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X-Y Stage Motion Control Software

By

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Abstract

Noble gas mass spectrometer of PRL is equipped with Nd-YAG laser microprobe for analysing nitrogen and noble gases in small grains (usually less than a milligram) of meteorites and rock samples. The gases are extracted by laser heating of the sample. This process necessitates precise control of sample movements, which is normally achieved by a programmable motion controller. The existing programmable motion controller, accessed by its front panel buttons, has several operational limitations in terms of precision, time and convenience. Certain operations e.g. laser rastering of sample (removal of few nanometers of the surface by irradiating it with laser beam for a short duration), are difficult to perform from front panel buttons.

To overcome such operational problems, a window-based motion controlling software has been developed which is capable of controlling general purpose motion as well as application specific motion operations such as sample-grain positioning and rastering of the sample.

Acknowledgements

I am thankful to Prof. S.V.S. Murty, who introduced me to the laser heating technique, which is used in noble gas mass spectrometer laboratory. Efforts put in by Mr. R.R. Mahajan in systematising experimental setup are highly appreciated. He also provided vital information in deciding the software specifications. I am thankful to him. I also thank Mr. H.R. Vaghela of workshop for making necessary drawings and sample plate.

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1. Introduction

In noble gas mass spectrometer laboratory of PRL, isotope ratio and abundance of noble gases and nitrogen are measured in meteorite and rock samples to address various scientific issues such as the evolution of early solar system and the dynamics involved in transport of meteorites from its parent body to earth. The study of rock samples also provides vital information about the evolution of interior and atmosphere of the earth.

Above mentioned gases can be extracted from a solid sample by heating it to progressively increasing temperatures until it melts. Different techniques e.g. radio frequency (RF), resistive and laser heating are common in practice and each has its own merits and demerits. For example, the laser heating is preferable for a small grain analysis, where amount of sample is less than 1 mg. In contrast, RF and resistive heating is used for bulk sample analysis. Presently, all the three heating techniques are being used in the laboratory.

During heating, several other gases are released along with the noble gases. These unwanted gases are removed in a specially designed cleanup and separation system. The purified noble gases are injected into the mass spectrometer, Where concentration and isotopic ratios of the noble gases are measured. This information is useful in estimating several scientific parameters, like trapped gases, amount of cosmic ray produced nuclide and radiogenic gases. These parameters are very important in understanding various scientific objectives relevant to the earth and solar system evolution.

Laser heating necessitates precise control over the movements of the sample. It is normally accomplished by a programmable motion controller. However, the use of motion controller through its front panel keys to perform such application specific operations, e.g. laser rastering and sample-grain positioning, has operational limitations in terms of precision, reproducibility of the operation, time and convenience. (The rastering is in fact a type of scanning in which the material from the sample surface is removed due to degassing on laser heating. Despite this minor difference, the two terms are often used interchangeably. In the present report, the term scanning used hereafter, actually refers to the rastering.) To overcome such drawbacks, a window-based motion controlling software has been developed, which is capable to perform various operations required during laser heating. Basically, this software manoeuvres two platforms, which are mounted one over another and move perpendicular (X and Y direction) to each other. Therefore, it is called X-Y stage motion control software, which is named PMC200-P2.VI.

2. Experimental Setup

Schematic diagram of the laser microprobe setup of noble gas mass spectrometer laboratory is shown in Figure 1. It consists of

2.1. The Laser System
2.2. Sample Chamber

2.3. Motion Control
2.4. CCD Camera and Monitor
2.5. Cleanup and Separation System
2.6. Mass Spectrometer

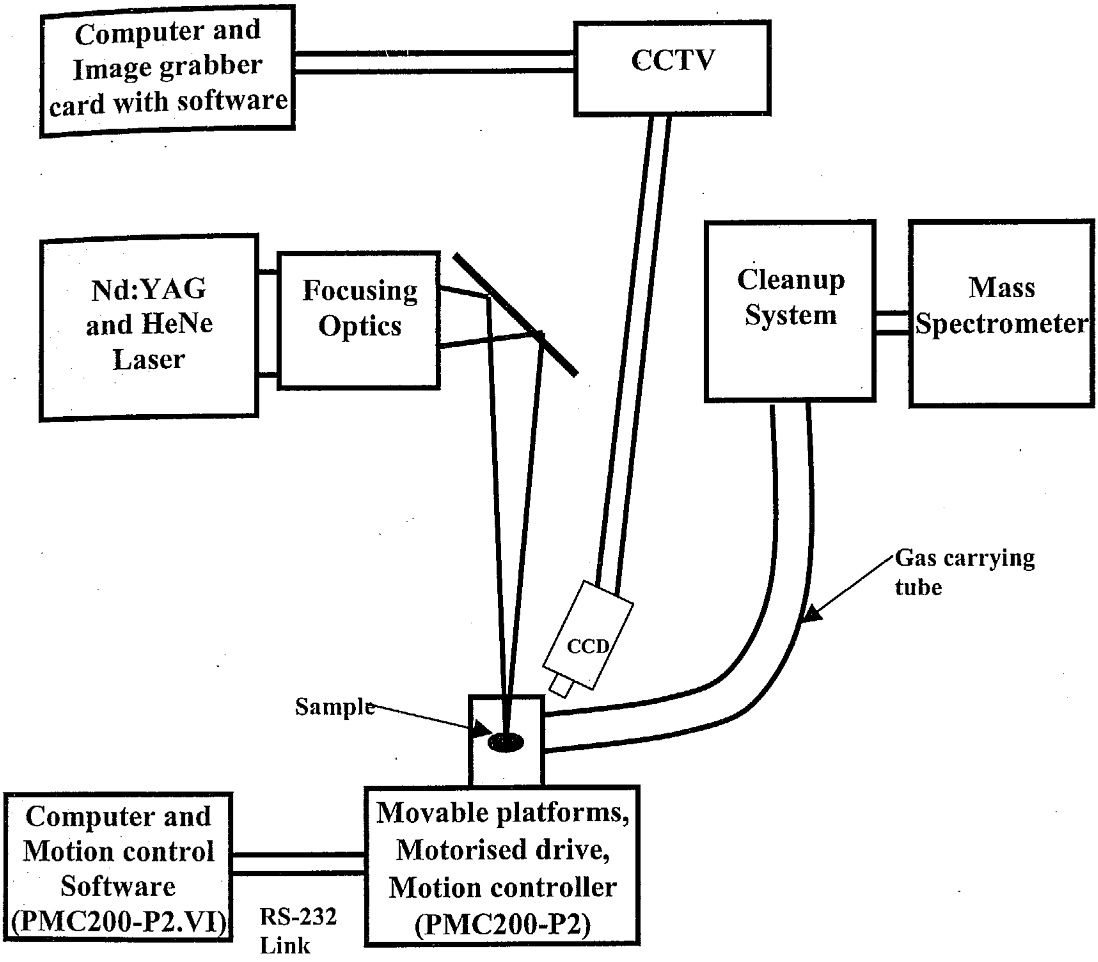


Figure 1. Schematic of the laser microprobe setup.

2.1. The Laser System

The Nd:YAG laser (Model SL900GT, Spectron Laser Systems, U. K.) is used in the laboratory for the heating of the sample. This laser can be operated in continuous wave (CW) as well as pulsed (Q-switched) mode. At the fundamental wavelength (1064 nm) the maximum output of the laser in CW mode is 16 W and the divergence of the output beam is 1.8 mrad. In the pulsed mode the average power is 8 W. The laser can also be operated at 2nd harmonic, and has an average output power of 3 W at 532 nm, operated in the pulsed mode. The pulse width of the Q-switched laser output is 120 ns. The operation of laser in the CW mode is useful in heating a grain uniformly, while in the pulsed mode operation it can be used to selectively melt a part of the sample.

Different mineral grains have different absorption properties for light radiation, some absorb light in the visible range while others in IR range. The laser used have outputs both in IR (fundamental, 1064 nm) and visible (532 nm, second harmonic generation) region. For those mineral grains, which do not absorb light in either range, the laser may be operated in the Q-switch mode to dump large power in a single shot to heat / melt such mineral grains.

Along with Nd:YAG laser beam, a He-Ne laser is integrated on the main laser assembly such that its output followed the same path as that of the Nd:YAG laser beam. The He-Ne laser serves four purposes:

- Focusing of the main laser beam at the sample.
- Alignment of the optical components of the focussing optics.
- Calibration of motion controller software (discussed in section 4) for sample-grain position detection.
- Verification of the laser-scan path.

Because the lasing output of the main laser at both 1064 nm (invisible) and 532 nm (green) has high output power, they are not useful for adjusting the sample under the focusing spot, as this process can preheat the sample and gases may be lost from it. Since the output power of the He-Ne laser is only 2 mW and its wavelength (632.8 nm) is in the visible (red) region, it is useful both for adjustment of the sample as well as optical alignment of the different components of the laser system, some of which have to be changed for varying the laser output from fundamental to second harmonic. The output of the He-Ne laser is directed through two mirrors in such a way that it travels the same path as followed by both the fundamental and second harmonic outputs of the main laser. A telescope is used for collimating the laser beam. Collimation is essential for getting parallel size of output laser beam. The laser beam is then focussed by a lens to a small spot.

Before using a sample-grain positioning mode of the software (described in section 4.4.2), the co-ordinates of two reference points A and B, marked on the sample plate are to be registered in the software. It is done by bringing these two points at laser focusing point and executing appropriate software commands. During the registration process, sample-grains loaded in the sample plate may be exposed to laser beam and liberate the gases if the laser power is high. To avoid such unwanted heating of the sample-grains, the He-Ne laser is used instead of Nd:YAG for the registration of reference points.

In scan mode (described in section 4.4.3), user provides scan parameters like start and end point, velocity and incremental value to the software. Software calculates the scan path using these parameters. However, it is advisable to verify this path before the actual scanning is performed using Nd:YAG laser. This is normally accomplished by running a dummy scan sequence with He-Ne laser kept on. As the power of this laser is low, it does not heat the area, which is to be scanned and hence, keeps its trapped gases intact.

2.2. Sample Chamber

The stainless steel (SS) chamber comprises of three parts namely top flanged, middle section and bottom flange (Figure 2). The top flange is fitted with optical (quartz)

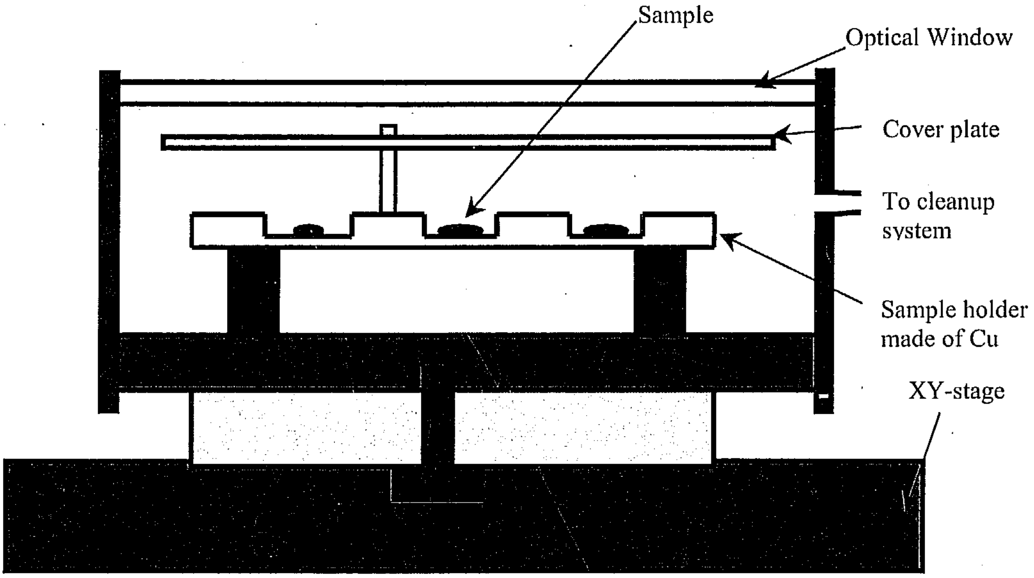


Figure 2. Schematic of the sample chamber. The quartz cover plate is mounted on a nickel frame to enable its positioning through rotation, using an external magnet. This facilitates covering of the sample (and its surrounding region) under laser irradiation and prevents vapour deposition on the main quartz window.

