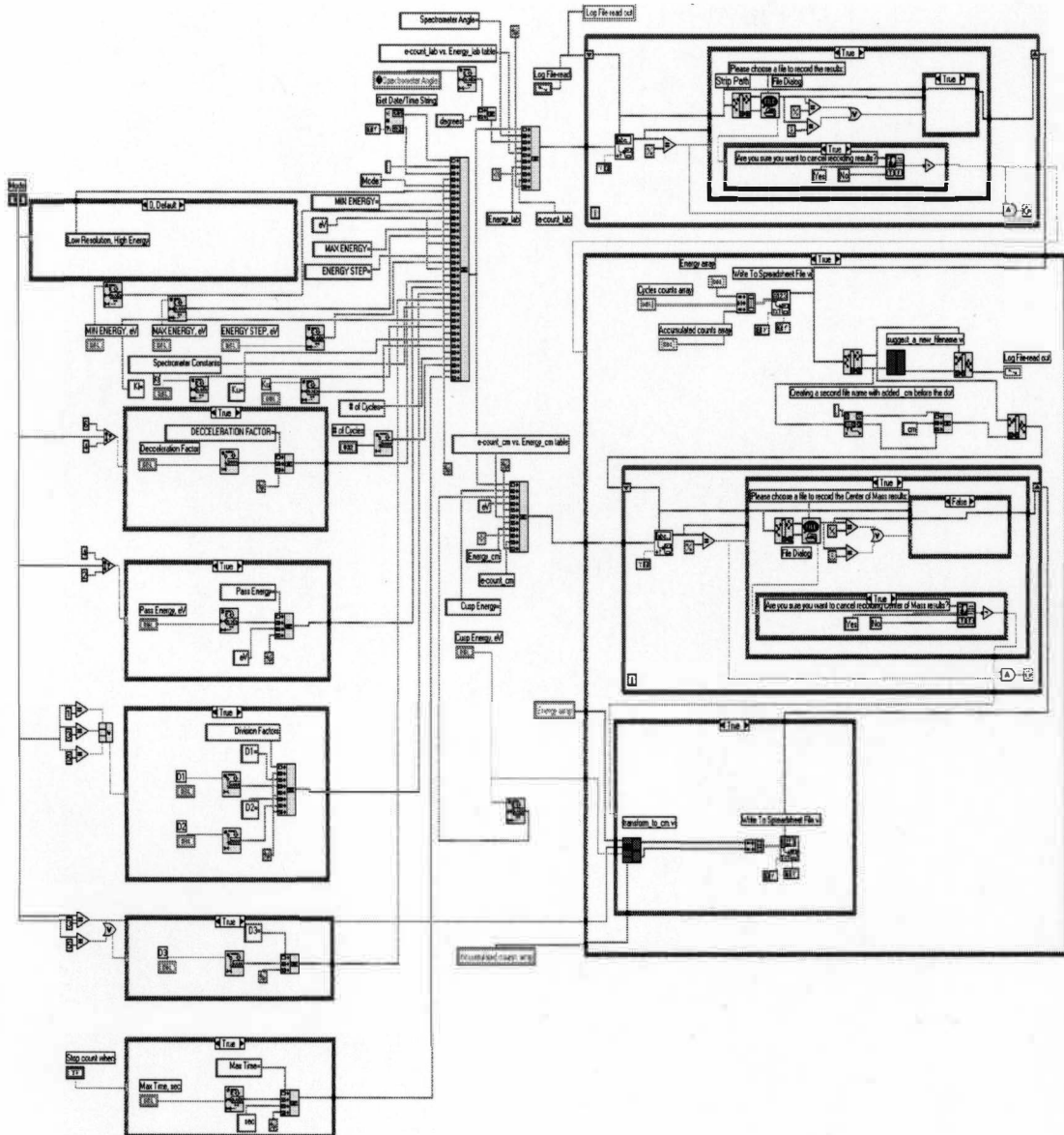

Figure 34.   The RECORD_RESULTS.VI Module.

