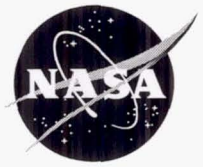
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NASA/TM—2003-212377



A Programmable System for Motion Control

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April 2003

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NASA/TM—2003-212377



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Prepared for the
49th International Instrumentation Symposium
cosponsored by the Aerospace Industries and Test Measurement Divisions
of the Instrumentation, Systems, and Automation Society
Orlando, Florida, May 4–8, 2003

National Aeronautics and
Space Administration

Glenn Research Center

April 2003

The Propulsion and Power Program at
NASA Glenn Research Center sponsored this work.

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KEYWORDS

Motion control, Programmable, Motion profile, Programmable logic controller

ABSTRACT

The need for improved flow measurements in the flow path of aeronautics testing facilities has led the NASA Glenn Research Center to develop a new motion control system. The new system is programmable, offering a flexibility unheard of in previous systems. The motion control system is PLC-based, which leads to highly accurate positioning ability, as well as reliability. The user interface is a software-based HMI package, which also adds flexibility to the overall system. The system also has the ability to create and execute motion profiles. This paper discusses the system's operation, control implementation, and experiences.

INTRODUCTION

Applications requiring precise motion control have become more and more common over the last decade. These applications include control of equipment used in assembly processes, movement of products, robotics, and countless others. These applications frequently require a motion control system that is versatile, user friendly, and able to be adapted to individual uses and applications. Moreover, many of these motion control applications demand more stringent control of the axes to a degree unheard of ten years ago. A good example of these more stringent requirements includes the movement of measurement probes in aeronautic applications. These measurement probes are used to map various physical aspects of a flow path. A strong driver for these highly precise motion control requirements is the validation of numerical tools used for the design and analysis of turbomachinery, which has required increasingly more detailed surveys of the flow path. To meet these demands, a Programmable Motion System has been developed to be user-friendly and versatile, giving the user many features not available in previous systems. Although originally developed to control probe actuators, the Programmable Motion System can be used to control action of movable stator vanes, laser tables, or any other device that accepts a ±10 VDC signal.

One of the best features is the minimal communications overhead for probe actuation systems, resulting in a measured speed of 5 seconds per data point. In addition to reducing the time required to take research data, real-time editing of axis parameters, integrated profile programming, and point and click operation all serve to simplify operation. The system's ability to incorporate auxiliary positioning devices on the actuator at a point closer to the position of interest (as opposed to the motor), and its continuous communication with external data, control, or other systems also help to obtain accurate and repeatable results. Additional features include the ability to program test-specific functions in the field, the system's independence of specific motor drives or motors, ease of troubleshooting, and its ability to be upgraded or expanded. Recognizing the benefits of a motion control system using hardware and software that was familiar to other engineers in the field, the system was designed to accommodate 18 axes of motion. A detailed description of all of the system features will be presented in this report, as well as an overview of the system's operation and design.

MOTION SYSTEM OPERATION

The programmable motion system is a design consisting of three main parts: a programmable logic controller (PLC) running the motion system control program, a PC running a human-machine interface application, and a motor/drive system (along with its associated gears, ballscrews, and other external components). The motion system was designed with the goal of providing a system that was flexible and easily modified by engineers in the field. To this end, the system's two main control portions, the PLC and the HMI, are programmed in a modular fashion, in programming languages that are widely accepted and understood by engineers. In addition to the basic programming structure lending itself to the system flexibility, the third portion of the system, the motor/drive system, can be any system of devices that accept a standard ±10 VDC velocity signal. The motors and drives could be large machines or small machines, or stepping motors or brushless servos.

The types of movement that are available to the user are given in Table 1. Both the incremental move amount and the commanded absolute position can be entered for each individual axis, or for a group of axes simultaneously. Jogging an axis refers to the movement of selected axes at the jog speed only while the jog button is activated (clicked). An example of positioning based on an external parameter will be discussed later. The speeds at which all the motion occurs is the positioning speed for each axis, with the exception of jogging. Jogging occurs at the jog speed for each axis.