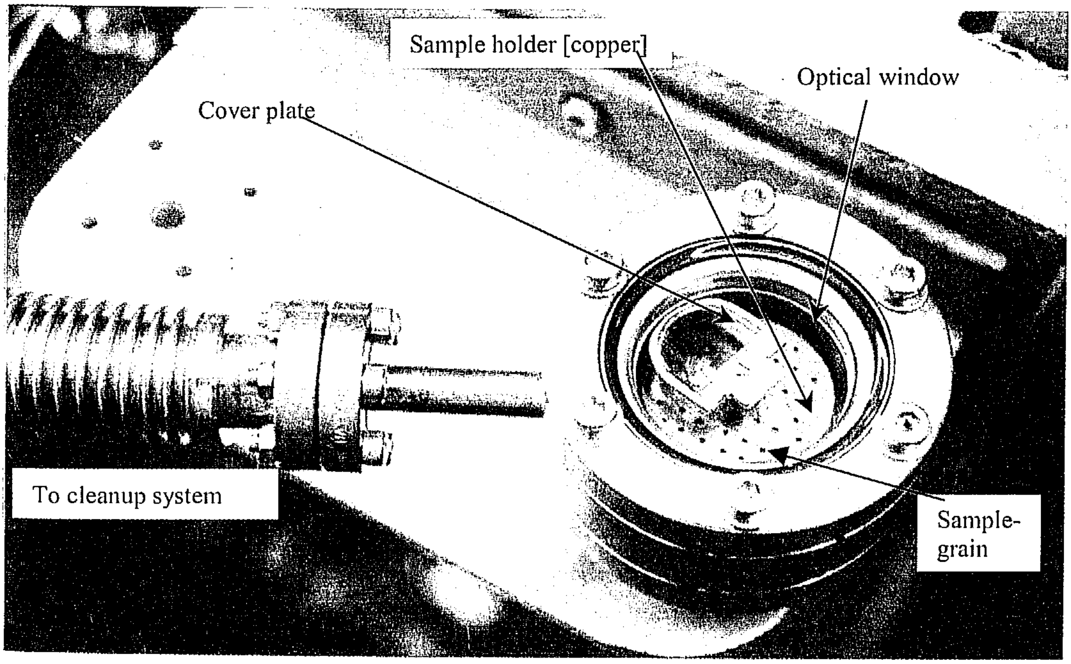


Figure 3. Sample chamber. The blind holes in the copper plate, where sample-grains are placed and the cover glass preventing sample vapour to reach to the quartz window can be clearly seen.

window that allows both 1064 and 532 nm radiation to pass through it with minimum attenuation. A double-sided flange forms the middle section of the chamber, which is connected to the cleanup system through a flexible stainless steel tube. The bottom flange is used to mount the sample plate.

An additional quartz cover plate, fitted on a nickel holder, is also mounted inside the sample chamber (Figure 3). The nickel holder is movable in a circular way using an external magnet. During the laser irradiation of sample, the nickel holder is appropriately moved such that the region around the sample is covered by the quartz plate. This prevents deposition of material, vaporised from the sample during laser irradiation on the main quartz window, without any loss of laser power during transmission, prolonging its (quartz window) use. The sample plate is made of 3mm thick copper. Since it is a good conductor of heat and suppresses background gases that may result from localised heating. Different sizes of blind pinholes are punched on the sample plate for lodging the samples (individual grains). The sample chamber has been fixed on a platform, which in turn is fixed on the XY stage.

2.3. Motion Control

Motion control section consists of the following components.

- Moveable platforms
- Motorised drive
- Programmable motion controller
- Motion control software

Movable Platforms. There are two platforms (for X and Y movement, called XY stage), mounted one over another (Figure. 4). They move in the axial slots with their direction of motion perpendicular to each other and in the planes, which are parallel to each other. Sample chamber is fixed on the upper platform.

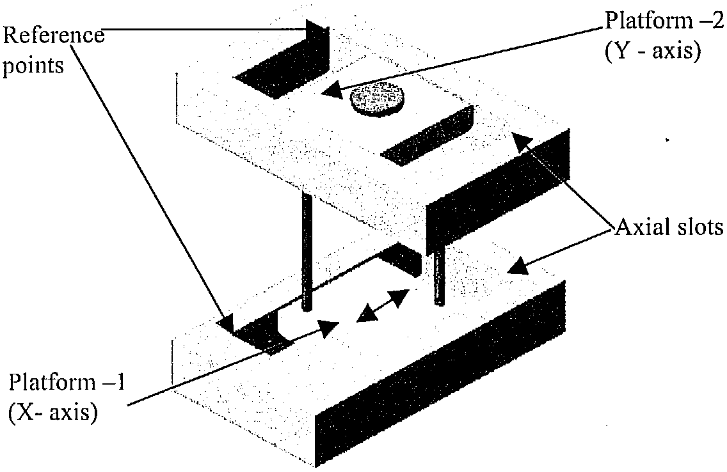


Figure 4. Schematic of platform assembly.

Motorised Drive (Actuator). The two movable platforms are pushed back and forth by the non-rotating tip of motorised drive. This drive is powered and driven by the programmable motion controller. This type of drive (Figure 5) has a DC brushed servomotor for quiet and smooth operation. When used with programmable motion controller it provides µ-scale motion control over long distance. It has integral magnetic encoder, which provides 0.1 µm resolution. Encoder's output is useful in finding out platform displacement with high accuracy. Non-rotating tip eliminates torque on motion reversal.

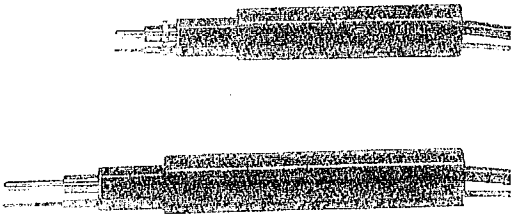


Figure 5. Motorised drives (850 series) with non-rotating tip of different lengths.

- Specifications

- Speed range	40 to 500 µm /sec continuously variable
- Accuracy	0.2% of travel
- Minimum incremental motion	0.5 µm
- Maximum axial load	10kg
- Temperature range	68 ± 15 F
- Tip length	From 13 to 102 mm range
- Magnetic encoder	Dual output, 90 phase, +5, -0.5 V, 1800Hz maximum

PMC200-P2, A Programmable Motion Controller. PMC200-P2 is a Newport make, two-axis programmable motion controller powered by 16-bit Motorola 68000 microprocessor to manage system operations and communications (Figure 6). It is useful in micron-scale laboratory positioning application and designed to drive Newport 850 series motorised drive (linear actuator). Each axis has its own state-of-the-art H-P HCTL-110 dedicated motion control microprocessor and performs all the position and velocity control. It allows two axes of motion to be controlled and actuated simultaneously. This is a digital control system so analogue compensation and velocity feedback are not necessary. Velocities are regulated via advanced digital servos, which compensate for changing loads and never need adjustment. The controller also features motor protection, continuous motion, tracking and automatic stall and limit detection. Real-time velocity and position are continuously monitored and displayed on fluorescent display. The axes are setup and controlled in menu driven environment and parameters are stored in battery backed up memory.

For manual operation it has got front panel motion controls for velocity, continuos run and displacement. An interactive vacuum fluorescent display and status LEDs facilitate the easy operations.

For better motion control, the PMC200-P2 is equipped with RS-232 and IEEE-488 (GPIB) connectivity, which facilitates the computer interfacing. A powerful set of general-purpose and device specific instructions are embedded inside. When connected to the PC and controlled by application specific software, it becomes powerful and versatile instrument, which can handle many critical and application specific motion operations with high precision. In addition, a dynamic status and error reporting system accessible by the software, provides vital information about the status of motion. The block diagram of PMC200-P2 is shown in Figure 7.

- Specifications

- Number of axis	2
- CPU	16-bit Motorola 68000 @ 10 MHz
- Motion processor	HCTL-1100/ axis @ 2 MHz
- Limit sensing	Automatic stall/limit detection via encoder monitoring
- Power requirements	100-265VAC, 100W
- Power supply type	Switching regulator
- Interface	GPIB, RS-232, Joystick

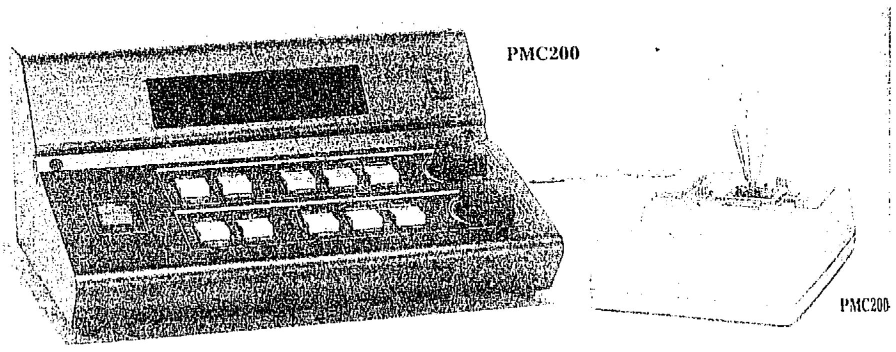


Figure 6. Programmable motion controller, Model PMC200-P2, Newport

- PMC200-P2 Setup Menu

- JOG step size	0 – 100.000 mm
- Display unit	mm
- Actuator direction	Forward = out
- Display scale factor	1.000
- Preset display	0.0000
- Backlash	0.0000
- Audio alarm	Enabled
- Actuator type	850 B
- Joystick	Disabled
- RS-232	Enabled
	Flow control =XON/XOFF
	Baud rate = 19200 bps
	Parity = None
	Data bits = 8
	Stop bit/s = 1
- Input echo mode	off
- IEEE –488	Disabled

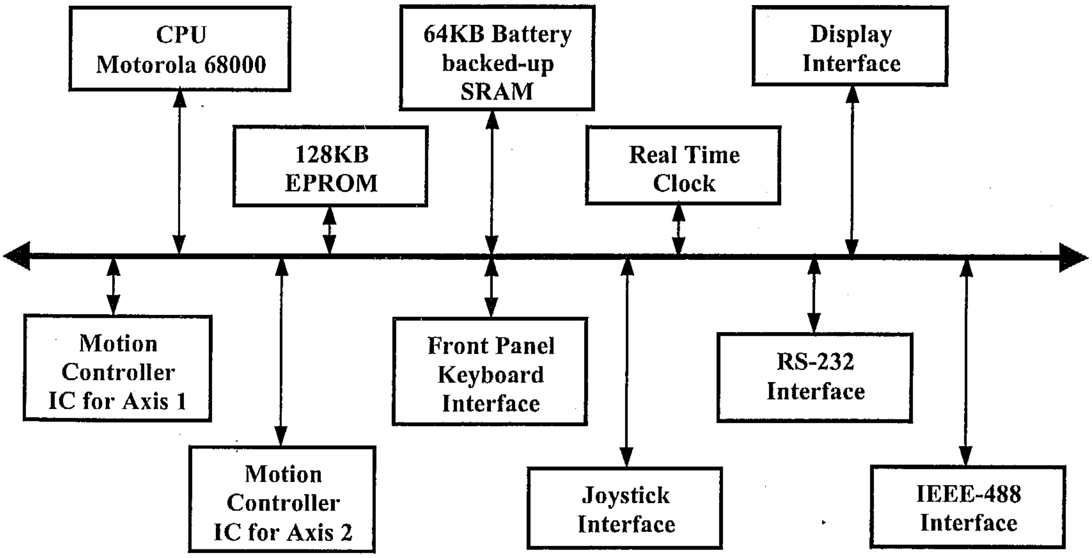


Figure 7. Block diagram of PMC200-P2 motion controller.

Motion Control Software. Programmable motion controller is commanded by the motion control software (named PMC200-P2.VI) to manoeuvre the platforms for variety of operations like sample-grain positioning, scanning etc. The details of this software are described in section 4.

2.4. CCD Camera and Monitor

Online monitoring of sample for recording the processes before, during and after the laser irradiation is necessary. This is done by using a monochrome CCD camera coupled to a zoom lens (Leica monozoom 7) for imaging and observing the sample using a CCTV and a PC that serves the purpose for online monitoring as well as image grabbing. In addition, these are also useful in monitoring the sample movements required between two consecutive laser heating.

2.5. Cleanup and Separation System

Several undesirable gases are liberated along with noble gases and nitrogen from the sample on heating and they are removed before introducing noble gases and/or nitrogen to mass spectrometer for measurement. This is essential to get reliable signal, without any artefact of unwanted gases. For this purpose TiZr getter is used, which removes undesirable gases by physorption and/or chemisorption process.

At the end of clean-up operation, the noble gas fraction is clean enough and is ready for separation into Ar, Kr and Xe fractions. The separation is achieved by differential adsorption on charcoal at different temperatures, wherein only one gas species from a mixture of gases can be selectively adsorbed.

2.6. Mass Spectrometer

Purified noble and nitrogen gases from cleanup system are introduced into the mass spectrometer, where they are positively ionised by electron emitting filament. These ionised molecules are accelerated by applying high voltage (negative) and passed through the pair of magnets, where they deflect by certain angle depending upon its mass to charge (M/Q) ratio. These deflected molecules are collected on faraday cup at the far side of flight tube and fed to the electron multiplier tube for amplification. Different isotopes have different mass to charge ratios and hence different angle of deflection, which separates them from each other. The resultant ion current for individual isotopic molecular species is proportional to its abundance. This is how the abundance of each isotope is measured in mass spectrometer.

3. Significance of motion control software

Normally three different modes (normal, scan and pulse) of operation are employed for laser heating.

Normal Mode

In this mode of operation, the laser spot is focused (or defocused) in such a way that the spot area equals the size of the sample-grain. However, the defocusing reduces the actual power applied to the sample-grain. To compensate this loss of power, the duration of exposure is increased.

In this mode of laser heating, about 25 individual grains are placed in a copper sample plate in different blind holes as shown in Figure 8.