10. JOERGER_CS_5_INPUT_REGISTER.VI reads the input register to verify the spectrometer angle. Absolute position information is provided, which is interpreted as an angle in the higher level files calling this one (Figure 35.)
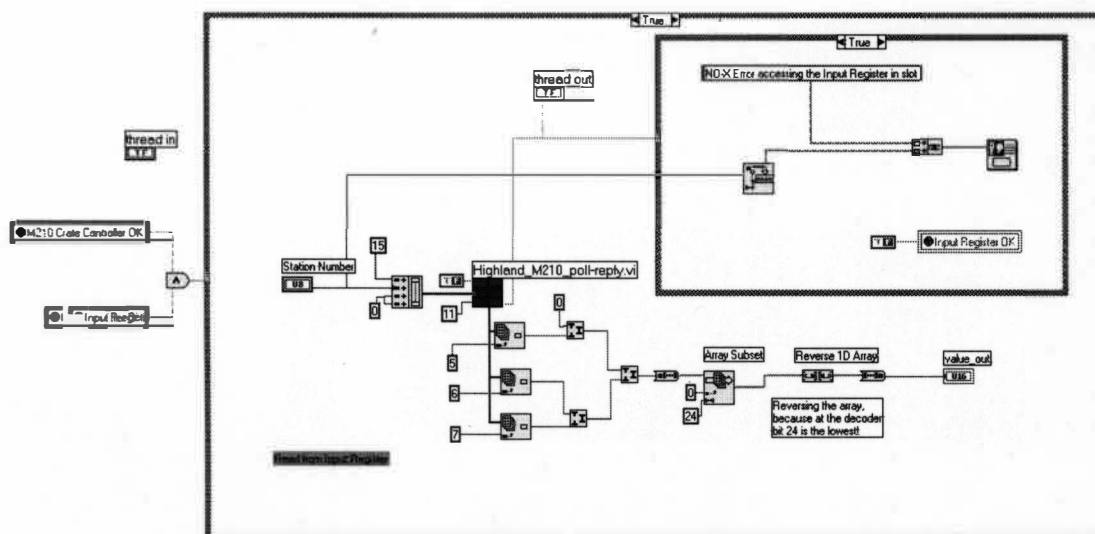

Figure 35. The JOERGER_CS_5_INPUT_REGISTER.VI Module.

11. JOERGER_MOTOR_CONTROLLER.VI controls the stepping motor controller. It allows the user to set the desired angle, and the stepping motor controller then rotates the spectrometer to that angle (Figure 36.)

12. KEITHLEY_197A_DMM.VI reads the three DMMs to give accurate readings of the high voltage power supplies(Figure 37.)

13. KEITHLEY_617_ELECTROMETER.VI allows remote control of the electrometer eliminating the need to enter the target room, where radiation may be present, to change the settings of this instrument (Figure 38.)

Figure 36.   The JOERGER_MOTOR_CONTROLLER.VI Module.
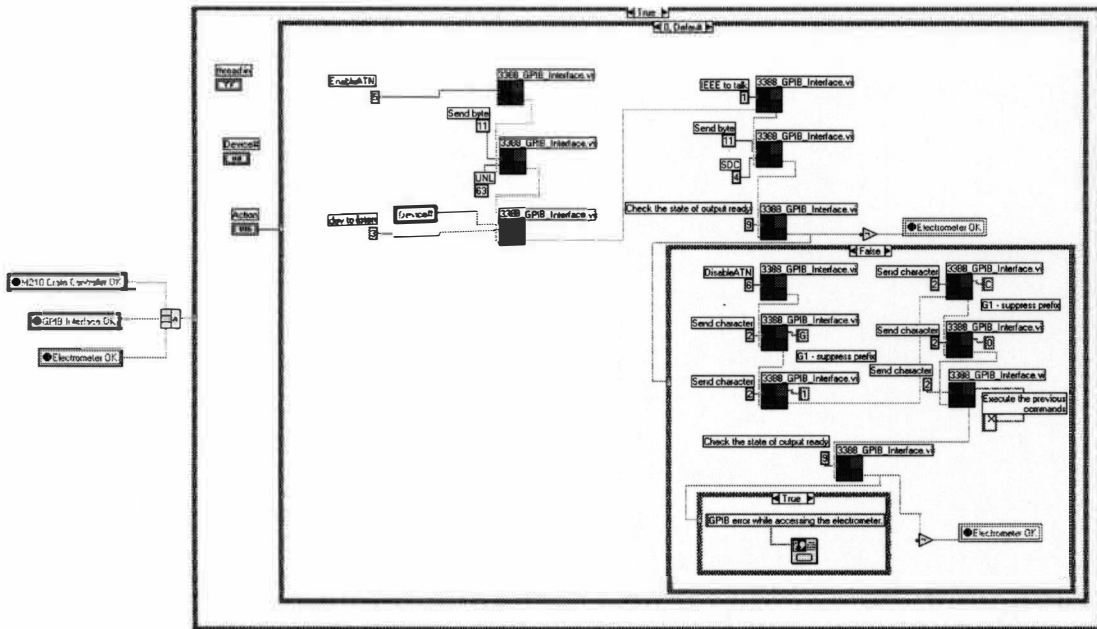