One of the most crucial features of the system is the ability to execute motion profiles that are written in Microsoft Excel. The profiles incorporate a set of intuitive commands, which are executed sequentially. Most of the motion commands that are available to the user under direct control are also available as profile commands. Due to the asynchronous nature of the motion system components (PLC and the PC running the HMI software and Excel), extensive handshaking is used to ensure that the profiles are always executed correctly, regardless of timing or other issues. The handshaking ensures determinism of the entire system. The motion system's profile software is written in a modular approach, to allow the easy addition of any command not currently available.

Another feature is giving the user the ability to change positioning speed, jog speed, in-position band, following error for selected axes in real time, regardless of whether an axis is enabled or disabled, at rest or in motion. These parameters, as well as the commanded position (absolute positioning) and the incremental move amount, can all be set in either engineering units or base units. Base units for an axis are generally units that are easy to measure, and can remain unchanged once the axis is set up. Typical examples may be units of inches or millimeters for a linear axis, or revolutions or degrees for a rotational axis. Engineering units are dependant upon an application, and may be percent span or some other application-dependant units. The standard conversion between base units and engineering units is a simple slope and offset. Other conversions can be easily programmed to suit individual application needs.

Every parameter required for standard motion control is available to the user. These parameters are given in Table 2. In the unlikely event that a particular application requires the user to have the ability to set a parameter not already available, the motion system can easily be programmed in the field to provide it.

Another feature that the motion system offers are the ability to display and reset fault conditions. The system also incorporates on-line help screens, which aid in the set up, debugging, and operation of the motion system. The help feature includes examples of profiles, as well as descriptions of all profile commands and their operation.

One highly critical feature that is incorporated is the ability to communicate to other separate systems or devices in real time. These devices or systems may be closely linked to the motion system, or they could be completely autonomous and independent of the system. Examples include other PLCs controlling other systems, data acquisition systems, data archival and logging systems, or the Internet or an intranet. The performance and speed of the communication with these other systems is generally a function of the type of data being transmitted and the type of communication protocol.

CONTROL SYSTEM DESCRIPTION

The components of the motion system (the PLC, HMI, and the motor drive system) operate together to control the speed and position of the specified axes, as shown in the block diagram in Figure 1. The position control loop is accomplished in the PLC. The velocity control loop is performed in the motor drive system. Commands from the user are sent to the PLC via the HMI. The interface to the data acquisition system is performed through the PLC. The interface to user motion profiles is performed in the PC running the HMI application. This section will present system requirements and an overview of the PLC, motor drive system, and HMI, as well as profiles.

The motion system requires a PLC using a Modicon Quantum 424 (or better) processor for proper operation, as well as one Quantum motion control module per axis to be controlled. The HMI application is written using WonderWare's InTouch software. The link between the PLC and the HMI can either be performed through the high-speed serial data link or Ethernet protocol.

The motion system will control the speed (and hence position) of any motor/drive that accepts a ±10 VDC velocity signal. The axis feedback device may be either the motor encoder or an auxiliary encoder. The selection of the type of encoder is used is set in the axis parameters. The typical control block diagram for one axis is shown in Figure 2.

PLC OVERVIEW

The PLC uses a single axis motion control module to control the position loop of each axis. Motion commands are downloaded into the PLC's central processing unit (CPU), processed, and sent to the appropriate motion module. The motion control modules are intelligent modules that communicate to the CPU through the PLC backplane or through remote I/O communications. The communication between the CPU and the motion modules is bi-directional, with different CPU words being used for transmitted and received data from each module. For data being transmitted to the motion modules, a control word, a command word, and four data words are used for each axis. Similarly, for data being received from the motion modules by the CPU, a status word, a command echo word, and four data words are used for each axis. The motion system's PLC program uses handshaking to verify that all commands are received and executed properly. The motion system's PLC program also converts the data from the user inputs (at the HMI) to the format required by the motion modules.