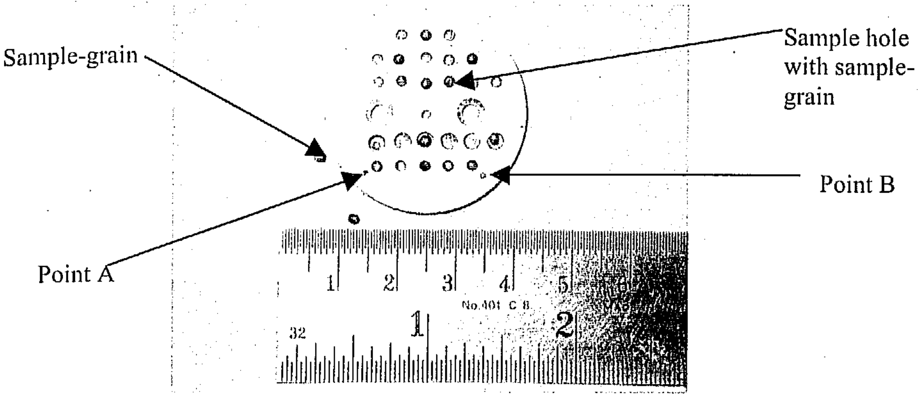


Figure 8. Sample plate with a few sample-grains placed inside the holes.

The sample plate is fixed in the sample chamber, which is kept at ultra high vacuum and mounted tightly (to prevent any undesired movement) on the surface of movable platform. A flexible stainless steel flow tube is connected to this chamber to carry liberated gases to the cleanup and separation system and finally to the mass spectrometer for analysis. Laser beam is directed on the sample-grain from the top of the sample chamber.

Practically, it is not possible to move the laser beam spot at different sample-grain locations, because of fine optical alignments of different optical components. Slight misalignment of laser will heat undesired sample-grain. Therefore, the laser is focused at one point and the platforms are appropriately moved to get the sample-grain under the laser spot.

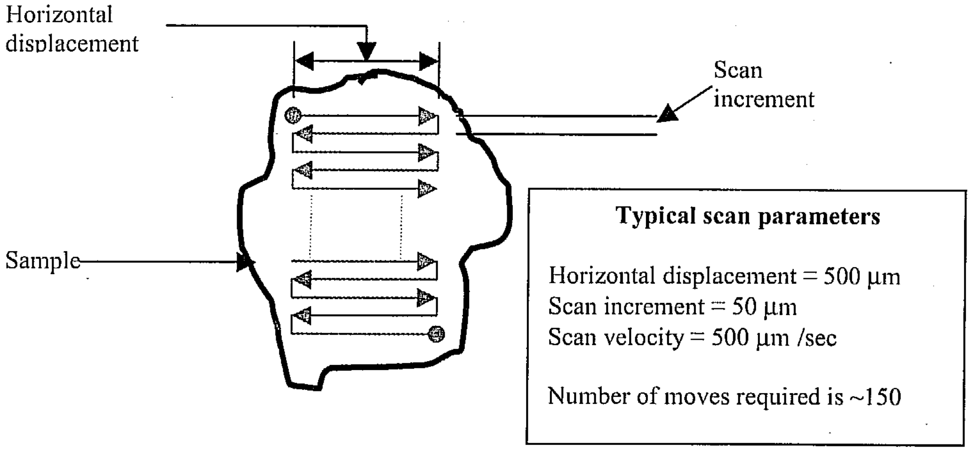
Generally, the average distance between the two sample-grain holes is of the order of few millimetres. Accurate positioning of the desired sample-grain is essential so that adjacent sample-grains do not get exposed to laser while the targeted grain is being melted.

During experiment, frequent movements of platforms are required to position the specific sample-grain at laser focusing point. This can be done manually, by trial and error using front panel controls of attached motion controller and viewing the motion on video screen, which is monitored by CCD camera. However, this method is time consuming and requires lots of effort. These drawbacks can be overcome by driving the motion controller with specially designed software, which is having ability to generate necessary motion. The computer software calculates the relative positions of each sample-grain and accordingly moves the platform to get the desired sample-grain at laser focusing point, at a click of a button. Thus, the motion can be programmed and the desired sample-grain can be moved under laser spot with least efforts, less time and high accuracy.

Scan mode

Scanning is useful for two different purposes. First, the gases coming out from the surficial layers during scanning can be studied to learn about the gases implanted to shallow depths on grain surfaces (e.g. solar wind implantation into lunar and meteoritic grains). Second, contamination can be avoided by removing the top layers of the sample before studying the composition of the gases in the sample.

In this mode of operation, the piece of a sample is kept into the sample chamber and the surface of the sample is scanned by moving the sample across the highly focused laser beam (spot diameter of about 50 µm) with desired speed. Two platforms are moved back and forth to scan the desired area as shown in Figure 9. Many a times, more than 100 such movements with small scan-incremental value of the order of 50 µm are required.



Typical scan parameters

Horizontal displacement = 500 µm
Scan increment = 50 µm
Scan velocity = 500 µm /sec

Number of moves required is ~150

Figure 9. Schematic of a typical sample and scan path (marked in red colour).

This requirement of precise movement of sample for scanning can not be achieved only by the use of front panel buttons of motion controller. Again the reason is same, it is tedious, time consuming, less precise, impractical in terms of reproducibility and does require lots of effort. All these shortcomings can be overcome by the programmable motion controller connected to the PC and controlled by specially designed motion control software. This software accepts scan parameters from user, calculates the scan path and instructs the motion controller for the required sequence of movements.

Pulse mode

At times, it is difficult to rupture a piece of sample into several grains for analysis. Therefore, it is required to analyse different sections of such sample separately without breaking it. If the technique mentioned in normal mode is used for the heating of a specific section of the sample, then the sections adjacent to the targeted section are unnecessarily heated as the laser is kept on for a relatively long time. As a result, these sections liberate some gases. This is not desirable, as the pristine signature is lost. To overcome this drawback the third method, referred to as pulse mode, is used in which the laser beam is focused as per the requirement and short duration laser pulses are applied to the desired sample area. In this case, the adjacent sections are not heated for a long duration and hence, their original signature is preserved.

In this mode, the sample is moved in such a way so that the specific area of sample comes below the laser spot. However, the shape and size of such area is not predetermined or fixed, the required movement is achieved by trial and error method. For this, the platforms are to be manoeuvred arbitrarily but with high accuracy. Software based general-purpose motion controls like velocity, continuos motion and displacement are very useful for such operations.

In order to achieve the precision of sample movements for laser heating with least effort and time, the motion control software is essential. For this, the application software, named PMC200-P2.VI is developed using LabVIEW (described in section 4.3), which is capable to perform all the required functions.

4. Motion Control Software (PMC200-P2.VI)

4.1. Overview

It is clear from the previous discussion that a specially designed software with following capabilities is necessary for the precise movement of the sample during laser heating.

- Sample-grain positioning at laser focusing point.
- Appropriate movements of platforms for the scanning of the sample.
- General-purpose motion controls (like continuous move, fixed displacement, and velocity adjustments) for arbitrary movements.

To achieve this functionality, a window-based software program is developed using National Instrument's instrument and control software (LabVIEW). The program is named PMC200-P2.VI and is capable to perform required tasks. In addition, it also features the following.

- User friendly environment
- Graphical representation of platform's movement (continuously monitored)
- Platform's position storage facility (on PC hard disk)
- Alert and Error reporting services
- Query mode to get the information about motion-related parameters.

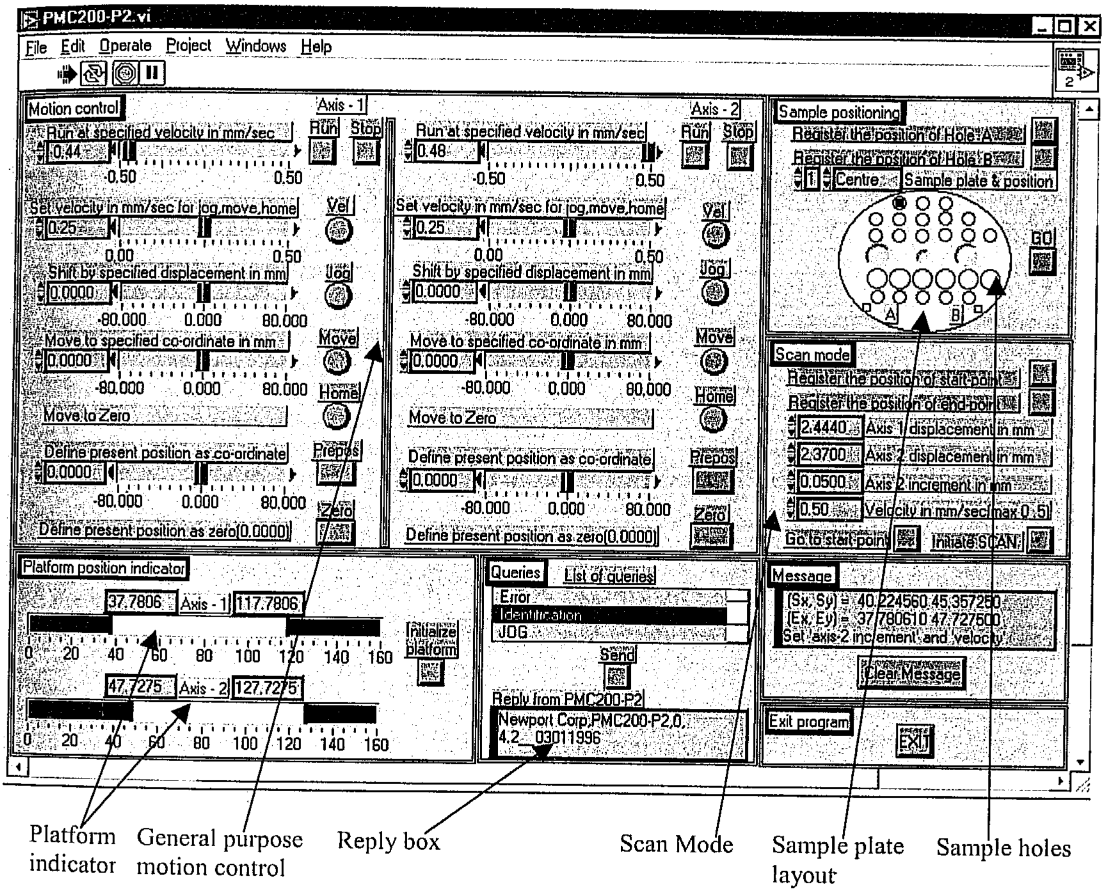
At a click of the front panel button of software, a corresponding code is generated, which is then transmitted to the motion controller over RS-232 link. The controller interprets this code and initiates appropriate motions.

The front panel of PMC200-P2.VI motion control software is shown in Figure 10.

4.2. Hardware and Software Requirements

For the successful operation of PMC200-P2.VI program, a personal computer (PC) with following minimum specifications is required.

- Pentium –I , 100Mhz, 32 MB RAM or higher configuration
- Serial port (RS-232)
- Windows-95/98/Me operating system
- National instrument's LabVIEW 5.0 software



Axis - 1: Run at specified velocity in mm/sec 0.44; Set velocity in mm/sec for jog,move,home 0.25; Shift by specified displacement in mm 0.0000; Move to specified co-ordinate in mm 0.0000; Define present position as co-ordinate 0.0000

Axis - 2: Run at specified velocity in mm/sec 0.48; Set velocity in mm/sec for jog,move,home 0.25; Shift by specified displacement in mm 0.0000; Move to specified co-ordinate in mm 0.0000; Define present position as co-ordinate 0.0000

Sample plate & position: 1 Centre

2.4440 Axis 1 displacement in mm
2.3700 Axis 2 displacement in mm
0.0500 Axis 2 increment in mm
0.50 Velocity in mm/sec(max 0.5)

Platform position indicator: 37.7806 Axis - 1 117.7806; 47.7275 Axis - 2 127.7275

Reply from PMC200-P2:
Newport Corp,PMC200-P2,0,
4.2 03011996

Message:
(Sx, Sy) = 40.224560 45.357250
(Ex, Ey) = 37.780610 47.727500
Set 'axis-2 increment' and 'velocity'

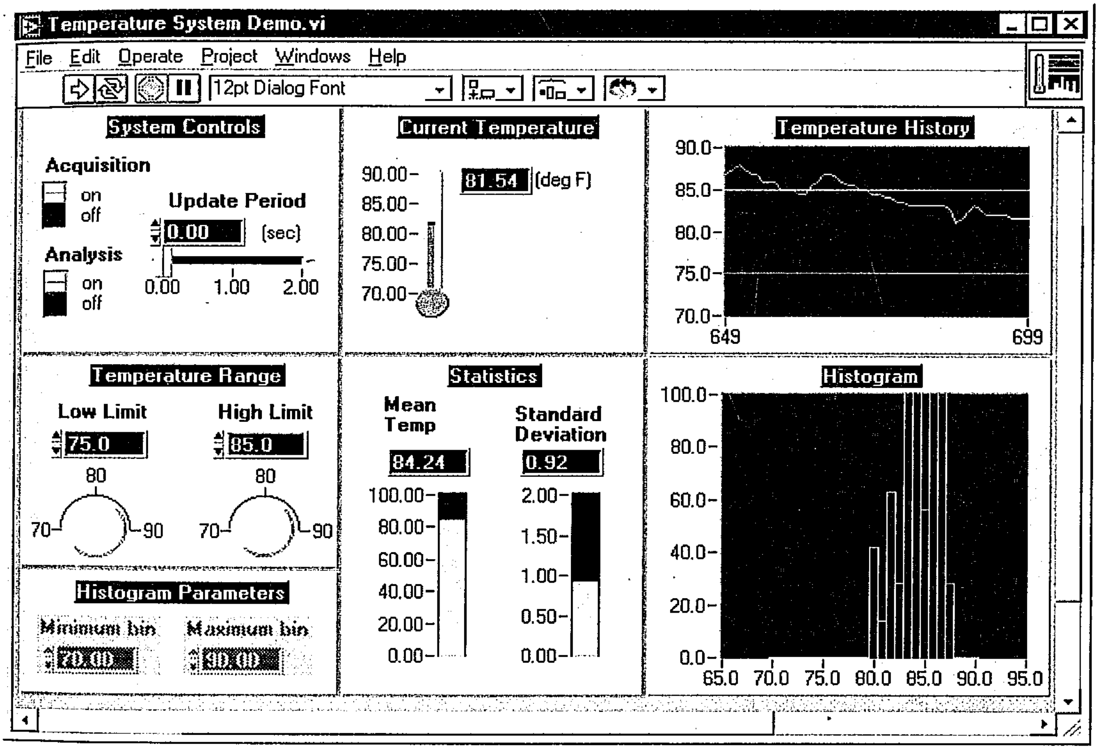
Figure 10. Front panel of PMC200-P2.VI software. Various controls, indicators and buttons are provided to manoeuvre the platforms.