Figure 37.   The KEITHLEY_197A_DMM.VI Module.

Figure 38. The KEITHLEY_617_ELECTROMETER.VI Module.

14. LECROY_2551_SCALER.VI controls the scaler allowing for reading the counts from the individual channels and then resetting the channels to zero (Figure 39.)
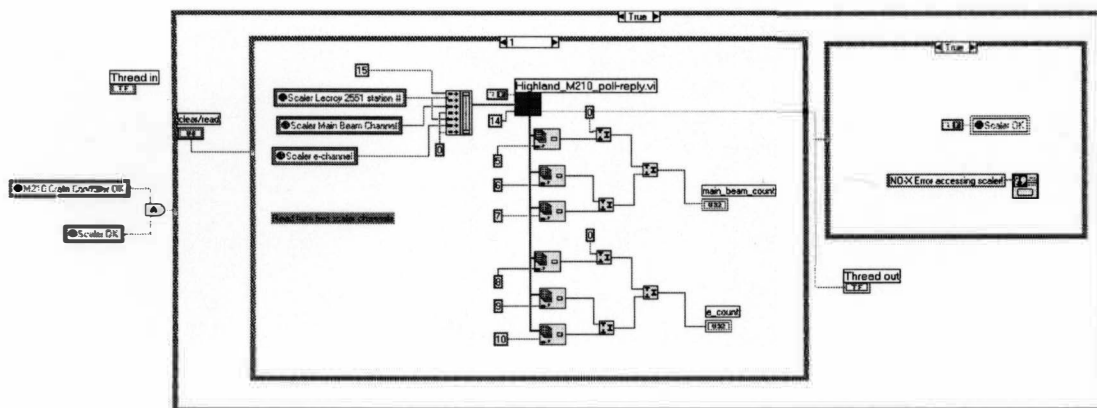

Figure 39. The LECROY_2551_SCALER.VI Module.

15. HVPSUPPLIES.VI controls all three power supplies simultaneously allowing for setting or reading the voltages or currents within one poll-reply cycle of the CAMAC crate controller instead of three.
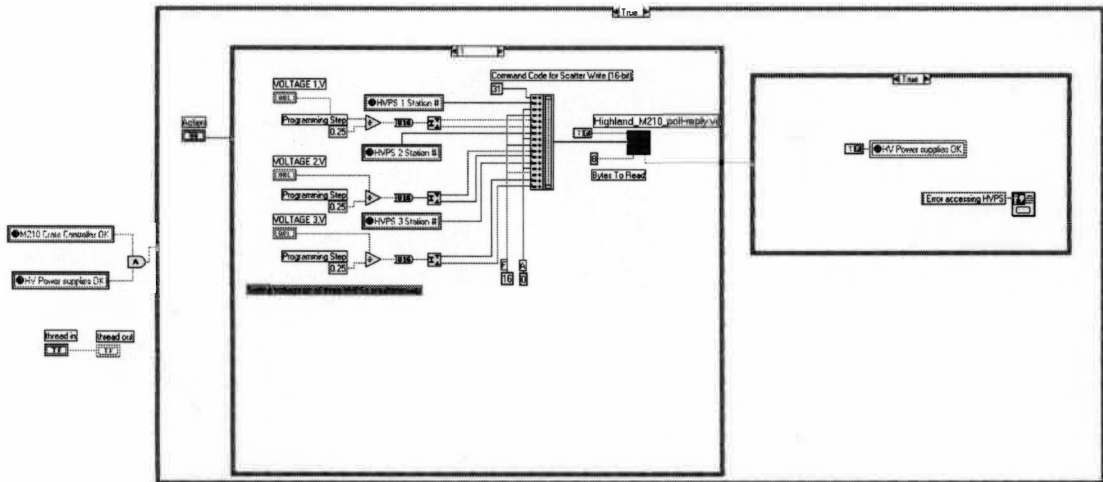

Figure 40.   The HVPSUPPLIES.VI Module.