The typical operation of sending a command from the CPU to a motion module for a given axis is to load the axis' data words with any required data in the axis' four command data words, then to load the command's opcode in the axis' command word. Then, the CPU must wait for the contents of the command echo word to be the same as the command opcode. After that, the CPU saves any necessary returned information from the motion module and proceeds to the next command opcode for the axis. The PLC program uses a module status register to keep track of which opcode is currently being sent to the motion module, and hence which operation the axis is currently performing. A simple "idle" cycle, or routine, is performed under normal operation. If a parameter is changed or motion is to be executed, the CPU interrupts this cycle, performs the operation, and then resumes the cycle.

The data registers to and from the motion module are used to send or receive desired information to or from the motion module. The high end of the range of numbers used in the data registers corresponds to (2^31/position encoder counts per base unit), or (2147483648/ position encoder counts per base unit).

The PLC CPU uses battery-backed RAM to store the user program, as well as the contents of the registers used. The PLC motion modules, on the other hand, use volatile memory to store the settings for each axis. PLC software, along with the HMI software, allows the user to download the parameters for all defined axes at once, or for a particular individual axis. The ability to download the parameters for all the axes is especially useful in the event of a power loss to the system, as the motion control modules lose their settings on power loss.

MOTOR DRIVE OVERVIEW

The motion system is capable of controlling the speed (and thus position) of any motor/drive that accepts a ±10 VDC velocity signal, allowing a wide variety of manufacturers to be used. The applicable parameters are easily set in the motion system parameters. Many manufacturers also feature software-based tools for motor drive setup, tuning, configuration, monitoring, etc.

Most motor drives make the motor encoder signal available to any other device. The motion system allows for the drive's motor encoder output signals to be wired into the PLC motion control modules. The feedback configuration for each axis is set up to use the motor

encoder or an auxiliary encoder for velocity control, position loop control, and motor commutation. In the first system, the encoders on the DC brushless servo motors were used simply for velocity control (and commutation) within the motor drive, while the motion modules performed the position control for each axis, based on the auxiliary encoder. In this configuration, the drives perform the velocity loop control, and the motion modules in the PLC perform the position loop control. The motion modules have the ability to perform velocity loop control, if desired.

HMI OVERVIEW

The HMI software consists of two main menus that are used to configure and run the axes. The Main Menu is used to set the system name, axis names and parameters, and system parameter file name. The Run Menu is used to actually command the axes to perform motion commands, set some axis parameters, and execute motion profiles. Each menu will be discussed separately.

MAIN MENU

The user can also download axis parameters to defined axes all at once, or only for a selected axis. The HMI stores the parameters for each axis in a specified system parameter file in comma separated value (.CSV) format, and can be printed viewed, printed, or edited from Microsoft Excel. If the parameters for a specific axis are changed, the changes also are written to the specified system parameter file. Multiple system parameter files may be defined, and the system allows the user to select a desired system parameter file, edit it, and download it to the PLC CPU and the motion control modules. A view of the Main Menu is shown in Figure 3.

The system also allows the user to edit parameters on a specific axis of motion. Clicking on the specific axis's parameter edit button will cause the system to read the parameters for the axis from the PLC CPU (stored in the CPU's battery-backed memory), display them, and allow the user to edit them. The parameters are displayed and edited in base unit format. The parameters can be downloaded with the fault bit either enabled or disabled. The parameters that are read from the PLC are read from the PLC CPU, not the motion control module for the specified axis. Allowing the user to manipulate individual parameters is especially useful for setting up an axis for a specific application, or for making minor changes to an axis' settings. A view of the main menu, with an axis open for parameter editing, is shown in Figure 4.

Other parameters that may be set are the system application's title, the system parameter .CSV file name, the name for each axis, and a window for system parameters. These parameters, as well as all axis parameters mentioned above, can be edited from the main menu. The HMI saves the title, system parameter .CSV file name, and axis names. The commonly changed parameters of axis positioning and jog speed, commanded position, incremental move amount, following error, in-position band, and nulling deadband can also be set from the run menu.