4.3. Lights on LabVIEW Software

Motion control program (PMC200-P2.VI) is developed using National Instrument's LabVIEW software. LabVIEW is a program development application, much like C or BASIC. It is different from other languages in one important respect. Other programming systems use text-based languages to create lines of code, while LabVIEW uses a graphical programming language, G, to create programs in block diagram form. G uses graphical data flow programming language on which LabVIEW is based. It simplifies scientific computation, process monitoring and control, test and measurement applications and can also be used for variety of other applications.

LabVIEW is a general-purpose programming system with extensive libraries of functions and subroutines for any programming task. It also contains application-specific libraries for data acquisition, GPIB and serial instrument control, data analysis, data presentation, and data storage. It also includes conventional program development tools, so you can set breakpoints, animate the execution to see how data passes through the program, and single-step through the program to make debugging and program development easier.

LabVIEW provides two workspaces, front panel and block diagram, for developing application specific program. Examples of these two workspaces of temperature monitoring software are shown in Figure 11 and 12 respectively.



Acquisition on off

Update Period 0.00 (sec)

Analysis on off

81.54 (deg F)

Low Limit 75.0

High Limit 85.0

Mean Temp 84.24

Standard Deviation 0.92

Minimum bin 70.00

Maximum bin 90.00

Figure 11. Front panel of temperature monitoring program. Various input and output controls, indicators and buttons are used to perform the specific task.

In front panel, various controls, switches, display, graphs etc are used, which represent input and output functions to control the instrument. Controls are useful to specify values of various parameters and conditions. Switches are used to make the certain operations on or off. Graphs and displays are output functions and show various results acquired during the process. In block diagram various numerical and text based expressions are linked with each other to decide the flow of data. Block diagram is thus, a graphical representation of program's source code.

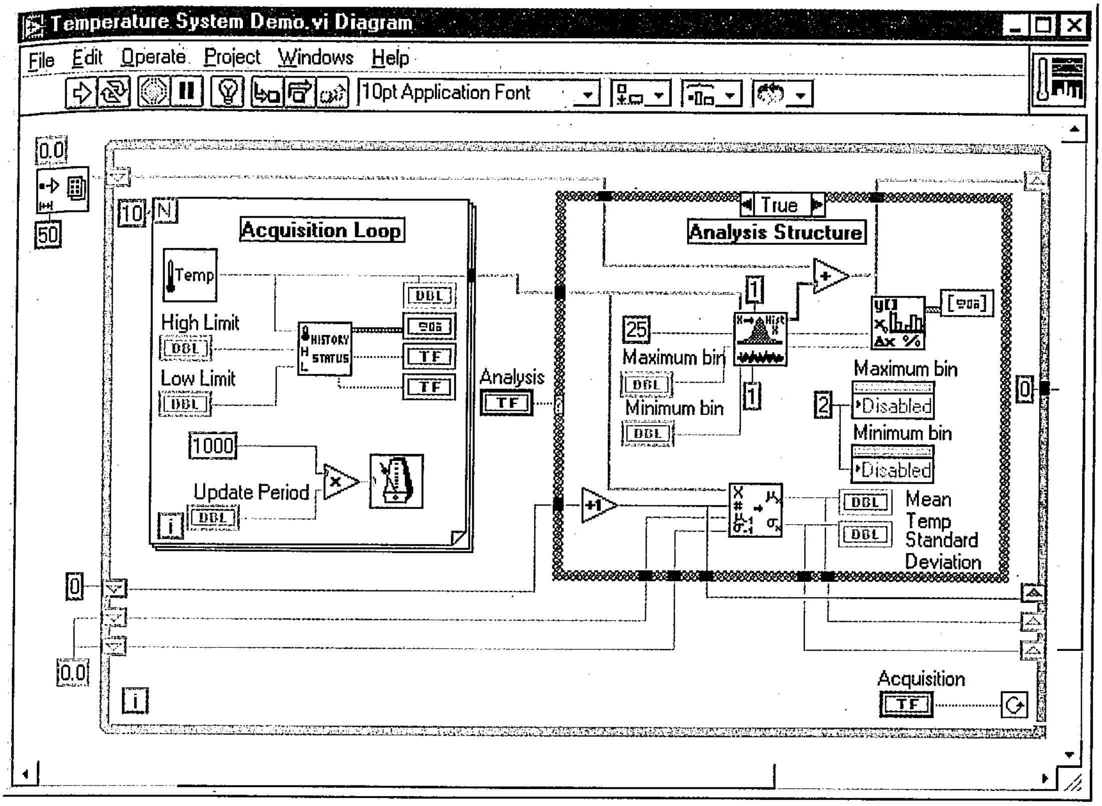


Figure 12. Block diagram panel of temperature monitoring program.

4.4. Software Design

The composite flow diagram of PMC200-V2.VI is shown in Figure 26, Appendix 7.1. PMC200-P2.VI front panel is divided in six functional menus as follows. The first three menus control the motion and the rest three serve as diagnosis tools.

- General-purpose motion control
- Sample-grain positioning
- Scan mode
- Platforms position indicator
- Query and reply from motion controller
- Alert-error message reporting section

For smooth operation of all the motion-related functions, two-dimensional (X-Y) co-ordinate system is formed. Two axial slots represent X-axis and Y-axis, as they are placed perpendicular to each other. Two platforms move in these slots. The axial slots are 160 mm long whereas platforms are 80 mm. Thus maximum possible displacement is 160-80 = 80 mm. This would be clear from Figure 13.

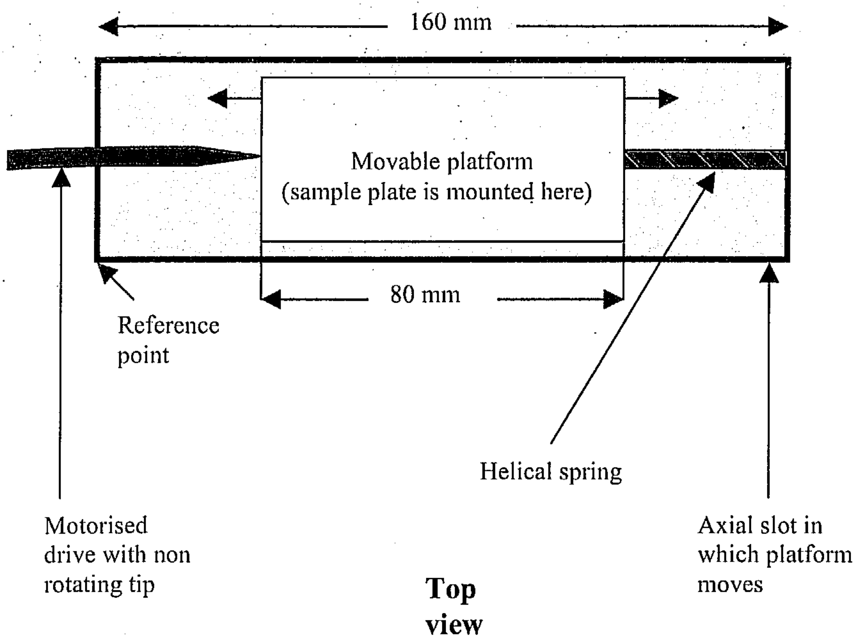


Figure 13. Schematic of the movable platform, which moves back and forth in the axial slot.

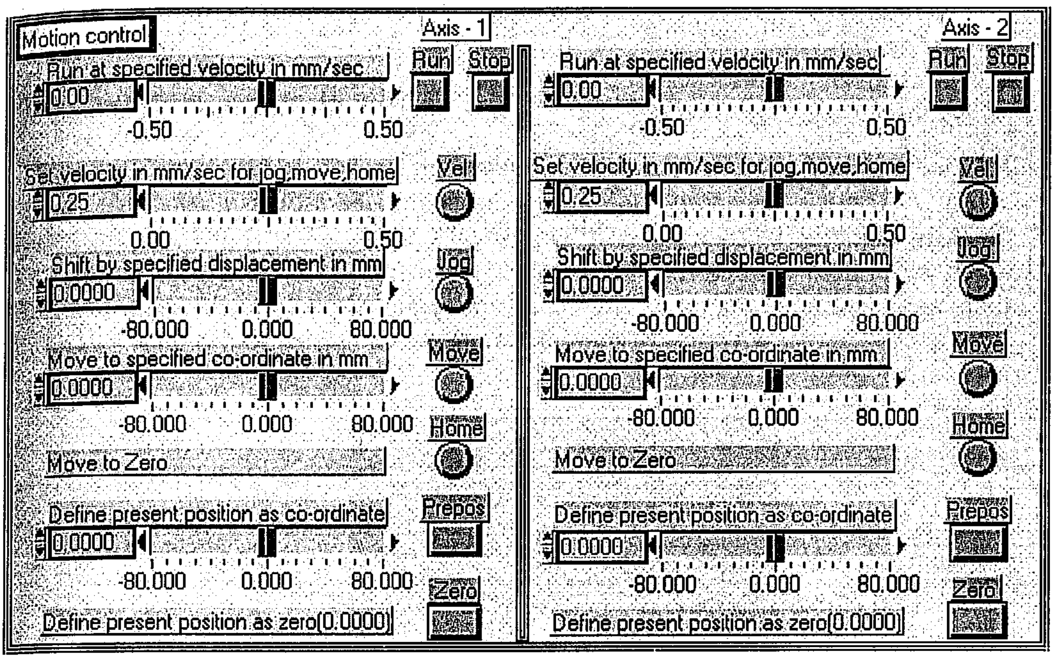
The left most corner of the axial slot is designated as the reference point (origin of corresponding axis) and the distance is measured between this point and the left edge of the respective platform. Initially, both the platforms are moved to the reference point and controller is instructed to designate the initial position of platform as 0.0000 (origin). This initialisation is retained and needs to be repeated only after improper shutdown of the software.

Initialisation process calibrates the axes such that any point located in X-Y quadrant would have unique co-ordinates.

4.4.1. General-Purpose Motion Control

In certain applications, it is desired to manoeuvre the platforms in arbitrary fashion. To perform such operations various controls are available under general-purpose motion control menu. Identical controls are at hand for both the axes, but they work independently, i.e. motion initiated by controls of X-axis does not affect the Y-axis motion. Thus, simultaneously motion of both the axes is possible. Controls and buttons available in this menu are shown in Figure 14 and described below. The detailed flow diagram is shown in Figure 27, Appendix 7.1.

- ***RUN.*** This button moves the platforms for indefinite time until *'STOP'* is pressed or platforms reach at the end point. For desired velocity and direction, its adjacent control called *'Run at specified velocity in mm/sec' is to be used.* The maximum velocity is 0.5 mm/sec. The sign (positive/negative) of selected velocity decides the direction of motion (forward or backward).



Run at specified velocity in mm/sec 0.00

Set velocity in mm/sec for jog,move,home 0.25

Shift by specified displacement in mm 0.0000

Move to specified co-ordinate in mm 0.0000

Move to Zero

Define present position as co-ordinate 0.0000

Define present position as zero(0.0000)

Run at specified velocity in mm/sec 0.00

Set velocity in mm/sec for jog,move,home 0.25

Shift by specified displacement in mm 0.0000

Move to specified co-ordinate in mm 0.0000

Move to Zero

Define present position as co-ordinate 0.0000

Define present position as zero(0.0000)

Figure 14. General-purpose motion control menu showing various motion related controls and buttons.

- ***STOP.*** It stops the platform if it is moving. However, during scan operation, it is not effective.
- ***JOG.*** It moves the platform by a distance, which is specified in its adjacent control called '*Shift by specified displacement in mm*'. The sign of this value decides the direction of motion.
- ***MOVE.*** It moves the platform until it reaches a co-ordinate, specified in its adjacent control called '*Move to specified co-ordinate in mm*'.
- ***HOME.*** It moves the platform to initial co-ordinates (origin 0.0000).
- ***VEL.*** It allows to set the velocity (max 0.5 mm/sec) for JOG, MOVE and HOME commands. This setting does not affect the velocity set for RUN command.
- ***PREPOS.*** It does not initiate any motion, but assigns a new co-ordinate to the present position of the platform. The value of new co-ordinate can be set in its adjacent control called '*Define present position as co-ordinate*'.
- ***ZERO.*** As like PREPOS, this command does not initiate any motion, but assigns 0.0000 (origin) to the present position of platform.

Execution of PREPOS and ZERO commands make changes in the respective co-ordinate system, i.e. the origin (0.0000) is shifted. This also changes the co-ordinates of point A, B and two platforms. PMC200-P2.VI takes care of these changes by introducing the required offset in the current value of their co-ordinates.