16. LECROY_2415_HVPS.VI controls a power supply allowing for setting and reading voltages and currents (Figure 41.)

17. TRANSFORM_TO_CM.VI transforms the data from the laboratory system of coordinates to the center of mass system of coordinates (Figure 42.)

18. CALCULATE_ACTUAL_ANGLE.VI calculates the angular position of the spectrometer from its absolute position as reported by the shaft encoder through the input register. First the set position is calculated, as shown in the next diagram, depending on (a) the absolute position itself, (b) the position chosen as the zero position, and (c) the number and direction of the input register counter rollovers from 8191 to 0 or from 0 to 8191 (Figure 43.)
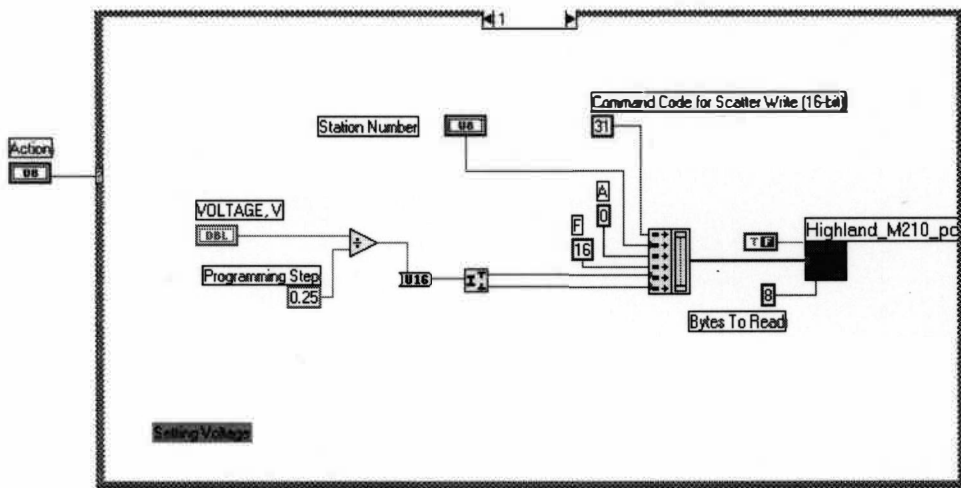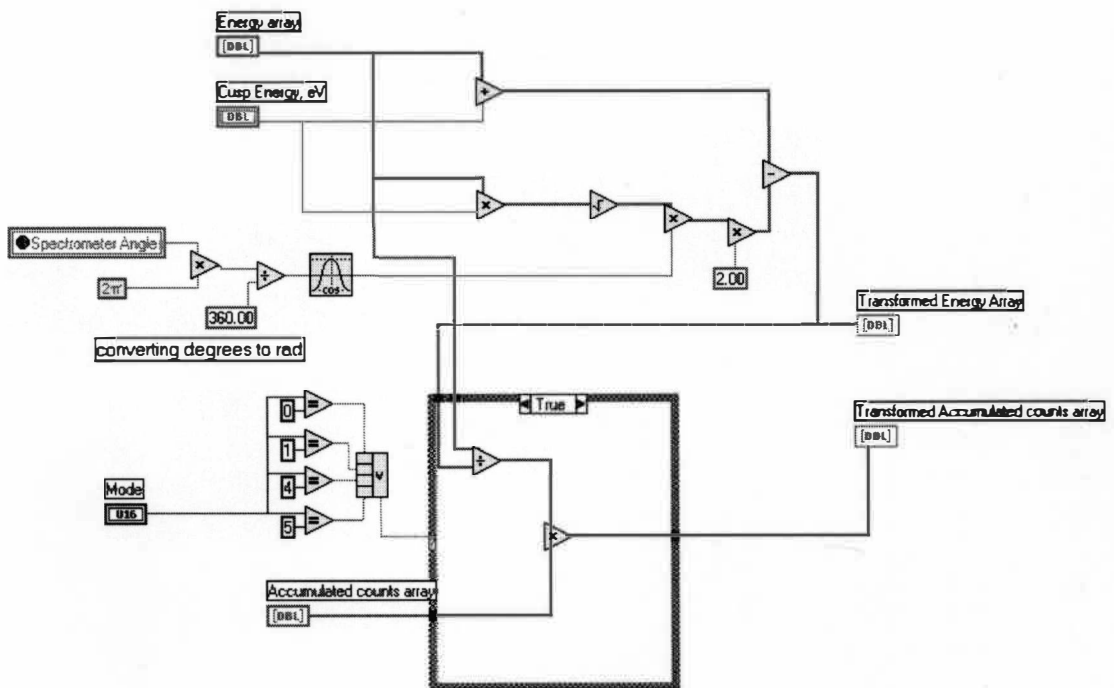
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Figure 41. The LECROY_2415_HVPS.VI Module.