RUN MENU

Controlling the actual movement of the axes is performed from the Run Menu. The Run Menu is entered from the Main Menu. The Run Menu consists of an Axis Table, an Axis Control Panel, and an area for user defined functions. A view of the Run Menu is shown in Figure 5. A view of the Run Menu, along with the Axis Parameters and the Profile Parameters windows, is shown in Figure 6. The Axis Parameters and Profile Parameters windows will be discussed later. For the purposes of clarity, button labels are referred to in *italicized, underlined* print.

On the run menu, the user can change the parameters of in-position band, following error, positioning speed, and jog speed. Parameter changes only affect the axes that are selected by the user, who selects or de-selects an axis by clicking on the axis' name (selected axes appear in a yellow box, while unselected axes appear in a gray box). The user can input axis parameters in either easily measured base units, which are generally invariant from one application to another, or engineering units, which are dependent upon a particular test. The default conversion from base units (BU) to engineering units (EU) is simply a linear slope and offset conversion. Other types of conversions may be easily programmed. If Axis 1 is in base units and Axis 2 is in engineering units, the value entered for any parameter will be in base units for Axis 1, and engineering units for Axis 2. It is recommended that, after the axes have been set up, the axes should be left in engineering units mode for most operations.

Axis motion follows a similar operation as setting axis parameters. All motion commands are performed on selected axes only. The standard motions are jog positive or negative, incremental move positive or negative, move to commanded position, and home axes. The commanded position or incremental move amount for a selected axis or axes can be input in base units or engineering units (depending on which mode the axis is in). Motion for any axis need not be complete before another move command is entered for any axis, including the axis currently in motion. This feature is due to the fact that motion commands are downloaded to the axis MSB modules almost instantaneously, and the PLC CPU can then download additional motion commands (or any other command, such as change a parameter) subsequently. If a new move command is issued before the axis has completed the completed the current motion, the axis simply immediately starts executing the new motion command; the old command is overwritten.

If the user desires, additional features may be programmed. The Run Menu window is set up such that adequate room is left near the bottom of the menu to program any desires features or functions. Buttons, HMI variable values, and PLC register values are some examples of items that may be programmed. The motion system lends itself well to user programming of the system.

Axis Table

The axis table lists, for each axis, axis number, axis name, axis mode, axis current position (in base units or engineering units), negative and positive limit switch status, homing and `homed since last enable' indications, moving indication, in-position bit indication, and drive enable indication. Axes are selected by clicking on the desired axis name(s). Any or all axes may be selected at any time. If an axis is selected, the box that the axis name appears in is yellow; otherwise the box is gray. All axis operations are performed on the selected axes only; the other axes are left unchanged.

There are several buttons associated with the axis table. The *Show/Hide Axis Parameters* is a toggle button that opens (or hides) a window that gives the parameters that are of interest to the user while operating the axes, such as speeds and commanded move amounts, in either base units (BU) or engineering units (EU), depending on the selected units for each axis. The *Show/Hide Axis Move Parameters* is opens (or hides) a window giving only the incremental move amount and commanded position for each axis, either in base units (BU) or engineering units (EU), depending on the selected units for each axis. The *Show/Hide Axis Errors* button and *Reset All Axes* buttons are available for fault detecting and recovery, if needed. The *Select All Axes* button simply selects all axes that have been named on the System Configuration Table on the Main Menu, while the *Un-Select All Axes* button un-selects all axes, regardless of whether any individual axis was selected or not. The *Disable all Motion and Profiles* button disables all axes immediately and stops the profile execution, immediately stopping all motion and resetting motion system control variables. The *Main Menu* button sends the user back to the Main Menu, not affecting any motion or profile currently underway.

Axis Control Panel

As mentioned above, the axis positioning and jog speed, commanded position, incremental move amount, following error, in-position band, and nulling deadband for any or all axes can be set from the run menu. Toggling selected axes from one units mode (base units or engineering units) to the other is also accomplished from the Run Menu, as well as other functions that will be described below.

The *Enable Axis* button will enable all selected axes, shown by the "enbl" symbol in the axis mode space on the axis table. Selected axes must be enabled before any motion is executed. The *Home Axis* button commands the axis to enter its homing routine and the word "home" will appear in the axis mode space on the axis table. The *Off* button will disable the motor drives for the selected axes, and "off" will appear in the axis mode space on the axis table.