For the sake of simplicity and smooth operation, the buttons other than STOP of a given axis remain disabled until the motion of corresponding platform is over. However, during scanning even STOP button remains ineffective along with others.

4.4.2. Sample-grain Positioning

The sample-grain positioning menu is shown in Figure 15. The detailed flow diagram is shown in Figure 28, Appendix 7.1. Sample-grains are placed in blind holes of copper sample plate (see Figure 5). The sample plate is mounted on upper platform. Due to a special logic used in the software, the mounting of sample plate does not require specific alignment i.e. sample plate can be placed in any orientation. This menu can handle two such sample plates with different layouts.

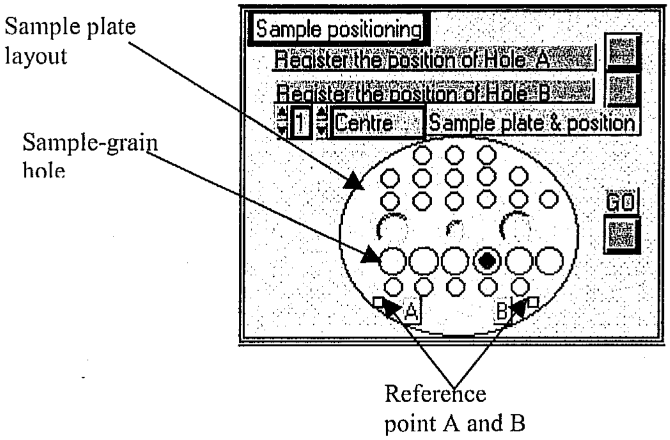


Figure 15. Sample-grain positioning menu. The layout of sample plate with sample holes facilitates user to select desired sample-grain, which can be moved at laser focusing point by clicking appropriate sample-grain hole and then GO button. Buttons are also available to register the position of point A and B.

The positioning of specific sample-grain at laser focusing point is geometrical in operation as described below. Consider two axes, X1-Y1 and X2-Y2 as shown in Figure 16. The origin of X2-Y2 is located at a distance (AX, AY) from the origin of X1-Y1 axis and rotated by angle θ with respect to X1. If these parameters (distance and angle) along with the co-ordinates of point P with respect to X2-Y2 are known then co-ordinates of P with respect to X1-Y1 can be calculated using following equation.

$$Px1 = Ax + (Px2 * \cos\theta - Py2 * \sin\theta) \qquad \text{..........Eq - 1}$$

$$Py1 = Ay + (Px2 * \sin\theta + Py2 * \cos\theta) \qquad \text{..........Eq - 2}$$

Alternately if co-ordinates of two points A and B with respect to X1-Y1 are known then

$$Px1 = Ax + [\ Px2 * (Bx-Ax) - Py2 * (By-Ay)\ ] / AB \qquad \text{..........Eq - 3}$$

$$Py1 = Ay + [\ Px2 * (By-Ay) - Py2 * (Bx-Ax)\ ] / AB \qquad \text{..........Eq - 4}$$

$$\text{Where } AB = [\ (Bx-Ax)^2 + (By-Ay)^2\ ]^{1/2} \qquad \text{..........Eq - 5}$$

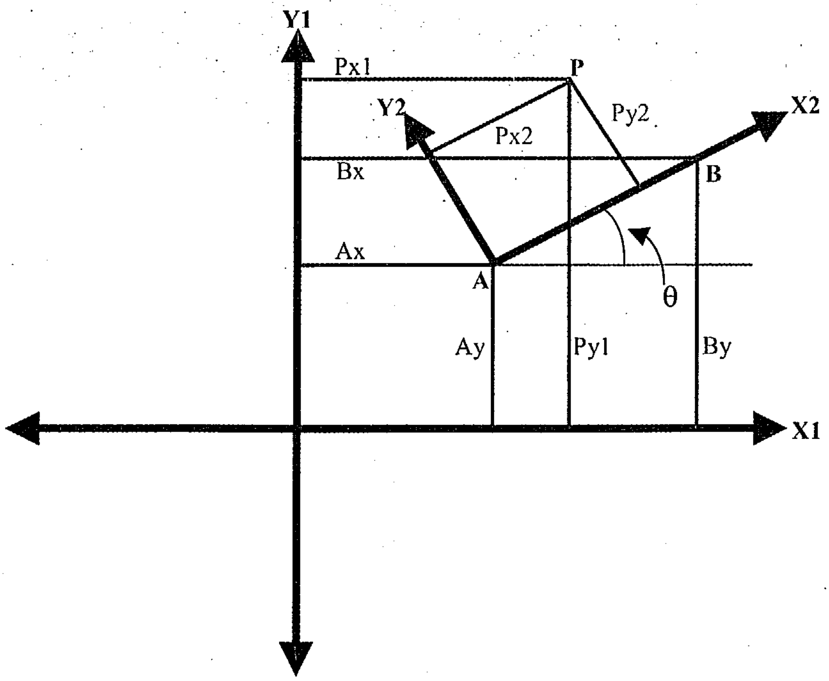


Figure 16. Axis X2-Y2 is located at distance (Ax, Ay) from the origin of axis X1-Y1 and rotated by the angle θ with respect to X1. If these two parameters (distance and angle) along with the co-ordinates of point P with respect to axis X2-Y2 are known then the co-ordinates of point P with respect to axis X1-Y1 can be calculated. It is useful for locating specific sample-grain hole at laser focusing point.

In our experiment,

Axis X1-Y1 ≡ Co-ordinate system formed by two axial slots, in which the platform-1 and platform-2 move (See Figure 4 and 13).

Axis X2-Y2 ≡ Co-ordinate system formed (on sample plate) by line (imaginary) joining point A and B and its perpendicular line (imaginary) intersecting at point A.

(Px1, Py1) ≡ Co-ordinates of the centre of desired sample-grain hole with respect to X1-Y1, which is to be calculated.

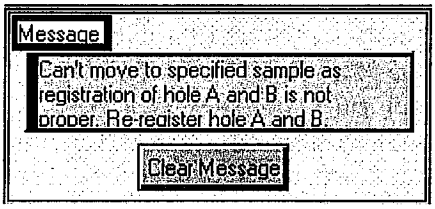
(Px2, Py2) ≡ Co-ordinates of the centre of desired sample-grain hole with respect to X2-Y2, which is already stored in the software.

(Ax, Ay) ≡ Co-ordinate of point A (marked on sample plate) with respect to X1-Y1, which is provided by user by bringing this point under laser spot and clicking 'register the position of point A' button.

(Bx, By) ≡ Co-ordinate of point B (marked on sample plate) with respect to X1-Y1, which is provided by user by bringing this point under laser spot and clicking 'register the position of point B' button.

θ ≡ Angle of rotation of axis X2-Y2 with X1-Y1, which can be calculated from the co-ordinates of point A and B with respect to X1-Y1.

AB ≡ It is the distance between points A and B (marked on sample plate), pre-recorded (embedded) in the software and equal to 20.0000 mm. When user registers the position of point A and B, software calculates the distance AB by equation –5 and allows positioning of the sample-grain at laser spot, only if it is between 20.0000 – 20.1000 mm. Otherwise it displays the error message shown in Figure 17.


Message

Can't move to specified sample as registration of hole A and B is not proper. Re-register hole A and B.

Figure 17. Error message, if the registration of point A and B is improper.

The diameter and co-ordinates (equivalent to Px2, Py2 in Figure 16) of the centre of each hole are pre-recorded (embedded) in the software (PMC200-P2.VI).

Before using this menu, user has to provide the co-ordinates of two points A and B [(Ax, Ay) and (Bx, By) in Figure 16]. This is done by bringing these points (using general-purpose motion controls) below the laser spot and registering these values in the software. By having the co-ordinates of point A and B, it is easy to calculate the co-ordinates of the centre of each sample-grain hole with respect to the platform axes (X1-Y1) using equations 3-4. Once the co-ordinates are found, the software generates appropriate codes for required movements. Thus, desired sample-grain could be brought at the laser focusing point for heating.

Three controls and three switches are provided under sample-grain positioning menu.

- ***Register the position of hole A.*** This command stores present position of platforms as co-ordinates of point A. (with respect to platforms axis, X1-Y1)
- ***Register the position of hole B.*** It is the same as above but for point B.
- ***GO.*** This command moves the platform to get the desired sample-grain at laser focusing point.
- ***Sample plate and position.*** This control provides selection of two sample plate layouts. User has to select appropriate plate (1 or 2) before proceeding for any movement. The '*position*' control allows user to bring either centre or top-left position of sample-grain hole at laser spot. In top-left selection, the top-left corner of an imaginary square around the sample-grain hole comes at laser focusing point. This option is useful when scanning within the sample-grain hole is required.

- ***Sample number selection.*** There are 25 buttons available on the layout of sample plate. These buttons represent the different sample-grains. To move specific sample-grain at laser spot, user has to click one of these buttons and then GO button.
- ***Auto saving feature.*** Generally nitrogen and noble gas analysis for a given set of sample-grains takes several days. Gases liberated by laser heating of a sample-grain (out of 25) are injected into mass spectrometer after cleaning. There it has to undergo several other processes, which takes about 3-4 hours. As a result only two or three sample-grains can be analysed per day and the pending sample-grains remain loaded on the sample plate. But at the end of the day, the motion controller is switched off and the program is exited to prevent sample-grains from inadvertent exposure to laser. When PMC200-P2.VI is exited, it stores the co-ordinates of point A and B on the hard disk. During next use when it is restarted, these co-ordinates are restored to recalculate the positions of each sample-grain. Thus user can easily move the previous days pending sample-grains for laser heating. This feature eliminates the registration of point A and B, every time when analysis is restarted. (Here it is essential that the sample plate is not re-oriented between the two consecutive uses.)

The precision in positioning the sample-grains at laser focusing point mainly depends on the accuracy maintained in fabricating the sample plate and registration of point A and B by user. Software has used 64-bit floating-point numbers to calculate the co-ordinates of sample-grain hole and the programmable motion controller has resolution of 5 micron. Therefore, introduction of error from software and controller is the least.

The biggest advantage of sample-grain position mode is its ability to detect the orientation of sample plate. This allows user to load the sample plate without specific alignments (i.e. the angle θ could be anywhere between zero and 360 degree), which reduces the hassle in mounting sample plate on the platform.

Note. As explained earlier in this section, the co-ordinates of sample-grain hole with respect to platform axis (X1-Y1) can be found if the co-ordinates of this hole with respect to axis (X2-Y2) is known and co-ordinates of point A and B with respect to (X1-Y1) are provided by user.

But this is true only if the plane of sample plate is perfectly perpendicular to the line of laser beam. Any deviation (even by a small angle) makes these equations wrong. To get the perfect result, another point C, as shown in Figure 18 is required with prior information of distance AB, BC and CA.

By knowing the co-ordinates of point C, deviation due to sample plate tilt can be calculated and appropriate correction can be made in the equations. However, the error which could be generated by above problem is of the order of few microns (assuming the deviation angle is less than 1 degree). Hence, the calculated co-ordinates of specific sample-grain hole would be slightly different from the actual one and the corresponding sample-grain will be positioned bit away from the laser focusing point. This is acceptable as far as this application is concerned. Because difference of few microns in positioning the sample-grain at laser focusing point does not expose the nearby sample-grains as the average sample-grain size and the average distance between two sample-grains are of the order of few millimetres and hence this correction is not incorporated in this software.

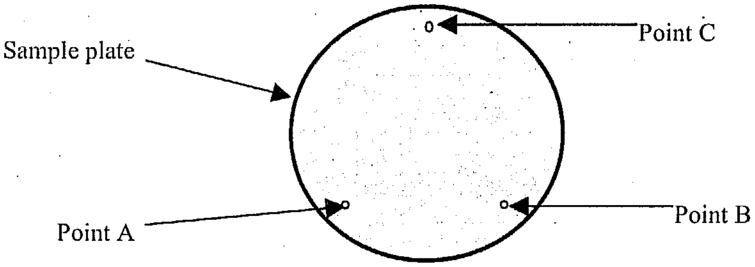
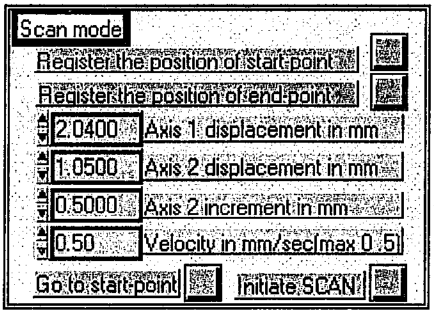


Figure 18. Schematic of sample plate showing the position of reference points A, B and C. Registration of point C is required if the plane of sample plate is not perpendicular to direction of laser beam.

4.4.3. Scan Mode

Under this menu, four controls and four buttons are available as shown in Figure 19. The detailed flow diagram is shown in Figure 29, Appendix 7.1.



2.0400 Axis 1 displacement in mm
1.0500 Axis 2 displacement in mm
0.5000 Axis 2 increment in mm
0.50 Velocity in mm/sec(max 0.5)

Figure 19. Scan Menu showing various controls and buttons.

Various controls available under scan mode are listed below.