Figure 42. The TRANSFORM_TO_CM.VI Module.

Figure 43.   The CALCULATE_ACTUAL_ANGLE.VI Module, Step 1.
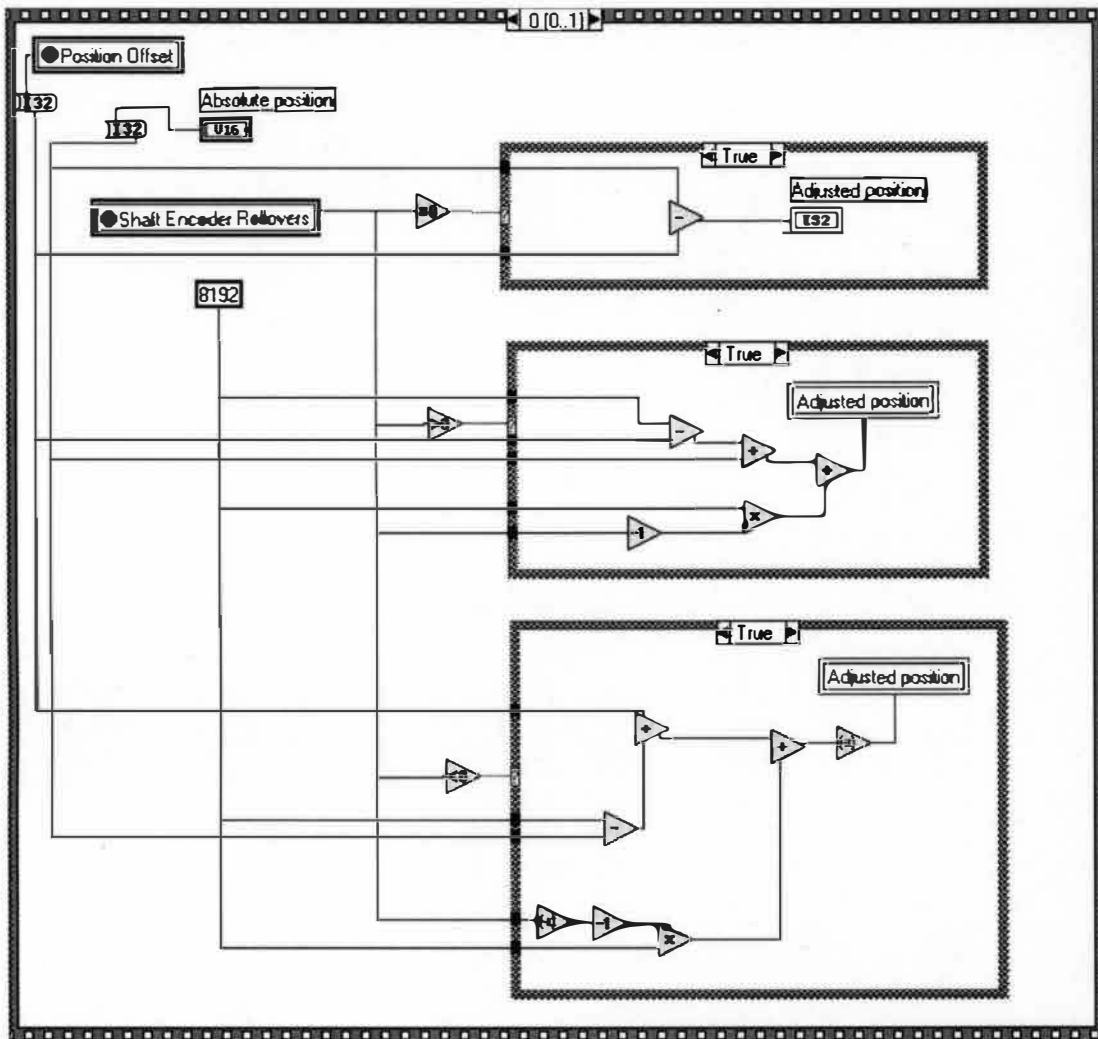
After the set position is known, the angle in degrees can be calculated as shown in Figure 44. One full rotation of the shaft encoder sends 128 counts to the input