The *Increment* button opens a windows allowing the user to set the incremental move amount for selected axes, in either base units or engineering units (depending on the mode of each selected axis). The user can move the selected axes incrementally in the positive or negative direction, at the selected positioning speed, by clicking the up or down arrow buttons next to the *Increment* button, and the axis mode is set to either increment positive (symbol "incr+") or increment negative ("incr-"), as displayed in the axis mode space on the axis table. As mentioned previously, the axes need not complete their current motion before another motion command is issued to any axis, including the selected axes.

On the run menu, the jog speed can be set for the selected axes, in either base units or engineering units (depending on the mode of each selected axis), by clicking the *Jog* button. As long as either up or down arrow next to the *Jog* button is clicked, the selected axes will move in the specified direction at the specified jog speed. If the axis is jogging, it is considered in either jog positive (symbol "jog+") or jog negative (symbol "jog-"), and once jog motion has completed, the axis is returned to the mode it was in prior to the jog command being issued.

The *Command Posn* button allows an axis to set the commanded position for the selected axes, in either base units or engineering units (depending on the mode of each selected axis). To move in positioning mode, selected axes must be placed in position mode by clicking on the *Mode* button next to *Command Posn* button, causing "posn" to appear in the axis status space on the axis table. Movement to the commanded position starts when the *Go To* button is

clicked. The axes need not complete their current motion before another motion command is issued to any axis, including the selected axes.

A good example of the motion system's flexibility is the nulling mode. As mentioned previously, the motion control system was originally developed to control the movement of flow measurement probes. Nulling mode allows the axis to follow a signal that is external to the axis motion control module, usually a pressure transducer signal measuring the pressure differential across a yaw probe. An axis is placed in null mode when the null mode button next to the *Nulling Deadband* select button is clicked, and the word "null" appears in the axis status space on the axis table. The axis motion is then controlled by a true proportional-integral-derivative loop around the positioning loop for the axis. The PID loop takes the actual differential pressure transducer signal (converted to engineering units of pressure) and calculates a desired command position based on the PID loop setpoint. The system allows the user to set the PID parameters of proportional gain, integral time constant, and derivative time constant for any axis by clicking the *Edit* button next to the *Nulling Deadband* button. Clicking the *Nulling Deadband* button itself allows the user to change the delta-pressure deadband over which the motion control system considers the selected axes to be in positioning (when those axes are in nulling mode).

Clicking the *Pos Speed* button allows the user to change the positioning speed for the selected axes, in either base units or engineering units (depending on the mode of each selected axis). The positioning speed for any axis may be changed at any time. Positioning speed is the speed at which incremental moves, absolute positioning moves, and homing operations are performed.

At any time, the difference between commanded position and actual position is defined as the following error. Using the following error fault is useful if a binding problem is suspected, as the actual following error will exceed the allowable following error. The user can change the allowable following error for selected axes, in either base units or engineering units (depending on the mode of each selected axis), by clicking on the *Following Err* button. The new allowable following error is entered on the direct data entry keypad in either engineering units or base units, depending on the axis units selected. The allowable following error for any axis may be changed at any time. In the default fault mask configuration, the following error fault is disabled (masked out).

When the actual position for an axis falls inside a range around the target position, the axis is considered to be in position, and the in-position bit is set for that axis. The in-position bit is used especially for profile operations. The user can change the in-position band, or range, for selected axes by clicking on the *In-Posn* band button. The new in-position band is entered on the direct data entry keypad in either engineering units or base units, depending on the axis mode selected. The in-position band for any axis may be changed at any time.

As mentioned previously, parameters for selected axes may be entered in either base units or engineering units, depending on the units mode for the selected axes. The units are changed for selected axes by clicking on the EU/BU toggle button. If an axis was previously in EU mode, it will now be in BU mode, and vice versa. Parameters entered are in the units format of the selected axes.