- ***Axis –1 displacement in mm.*** Platform –1 can be displaced in both the direction along axis –1 by the distance specified in this control. Minimum displacement is 5 micron and maximum is 80 mm.(Figure 20)
- ***Axis –2 displacement in mm.*** The value specified in this control decides the total distance covered by platform –2 (axis –2) during one scan. Minimum displacement is 5 micron and maximum is 80 mm.
- ***Axis –2 increment in mm.*** The platform –2 (axis –2) is moved by the distance specified in this control between each backward and forward movement of platform –1. Minimum incremental distance is 5 micron and maximum is 80 mm.
- ***Velocity in mm/sec.*** During the scan, the platforms move at the velocity specified in this control. However, velocity does not remain constant during the course of one move (One move is the distance travelled by one platform before second platform

starts its motion (Figure 20)). It follows the trapezoidal pattern. According to this,

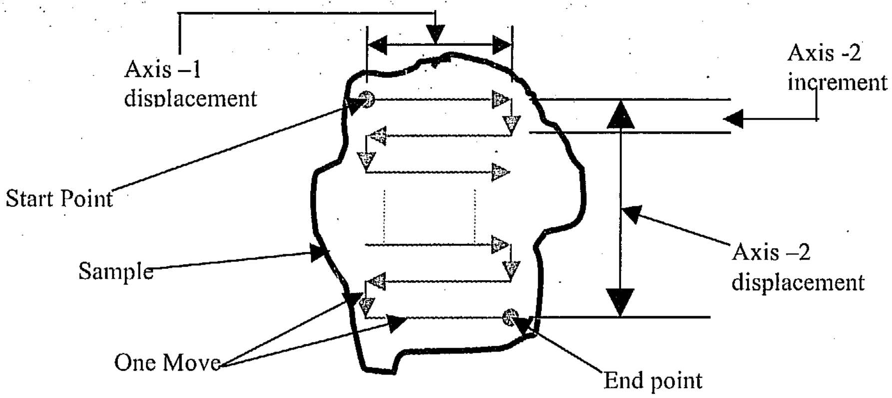


Figure 20. Schematic of a typical sample area showing scan parameters.

the platform starts from the rest and increases its velocity linearly till the specified velocity is achieved. Then it maintains this velocity until last phase during which the velocity decreases linearly and reaches to zero.

Various buttons available under scan mode are listed below.

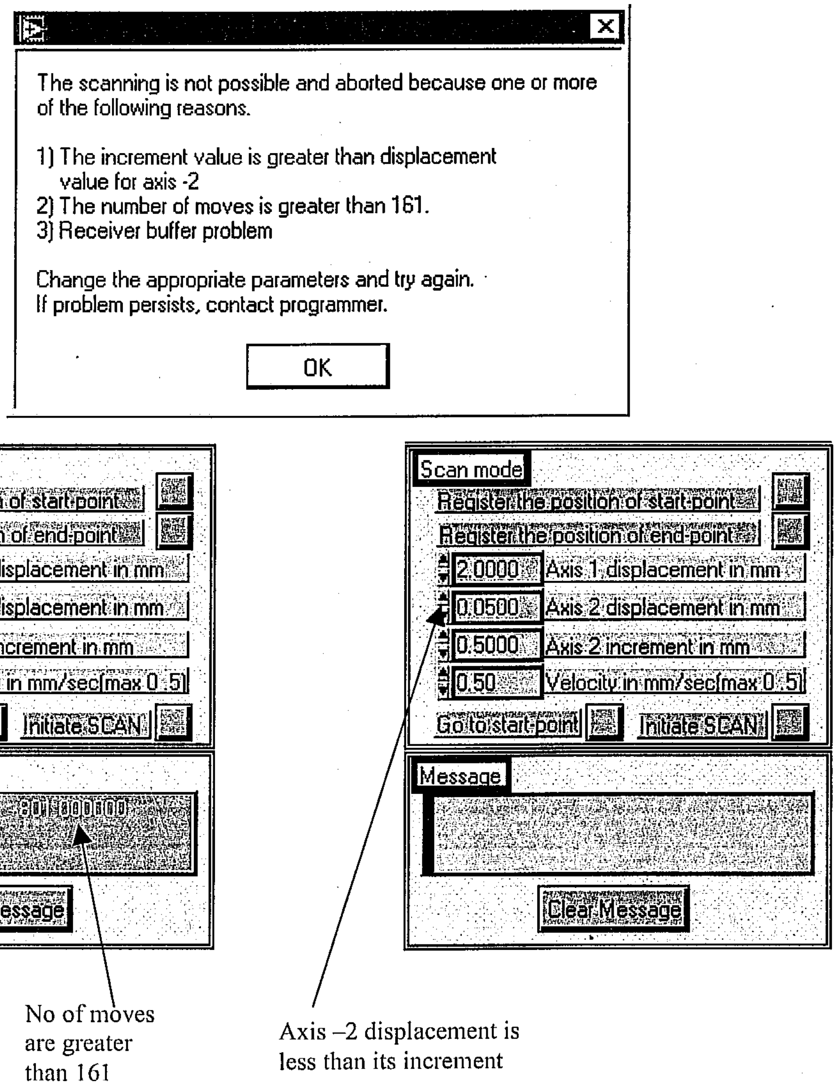
- ***Register the position of Start-point.*** This button registers the co-ordinates of the top, left-most point of the rectangular scan area (Figure 20), when brought under the laser focusing point.
- ***Register the position of end*-point.** This button registers the co-ordinates of the bottom, right-most point of the rectangular scan area (Figure 20), when brought under the laser focusing point.

Co-ordinates of these two points define the dimensions and location of scan area by calculating the length of maximum displacement along axis –1 and axis-2. This feature is optional to the manual calculation and entry of the two parameters, which is often cumbersome.

- ***Go to start-point.*** This command brings the start-point (assuming that it has already been registered by user) of selected scan area at laser focusing point. Normally before actual scan is started, a dummy scan sequence is run keeping He-Ne laser on. This is to verify whether scan path is correct or not. At the end of dummy sequence, the laser spot will be at the end-point. Before starting the actual scanning with Nd:YAG laser on, the starting point must be moved to the focusing point. This can be done by two ways.
  1) By trial and error method, which is not recommended due to very low precision.
  2) Using the MOVE command with start-point co-ordinates as its arguments. For this, however, user should have noted down the co-ordinates of start-point before initiating dummy scan.

'Go to start-point' function eliminates both of the above methods.

- *Initiate SCAN.* By pressing this button, scanning can be started. However, before scan starts, software evaluates the scan parameters to find out if:
  - The total no of moves are more than 161 or
  - Incremental value for axis –2 is more than its displacement value. Under such circumstances, the scan is aborted and the error dialog box is displayed (Figure 21) suggesting to change the appropriate parameters. The first problem is due to limited storage memory of programmable motion controller, whereas second problem is rather obvious.



The scanning is not possible and aborted because one or more of the following reasons.

1) The increment value is greater than displacement value for axis -2
2) The number of moves is greater than 161.
3) Receiver buffer problem

Change the appropriate parameters and try again.
If problem persists, contact programmer.

OK

Scan mode
Register the position of start-point
Register the position of end-point
2.0000 Axis 1 displacement in mm
2.0000 Axis 2 displacement in mm
0.0050 Axis 2 increment in mm
0.50 Velocity in mm/sec(max 0.5)
Go to start-point
Initiate SCAN
Message
[illegible] Minutes - [illegible] Moves
Clear Message

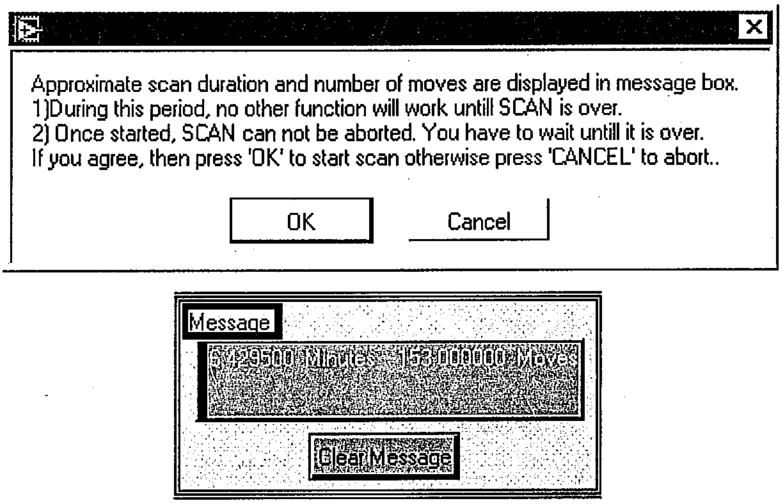
Scan mode
Register the position of start-point
Register the position of end-point
2.0000 Axis 1 displacement in mm
0.0500 Axis 2 displacement in mm
0.5000 Axis 2 increment in mm
0.50 Velocity in mm/sec(max 0.5)
Go to start-point
Initiate SCAN
Message
Clear Message

No of moves
are greater
than 161

Axis –2 displacement is
less than its increment

Figure 21. Scan error message, if the number of moves is greater than 161 or scan incremental value is larger than its displacement.

before scanning starts. User is informed about the approximate scan duration and number of moves and confirmation is sought to proceed with scan or abort it. It is extremely useful and important because once started, the scan can not be aborted (This is to minimise the delay between two moves. PMC200-P2.VI has achieved the lowest possible delay). If user has made a mistake in selecting the scan parameters (or in case of a typical scan requirements), the scan duration could go as high as several hours. So by any chance if scan is started, it can not be stopped for a specified duration and unwanted platform movements keep on going. As a result, the motion controller will not be available for other tasks till this scan is over. Such situation is not desirable. This scan sequence can only be stopped by shutting down the motion controller. This is because all the software commands remain disabled during scan. However, the power shut down of controller is not advisable during operation, because the software fails to register the platforms position. Therefore, intermediate step in the form of the dialog box (Figure 22) with useful information is provided. User must think, specifically on the specified duration before initiating the scan.


Approximate scan duration and number of moves are displayed in message box.
1)During this period, no other function will work untill SCAN is over.
2) Once started, SCAN can not be aborted. You have to wait untill it is over.
If you agree, then press 'OK' to start scan otherwise press 'CANCEL' to abort..

5.429500 Minutes - 153.000000 Moves

Figure 22. Scan alert message displaying approximate scan duration and number of moves.

Followings are few important points about the scan.

- Scanning starts from top-left point and ends at bottom-right point of an imaginary rectangle, which is decided by user to define the scan area.
- In one scan,
  Total number of moves = [2 * (axis –2 displacement / axis –2 increment) + 1] or
  Total number of moves = [2 * (axis –2 displacement / axis –2 increment) + 3],
  If the value of (axis –2 displacement / axis –2 increment) is non-integer
- During scan, all other buttons including STOP remain disabled. That means none of the functions, available on front panel can be used.
- Platform indicators will not be updated during scan. However, the final update about the displacement of platforms, which has taken place during scan will be done at the end of that scan.

4.4.4. Platform Position Indicator

PMC200-P2.VI has a graphical indicator, which continuously monitors the motion of both the platforms and displays their latest positions (Figure 23). This feature has two advantages.

- PMC200-P2 motion controller has in-built limit detection facility (for both the axes) that generates audio alarm and stops the motion of the platforms, when these reach the end point (beyond which platform can not move and collide with wall of the axial slot). However, it is desirable to prevent platforms from reaching to the end point. The platform position indicator helps the user in monitoring the motion of platforms to avoid this situation.
- Usually, all 25 sample-grains are loaded in the sample plate and it is required to move all these sample-grains at laser focusing point, during course of the experiment. The maximum distance, which is to be covered to access all the sample holes, is about 25 mm (in both X and Y direction). Therefore, before mounting the sample plate on the platform, it is necessary to ensure that platforms can move at least by 25 mm, without reaching the end point. With the help of platform indicator, user can anticipate maximum possible swing available to access all the grains.

In both the above cases, visual inspection of platform position is not required. This is especially helpful if platform assembly is either located far away or not easily accessible.

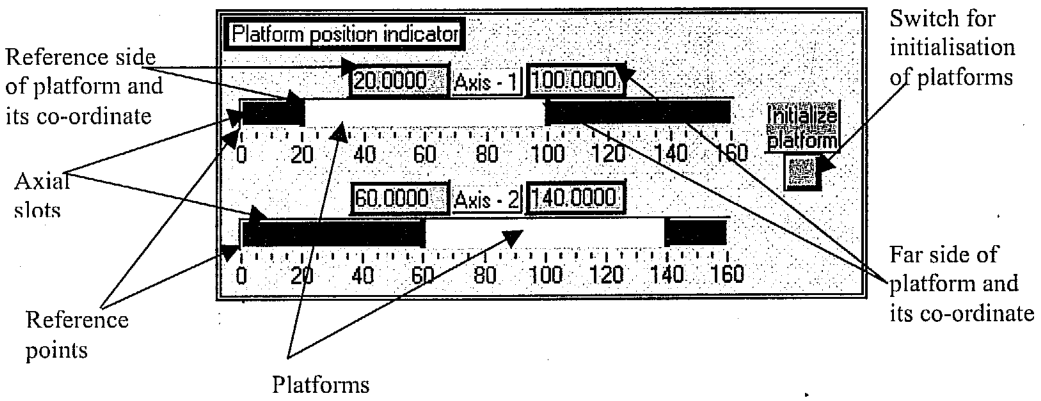


Figure 23. Platform position indicator showing the position of the platforms, both graphically and numerically.

To get the precise view about the position of the platforms, the axial slot (black coloured in Figure 23) is calibrated as per the co-ordinate system, defined by user. Additionally, the position values of both the front and rear edges of the platforms are continuously displayed with four decimal point precision in mm.