register. Three full rotations correspond to eight stepping motor rotations, which rotates the spectrometer by 16^0. So, every 16^0 of spectrometer rotation sends 128 x 3 = 384 counts to the input register.
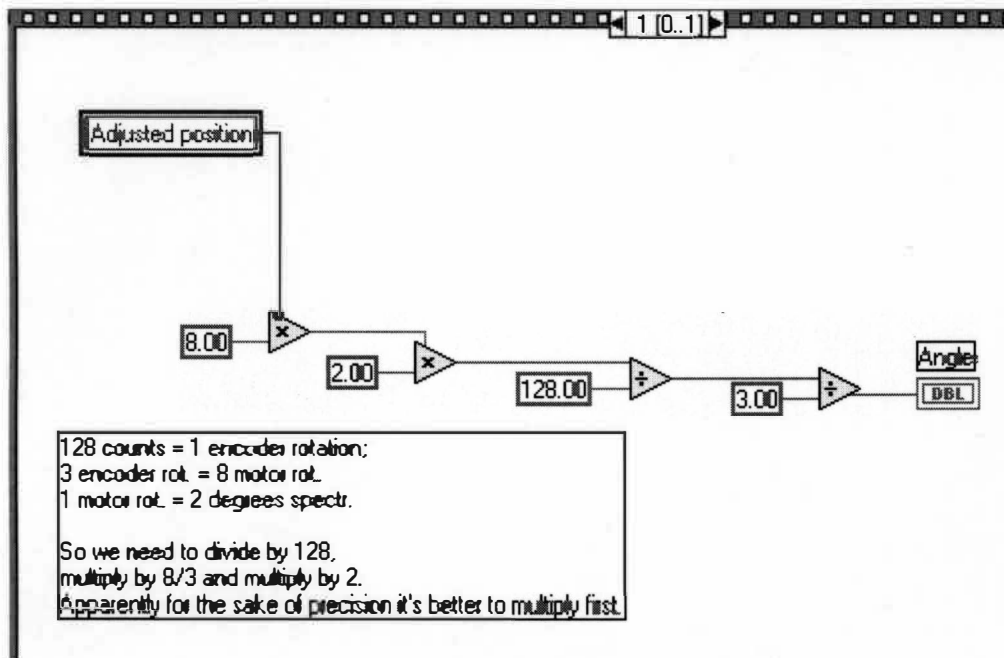
Figure 44.   The CALCULATE_ACTUAL_ANGLE.VI Module, Step 2.