The PLC is capable of communicating with external systems, such as other PLCs or data acquisition systems. The original motion system was designed to communicate with the standard system used in aeronautics facilities at NASA GRC, known as ESCORT. There are several data system-related functions that are available directly from the run menu. The *Escort On/Off* button

is used to toggle the motion system between attempting to communicate with the data system, and simulating communications with Escort. The *Single Reading* button initiates a single data system recording from the motion system. Other functions can be easily programmed to suit individual needs.

The *System Help* button opens a series of windows that are used for displaying general system help screens. Buttons for the next or previous help page allow the user to access all of the help screens. The help screens can be opened or closed at any time without affecting axis movement. The help windows can be altered, or additional help windows can be created, to suit individual needs.

MOTION PROFILES

Motion profiles are written in Microsoft Excel, and follow a specified format that allows the motion system to interpret the contents of the profile. Table 3 gives a sample motion profile. All data entered in the motion profile is considered case-insensitive. All of the commonly used manual commands, as well as many profile-based commands, are available to the user for any motion profile. To facilitate profile operations, a series of buttons to perform often used profile operations are provided. Those buttons are *Select Profile*, *Start Profile*, *Show*(profile) *Params*, and *Profile Help*.

In the motion profile, the first column, column A, is used to hold the desired command for the motion system to execute. The operands for the command are contained in the second through the nineteenth columns, or columns B through S. The motion system will step through the motion profile, executing one row at a time. Profile execution will start at row 1, consisting of determining the command in row 1, and then executing the command entered at row 1. The HMI will then repeat this sequence for row 2, then row 3, etc, until either a blank row is encountered or the "end" command is found in column A.

After reading the contents of a particular row, the HMI runs a script to determine the desired operation for that row, based on the contents of the first column. If the cell in the first column of the desired row contains a valid motion system profile command, the appropriate script is opened to execute the desired command. All valid commands have an associated HMI condition script to execute the command. Profile commands are discussed later.

After the appropriate script is run to execute the desired command, another script is executed to read the next row. Once the contents of the next row have been read, the system executes a script that determines the desired operation. The process of reading the next line, determining the command, and executing it, continues until either a blank cell in the first column is found, or the command "end" or "end profile" is entered in the first column. At that point, the motion system performs any operations required to complete data-taking tasks (or other tasks related to external systems), resets all necessary profile parameters, and ends the profile. Table 3 shows an example profile.

PROFILE COMMANDS

The profile command scripts may be broken down to six main groups. For purposes of clarity, profile commands are in *italicized, underlined* print. The first group is used to select various axes. The axes are selected by name with the *Select* command. The names of the desired selected axes are entered in columns B through S. All of the defined axes are selected by using the select command with "all" in column B. All subsequent axis motion and axis mode commands will take place only on the selected axes. In addition, for the motion commands, the data entered in columns B through S corresponds to the axes specified in the last select command issued. For example, if a select command selected axis 2 in column M, then all move commands entered after that would have to specify the positioning data for axis 2 in column M. The axes specified in a select command can be entered in any order, and any column may be left blank. The column match between axis name specified in the select command and axis positioning move data exists until another select command is entered.

The second group is used to enable or disable the selected axes, or set the motion mode or the units mode for the selected axes. Selected axes are enabled or disabled by the *enable* and *disable* commands, respectively. The axis mode for the selected axes is set to increment positive or increment negative with the *incrp* and *incrn* respectively, while absolute positioning is set using the *posn* command. Selected axes are placed in nulling mode through the *null* command. The units mode for the selected axes is set by the use of the *eu* or *bu* commands. The units and positioning mode for the selected axes is important, as the subsequent commands to actually execute the motion will use the units mode and positioning mode to implement that motion.