Platform indicator menu has one button called 'Initialise platforms' (Refer flow diagram in Figure 30, Appendix 7.1). This button is used when user starts this program,

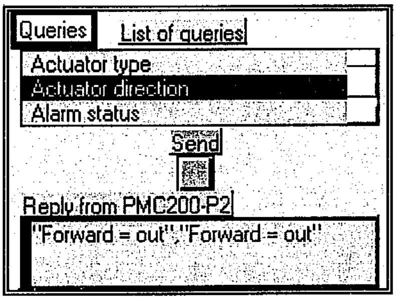
- for the first time, or
- after improper shutdown during previous use

Before pressing this button user must bring the front edge of both the platforms to the beginning of the axial slot (reference point as shown in Figure 13). When this button is clicked, co-ordinates of both the axes in motion controller are reassigned to (0.0000, 0.0000). At the same time, the axial slot will be re-calibrated by assigning 0.0000 (origin) to the reference point and the platform indicator (pink coloured in Figure 23) will be re-positioned at the origin.

The position indicators do not get updated during scan operation. The final update will take place only after the ongoing scan operation is over. Both the axial slots are re-calibrated after the execution of PREPOS and ZERO commands.

4.4.5. Query and Reply from Motion Controller

Several important parameters related to motion are stored in the battery backed-up memory of the motion controller. If the user wants to know about any of these parameters during the operation, the query and reply box under the query menu (Figure 24) can provide it. The detailed flow diagram of this menu is shown in Figure 31, Appendix 7.1.



"Forward = out","Forward = out"

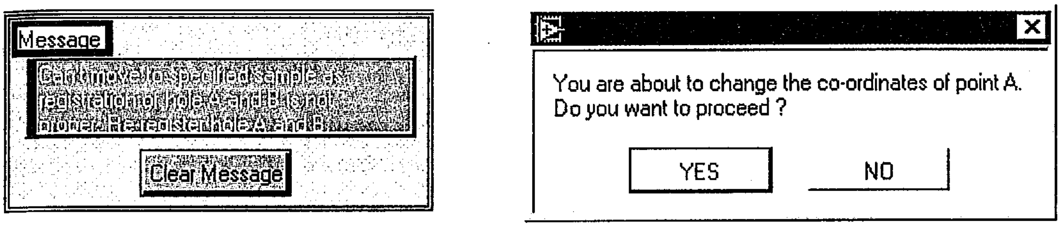
Figure 24. Queries Menu. Several motion-related parameters stored in motion controller's memory can be accessed using this menu.

User has to select the required parameter in the list of queries and has to press the SEND button. Upon getting query from software, motion controller will replay back and the result will be displayed in the reply box. User can raise a query about any of the following parameters.

- Acceleration
- Actuator type
- Actuator direction
- Alarm status
- Backlash
- Echo mode status
- Error
- Identification
- 'JOG' value (last used)
- Motion type
- 'MOVE' value (last used)
- Motor type
- Position of platform
- 'PREPOS' value (last used)
- 'RUN' value (last used)
- Scale factor
- Time (clock)
- Unit of measurement
- Velocity of actuators

4.4.6. Alert-Error Message Reporting System

At times, user might inadvertently select the control parameters or execute the command in such a way that the corresponding operation may not be possible or not advisable. In such situations the program will generate error or alert message either in a message box or in a separate dialogue box as shown in Figure 25.



You are about to change the co-ordinates of point A.
Do you want to proceed ?

Figure 25. Example of error and alert message.

The message, which is displayed in the message box will keep on blinking until user clears it by pressing CLEAR MESSAGE button or the new message appears, if any. Message which are displayed in separate dialog box will wait and not allow further operation until user selects one of the options available in this dialogue box.

Miscellaneous

- PMC200-P2 software is structured in such a way that user is guided right from the start of the software. It navigates the user with appropriate options and information for the successful commencement of the software.
- When PMC200-P2 is started, it searches motion controller on the COM-2 (serial port) of the PC and informs user if it is not connected and/or not switched on.
- When it is started, it automatically detects and reports improper shut down of itself, if occurred during the last use either due to user's mistake, power failure or PC problem and prompts for initialisation of the platforms and registration of points A and B.
- If shutdown was proper at the end of the last use then in the beginning of the next use, the software does the following.
  - Restores the last co-ordinate system and updates the platform indicators.
  - Restores the co-ordinates of point A and B for sample-grain positioning.
  - Restores the platform co-ordinates in the motion controller by sending appropriate commands.
- Online help for all the buttons is available during the operation.
- When user quits the program by pressing EXIT button, the position of both the platforms and points A and B are stored on the hard disk of the PC. These parameters are useful in the next session.
- When EXIT button is pressed, its action is discarded if the platforms are in motion. This is to prevent software from storing improper position of the platforms.
- The exit option in file-menu and 'close window' button (marked 'X' in the top-right corner of PMC200-P2.VI windows) becomes inactive when software is started and remains inactive until the software is exited by the use of EXIT button, available in

the front panel. This is to prevent improper shut down of the software that might occur due to inadvertent use of 'close window' button and exit option in file-menu. (As explained earlier, the position parameters [position of both the platforms and point A and B] must be stored on the hard disk when the software is exited. This is done when user exits the software by pressing EXIT button. This is because the code designed for EXIT button is capable to do this. But the 'close window' button and exit option in file-menu are not able (actually not designed) to do such task.)

4.5. Software Limitations

PMC200-P2.VI motion control software is capable of performing all the required operations for above-mentioned application. However, it has following limitations.

- After sending instructions to motion controller, software does not check for an error, which might be a communication error or motion controller's internal error. However, testing was carried out several times for this type of operations and in none of the cases such error is observed. Hence, this protocol is continued. However, if required, an additional loop of instructions can be added for the error handling.
- GPIB interface, which is not only faster than RS-232 but more flexible in terms of error handling, is not used (due to technical problem).
- Similar to sample-grain positioning mode (refer Note, section 5.4.2), in the scan mode also, if the surface of the sample is not perfectly perpendicular to the line of laser beam, the actual distance covered during one move would be larger than the value specified (required) in the scan parameters. To overcome this drawback, the tilt of sample surface is to be calculated and the appropriate correction has to be made in the specified distance of one move.

5. Conclusion

PMC200-P2.VI is tested rigorously in all respects and found working robustly and satisfactorily. The possible modifications and improvements mentioned in section 4.5 will be done as and when required. To conclude, the following benefits, compared to the manual operation, are observed while manoeuvring the motion with this software.

- User friendly windows environment with online help
- Superior in terms of reproducibility of the operations.
- More precision with least efforts and time.
- Easy and flexible manoeuvring.
- Availability of sample-grain positioning and scan modes, which are quite difficult with manual operation.
- Interactive and quick error-alert reporting system.

6. References

(1) LabVIEW reference manual and online help

(2) PMC200-P2 system and command reference manual

(3) The Newport catalogue

(4) R. R. Mahajan and S. V. S. Murty 2003. Laser microprobe for the study of noble gases and nitrogen in single grains; A case of individual chondrules from the Dhajala meteorite. Proc. Indian Acad. Sci. (Earth Planet sci.), 112, No. 1, March 2003, 113-127.

(5) S.V.S. Murty 1988. Fabrication and operational details of an ultra high vacuum (UHV) system for the simultaneous analysis of nitrogen and noble gases. PRL, Technical Note TN-88-59, 1988.

7. Appendix

7.1. Various Flow Diagrams of Motion Control Software (PMC200-P2.VI)

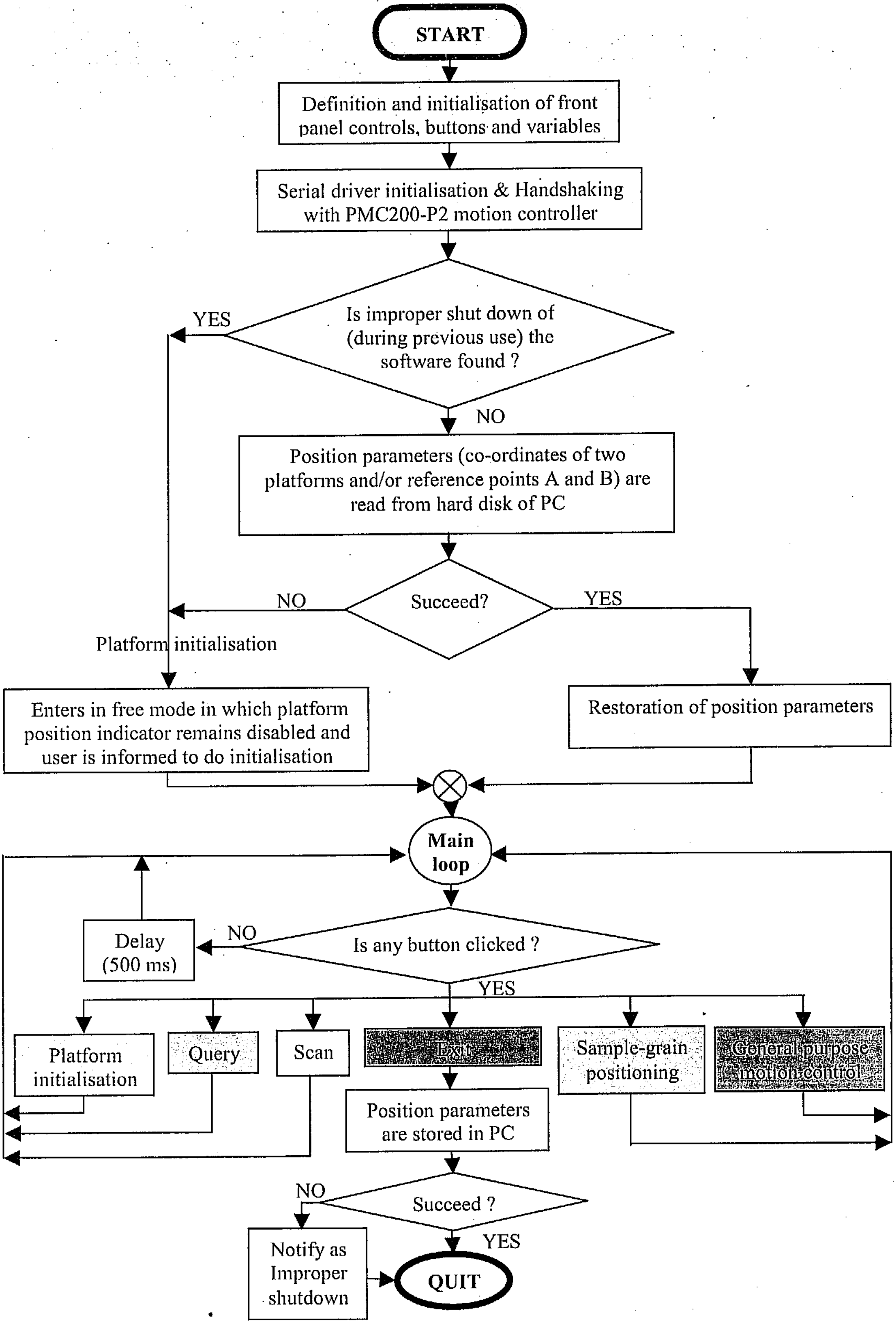


Figure 26. Composite flow diagram of PMC200-P2.VI software.