19.   SUGGEST_A_NEW_FILE_NAME.VI   automatically   increments   the
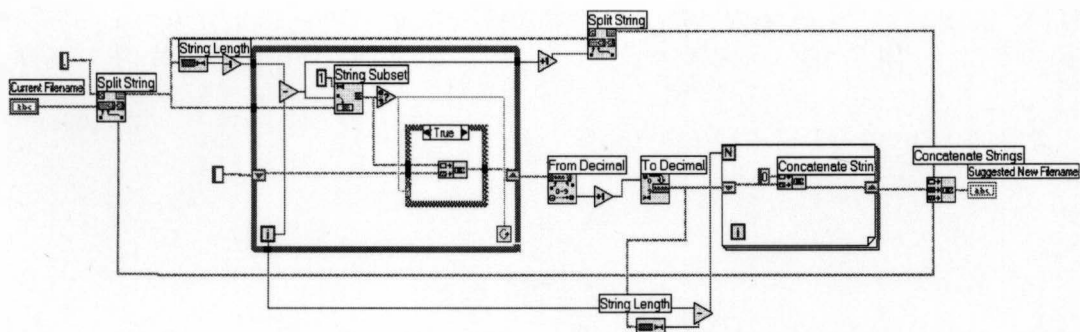number part of the log file name suggesting a new name with the number incremented
by one.

Figure 45.   The SUGGEST_A_NEW_FILE_NAME.VI Module.

20. WRITE CHARACTERS TO FILE.VI is a slightly modified file from the standard LabVIEW package, facilitating writing to text files.

21. 3388_GPIB_INTERFACE.VI provides the means of communication with GPIB devices (the DMMs and the electrometer) by transferring the GPIB commands through the crate controller to the GPIB to CAMAC interface (Figure 46.)
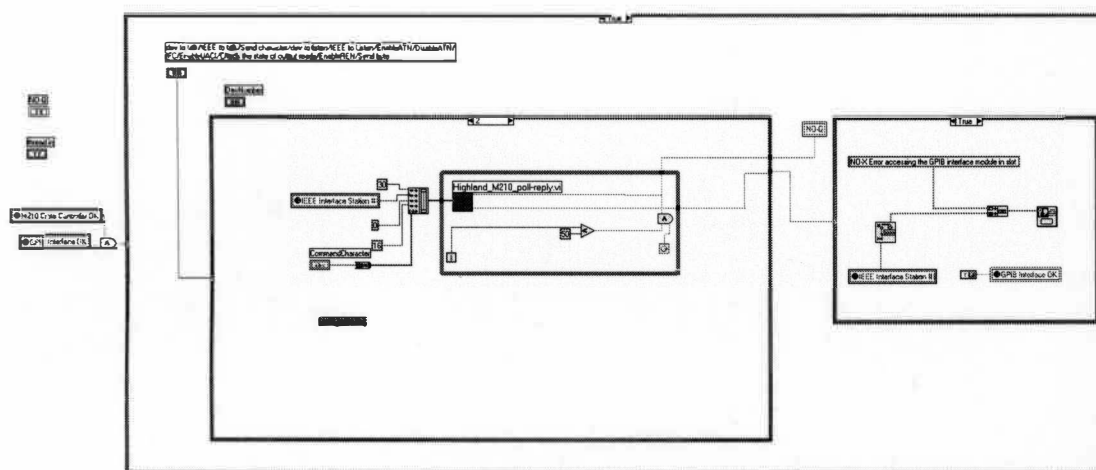
Figure 46.   The 3388_GPIB_INTERFACE.VI Module.

22. HIGHLAND_M210_POLL-REPLY.VI puts an input message, which is in the form of a byte array (byte_string_in), into the specific "envelope" required by the controller to form a poll message; sends the poll message to the controller; and reads the reply from it. Every message has a 4-byte header: (1) MSYN – a 1-byte start-of-message tag (ASCII code 11); (2) BCHI and (3) BCLO – 2 bytes containing the number of bytes (i.e., the byte count) in the message (BCHI is set to be 0 always, assuming there are no messages longer than 255 bytes, and BCLO is calculated as the

sum of the dimension of the input byte array and the number of mandatory "envelope" bytes, which is 7); and (4) ADDRESS – a 1-byte remote address (set to be 1 by the DIP switch S2 on the controller).