The third group is used to actually move the selected axes. Several move commands are available, but they are dependent upon the mode the axis is currently in. The *home* command simply homes the selected axes. The *go* command sends the selected axes to a position based on the axis mode and the data entered for the specified axes. The columns are matched with the axis names by the previous select command (see Table 3). For example, if Axis 5 was selected in column J of the previous select command, and if Axis 5 was put in absolute positioning mode, then the go command would send Axis 5 to the position specified by the contents of column J. The data in column J would be interpreted as either engineering units or base units, depending on the mode of Axis 5 when the go command was issued. Frequently, if the motion system is being used in conjunction with an external system, external commands must be executed once the selected axes have moved to their respective commanded positions. Handshaking ensures that motion is complete prior to advancing in the profile.

The fourth group is used to jump to different rows inside the profile. Several commands are available to aid in debugging and looping inside profiles. The *jump to row* N: makes the motion system start executing the profile command at the row (N) specified in column B. The *jump next* N command makes the motion system jump (forward) the number of rows specified in column B, and start executing the profile at that row. The *label* and *jump label* commands are used together, allowing the profile to jump back to a predefined label.

The fifth group is a group of commands that control other, external system parameters. Due to the programmable nature of the motion system, these commands can be programmed to meet individual needs. In the original system, these commands included storing and ending cyclic recordings, storing single data point recordings, calibrating data system components, and kill (abort) a cyclic recording. The capability to simulate external system behavior is also programmed, to aid the user in troubleshooting and debugging.

Finally, the sixth group consists of all other commands available to the user, to give the system more flexibility and making it easier to use. The *message* command opens up a message window, and displays the message given in columns B and C in the profile. The *pause* command pauses the profile; profile execution resumes upon clicking the continue button in the profile parameters window. The *no-op* command is simply a delay in the profile execution, with the delay time being specified by the user.

The profile parameter window allows the user to intervene in the execution of a profile, as well as view the profile parameters and the profile's execution. The window consists of three main areas. At the top, the state of the condition scripts used in the motion system is displayed. If a particular script is executing, its name is shown in red; if not, its name is shown in blue.

The middle of the window consists of eight buttons. The *Pause Profile* button halts the profile's execution until the *Continue Profile* button is clicked. The *Kill Profile* button discontinues the execution of the current motion profile altogether. The *Show Excel Params* button opens a windows that displays the contents of columns B through S of the current row, and these items will update as the profile is being executed from row to row. The *Force In-Posn* button forces the motion system's in-position bit, which is useful if an axis is at a point where it can't set its own in-position bit (such as trying to find the axis null point in an area of turbulence). The *Hide Window* button hides the profile parameters window; the window can be displayed again by clicking on the Show Profile Params button on the Axis Control Menu. The *Escort On/Off* button toggles the external system (ESCORT) communications on or off, and is used identically to the "Escort On/Off" button described in General System Buttons. Lastly, the *Spare* button can be used for user-defined functions.

The items on the bottom of the window are used to display the status of the parameters used for the handshaking, and the general profile status parameters. The profile parameters are the current row number, current command, and the whether the profile has been paused or killed. If a particular parameter is active (on), the name for that parameter is shown in red; otherwise the parameter is shown in blue. The handshaking parameters are set by either HMI or the PLC, and are reset by the HMI scripts. These parameters work together to ensure that the profile does not advance to the next row before the current row has completed execution, and also work to insure that the external system has performed all of its necessary operations before advancing.

As mentioned before, the motion system is written in a modular form. This type of programming greatly enhances the user's ability to modify or add functionality in the field. The profile programming is especially modular, allowing the user to add profile commands with a minimal change to the software application (both the PLC and the HMI) as a whole.

RECENT EXPERIENCE

In the first system, the motion control system was used to control the position and velocity of nine axes, consisting of three sets of three-axis actuators. The three axes of movement on each set are radial (linear) motion, circumferential motion, and yaw (rotary) motion. The axes use DC brushless servo motors, incorporate auxiliary positioning encoders for the axis position and velocity feedback, and use limit (proximity) switches for home and end of travel. On the yaw axes, the differential pressure transducer signal is also included to measure the differential pressure across the actuator.