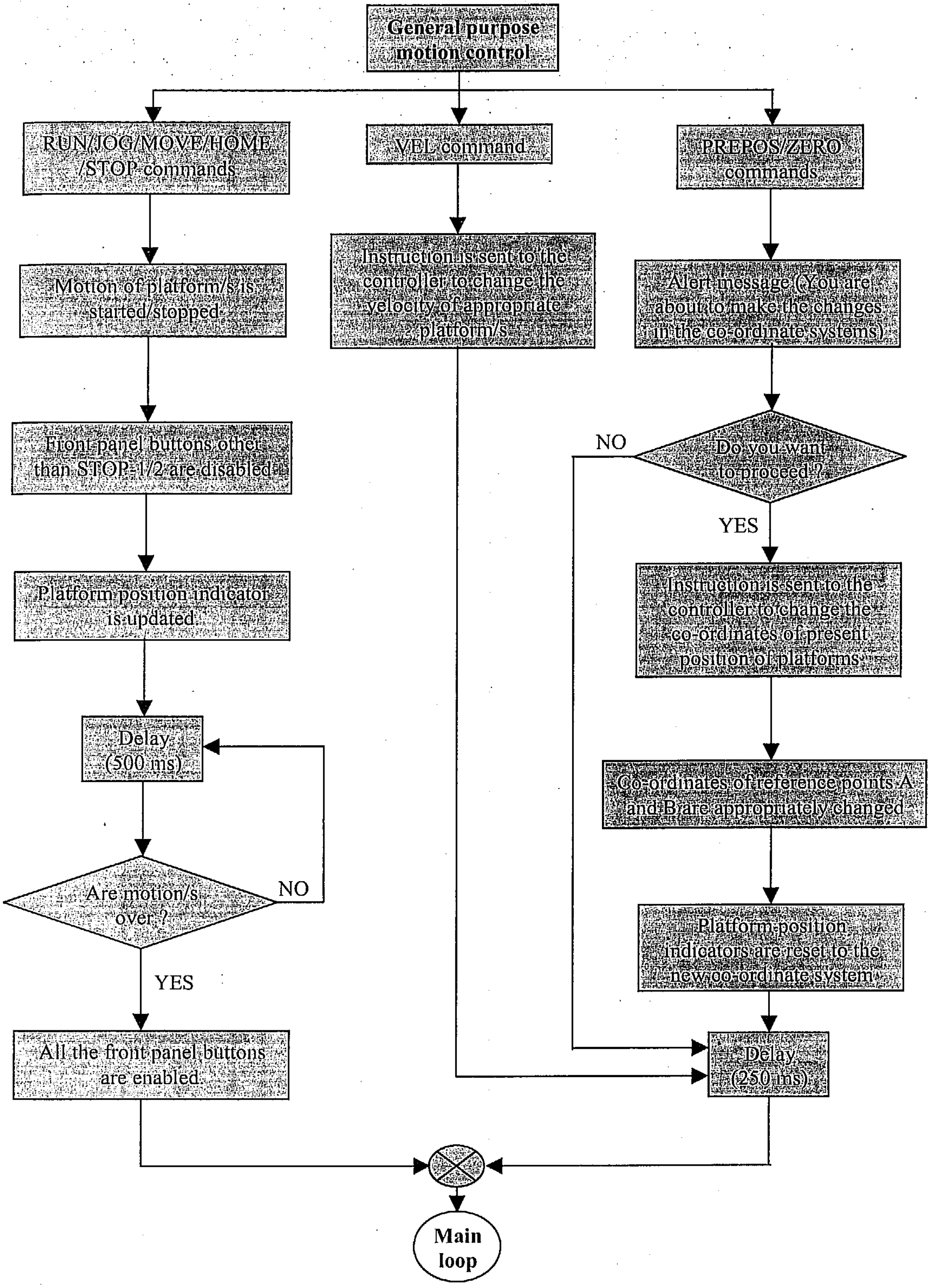


Figure 27. Detailed flow diagram of General-Purpose Motion Control mode

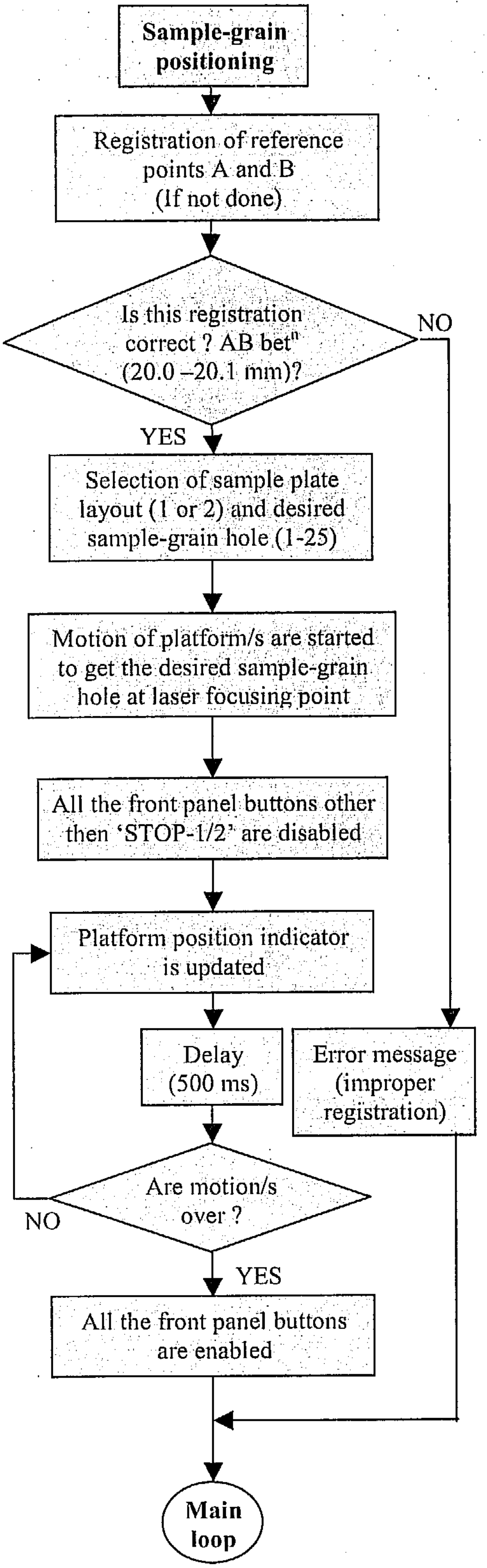


Figure 28. Detailed flow diagram of Sample-grain Positioning mode.

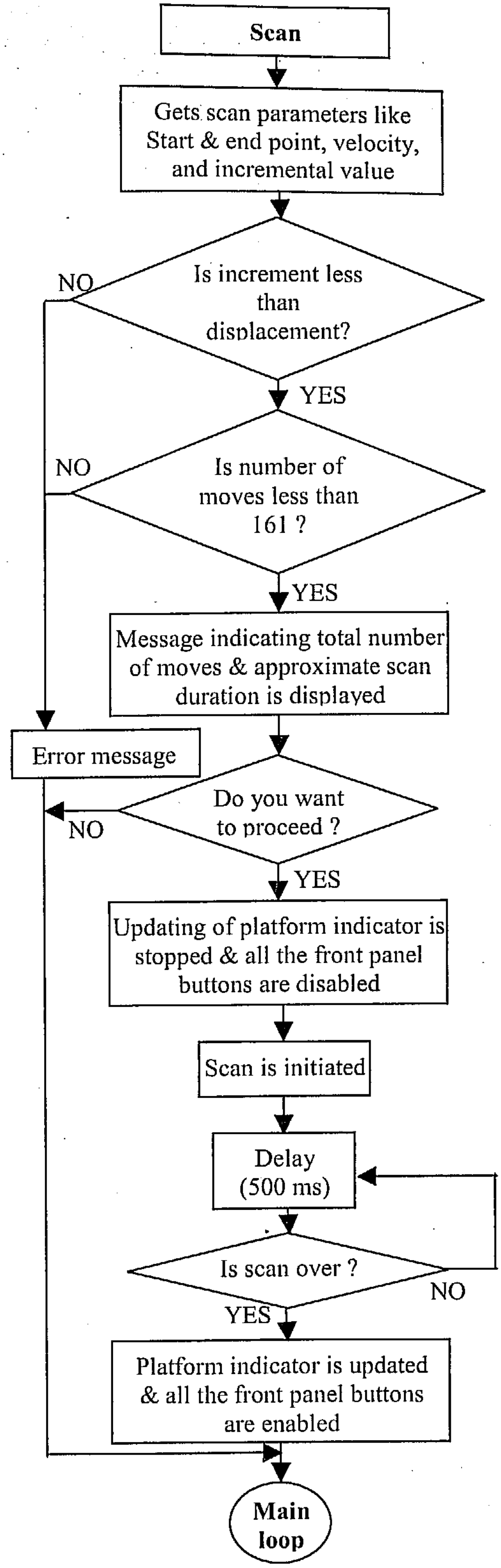


Figure 29. Detailed flow diagram of Scan mode.

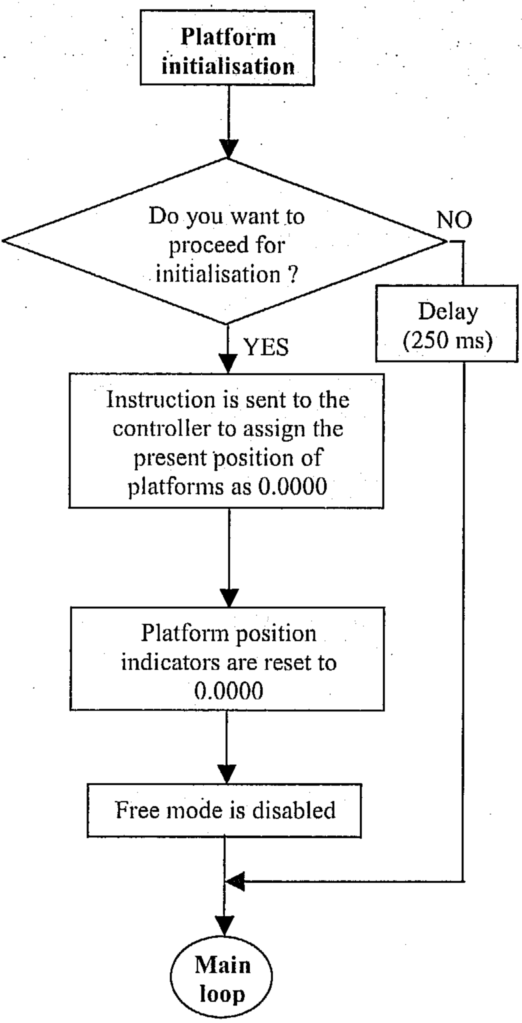


Figure 30. Detailed flow diagram of Platform Initialisation mode

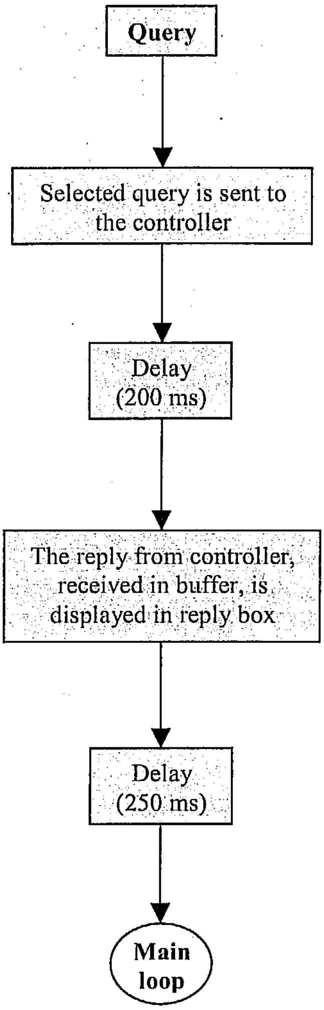


Figure 31. Detailed flow diagram of Queries mode

7.2. RS-232 Communication Protocol

Programmable motion controller (PMC200-P2) supports RS-232 (Recommended Standard -232) protocol and communicate with application program (PMC200-P2.VI) over RS-232 link.

RS-232 protocol is sometime referred as asynchronous serial communication. This is because data are transmitted/received one at a time and whenever ready as against synchronous communication. In this mode of communication, transmitter and receiver are not synchronised by the clock signal. However, synchronisation is done by either testing the amplitude of specific signal lines or by checking the software commands. Normally, following hardware lines are available in serial communication. (Originally this protocol was developed to establish a communication between computer and a modem.)

- ***Data Terminal Ready (DTR).*** The DTR signal indicates that the DTE (Data Terminal Equipment) is ready to communicate. Deserting this signal causes the DCE (Data communications Equipment) to suspend transmission. The DTR signal is the most important control line for a modem, because when it is deserted, most of the modem functions cease and the modem is disconnected from the telephone line.
- ***Request to Send (RTS) and Clear to Send (CTS).*** The RTS signal was originally intended to switch a half-duplex modem from transmit to receive mode. The computer would send an RTS signal to the modem and wait for the modem to respond by asserting CTS. Since most communications between microcomputers are full duplex nowadays, RTS/CTS handshaking is not often used in its original form. Rather, in most full-duplex modems, the CTS signal is permanently asserted, and the RTS signal is not used.
- ***Data Set Ready (DSR).*** It was intended to signal the computer that the modem has made a proper connection to the telephone line and received an answer tone from the modem on the other end. Modern modems communicate this information by sending messages to the computer.
- ***Transmitted Data (TD).*** The TD signal carries the serial data stream from the DTE to the DCE. The EIA (Electronic Industries Alliance) specifications dictate that the DTR, RTS, CTS, and DSR signals must be asserted before data is transmitted, but this requirement is not strictly followed in the computer industry.
- ***Received Data (RD).*** The RD signal is the counterpart of the TD signal, and carries data from the DCE to the DTE. Although the EIA specifies that this signal be in the 'Mark' state when no carrier is present, this requirement is rarely adhered to.
- ***Data Carrier Detect (DCD).*** In systems that use this signal, it is asserted by the DCE when a carrier signal is received.
- ***Ring Indicator (RI).*** In systems that use this signal, it is asserted by the DCE when the telephone line is ringing.

Out of these lines, DTR and RTS/CTS lines are used for the synchronisation. Software synchronisation is done using XON/XOFF flow control, which assigns ASCII

'DC1' character (also known as control-Q) as the start signal and 'DC3' character (control-S) as the stop signal.

Several other important parameters of RS-232 protocol are described below.

- ***Baud rate.*** It is a measure of data bits transmitted per second. Five different baud rates, 1200, 2400,4800, 9600 and 19200 bits per second (bps) are supported.
- ***Parity.*** It is an extra bit transmitted along with the data bits for error checking. Generally three types of parity 'None', 'Odd' and 'Even' are used.
- ***Data-bits.*** It indicates the number of data bits, which can be transmitted in one data frame. Options are 5,6,7,8 bits.
- ***Stop-bits.*** It shows the number of bit/s transmitted after the data bits for indication of end of one data frame. Options are 1 or 2 bit/s.
- ***Input echo mode.*** In this mode the character transmitted to the receiver are echoed back along with the error, if occurred any. Options available are enable or disable.

In laser heating experiment, programmable motion controller (PMC200-P2) and motion control software (PMC200-P2.VI) has used the following RS-232 parameters.

- Flow control	XON/XOFF
- Baud rate	19200 bps
- Parity	None
- Data bits	8
- Stop bit/s	1
- Input echo mode	off

In PMC200-P2, above parameters can be set by using its front panel buttons. In computer, operating system's (windows) serial driver is used by PMC200-P2.VI to set these parameters as a part of serial port initialisation.