Every message has a tail consisting of the following 3 bytes: (1) CRCHI and (2) CRCLO – a 2-byte cyclic redundancy check field (both set to 0, because CRC is not checked); and (3) ETB – a 1-byte end-of-message tag (ASCII code 23). A reply message is returned in the form of a byte array for easier further processing (Figure 47.)
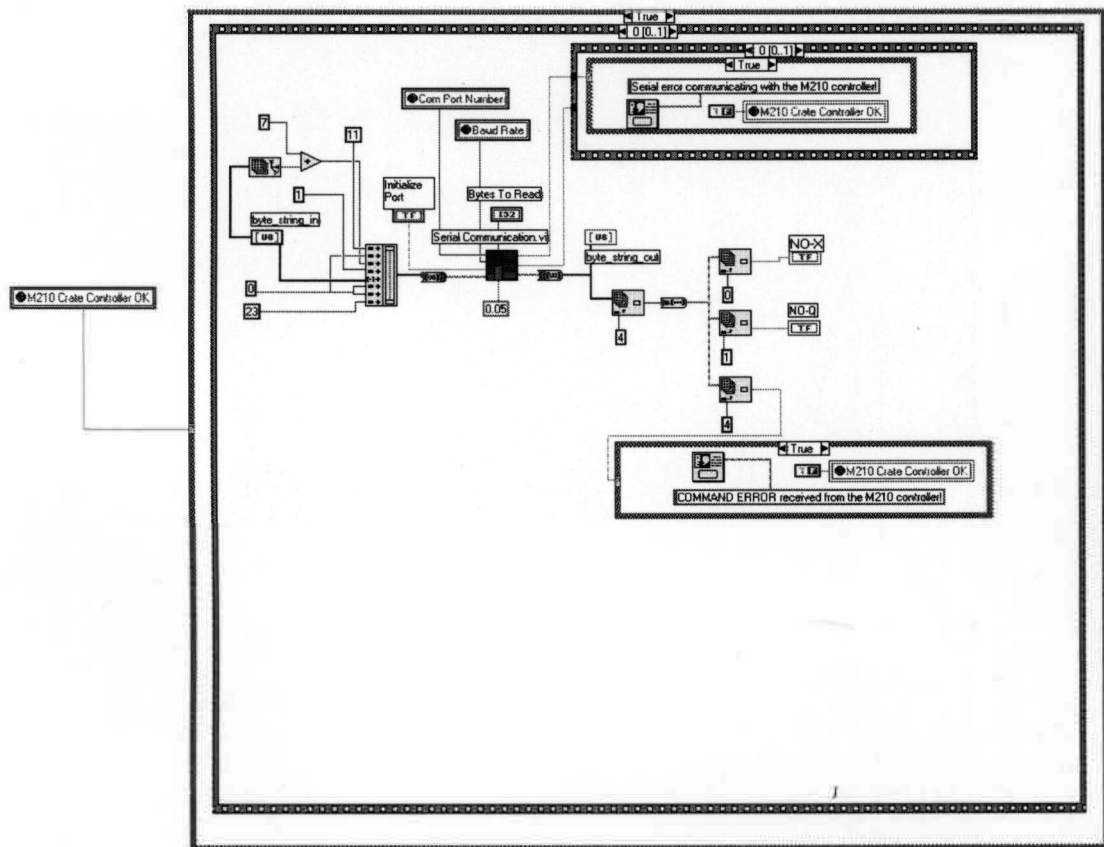

Figure 47.   The HIGHLAND_M210_POLL-REPLY.VI Module.

23.   SERIAL READ WITH TIMEOUT.VI   and   SERIAL COMMUNI-

CATION.VI are slightly modified files from the standard LabVIEW package. They

provide low-level control for communications via the serial ports.

CONCLUSION

A control and data acquisition program has been written to operate an electron spectrometer system, consisting of two 45^0 parallel-plate electrostatic analyzers, a decelerating grid for increasing the resolution, and a channeltron. The electron spectrometer system has proved to be an effective instrument for the detection and energy analysis of continuum electrons. The principles of operation of the spectrometer in different modes have been discussed as well as the equipment and electronics needed to provide experimenters with the tools for spectrometer control and data acquisition. The program checks accessibility of the equipment, collects user input regarding the mode and parameters of the experiment, and then executes the experiment. This is accomplished by programmatically setting and changing the voltages on the spectrometer plates, recording the detected electrons for each set of voltages, normalizing the counts to the beam intensity, and continuously displaying the collected data on graphs. A detailed description of the program has been presented. The program could be further improved by implementing programmatic control of the spectrometer angle and engaging three-dimensional graphing capabilities showing the dependence of electron counts on energy and angle simultaneously.

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