While a general-purpose actuator can usually accomplish the radial and yaw motion of a measurement probe, fitting an actuator to provide circumferential motion is more specific to the research hardware, as the casing diameters where the actuators mount will change. The radial and yaw actuator assembly, as well as the circumferential drive motor and encoder, all attach to the circumferential actuator's movable carriage. The only piece of the circumferential actuator that is somewhat generic is the carriage, as the other pieces are dependant upon the radius of the casing where the actuator will mount. Set up of an axis can be accomplished either on the bench or while installed in place. Set up includes setting the limit and home switches, the base unit offset, and the conversion between base units and engineering units.

The programmable motion system has thus far been to be reliable and quite user-friendly. The speed of taking data has been measurably increased, and is independent of the addition of more axes. Since the motion system is based on software and hardware that is familiar to other engineers, the ability to program additional features should prove to be quite useful as well. The system has been used in six test facilities at NASA GRC, and is scheduled to be used in several others. Applications external to NASA GRC are also being considered, due to the highly flexible nature of the system. The HMI and PLC software portions can be licensed from NASA GRC.

The motion system's flexibility has already been proven with its modification to provide the positioning of the servo motors used in a thrust measurement stand. The servo motors control the thrust loads placed on the stand during its calibration. The motion system's software was modified to provide automated calibrations, allowing the calibrations to be performed with minimal operator involvement and extreme accuracy in terms of desired loads placed on the stand.

Lastly, since the system is written in a modular, exportable format, a newer HMI interface software package is being investigated. It is hoped that a more modern package will incorporate much of the handshaking that is currently accomplished in programming, as well as overcome some of the other drawbacks of the current HMI package.

TABLE 1 – TYPES OF MOTION AVAILABLE

MODE	DESCRIPTION
Absolute positioning	Allows the user to move an axis to a user-defined absolute position, with respect to the axis home position
Incremental	Allows the user to move an axis a user-defined incremental amount (positive or negative) from the axis current position
Jog	Allows the user to move an axis (positive or negative) as long as the respective button is clicked
Home	Homes the axis

TABLE 2 – USER-ACCESSIBLE AXIS PARAMETERS

PARAMETER	DESCRIPTION
Speed Limit	User-entered positioning and jog speeds have to be below this limit
Maximum Speed	Speed corresponding to 10 VDC
Accel/decel rates	Acceleration / Deceleration rates (base units/time units)/sec (separate)
Pos/neg limits	Software positive / negative end of travel limits
EU/BU slope	Engineering unit / base unit slope
EU offset	Engineering unit offset
Motor Direction	Sets motor direction for positive travel (0 or 1)
Aux Encdr cnts / rev	Auxiliary encoder counts/revolution (used for homing)
Mtr encdr cnts/rev	Motor encoder counts / revolution (used for homing)
Pos encdr cnts/BU	Positioning encoder counts /base unit
BU offset	Base unit offset (sets position when homed)
Pos encdr dist units	Positioning encoder distance units (inches, mm, revs, etc)
Pos encdr time units	Positioning encoder time units (minutes or sec)
PARAMETERS NOT NORMALLY REQUIRING CHANGE	
Fdbk encoder config	Feedback encoder configuration (motor encoder or auxiliary encoder)
Fdbk loss counts	Amount of lost counts required to generate a fault
Current limit	Current limit in percent of max current
Fault mask	Bits to disable certain fault conditions
Homing direction	Direction which axis will home (positive or negative)
Digital in/out mask	Digital input / output masks (separate parameters)
Control wd mask	Mask for axis control word

TABLE 3 – EXAMPLE PROFILE

COLUMN A	COLUMN B	COLUMN C	COLUMN D	COLUMN E	...	COMMENTS
message	Sample profile	for tech paper				Simple message
select	Radial 6		Angle 6			B = Radial 6, D = Angle 6
enable						
posn						
bu						
go	2.0		.2			Position move in BU
select			Angle 6			
go			.1			Move only angle 6
EU						
incrp						Angle 6 increment positive
go			45			Angle 6 increment positive 45 EU
label	Here					Profile will stay in this loop indefinitely (would have to be stopped by user)
go			55			
pause						
go	–55					
jump to label	Here					
						End of profile

FIGURE 1 – MOTION SYSTEM BLOCK DIAGRAM

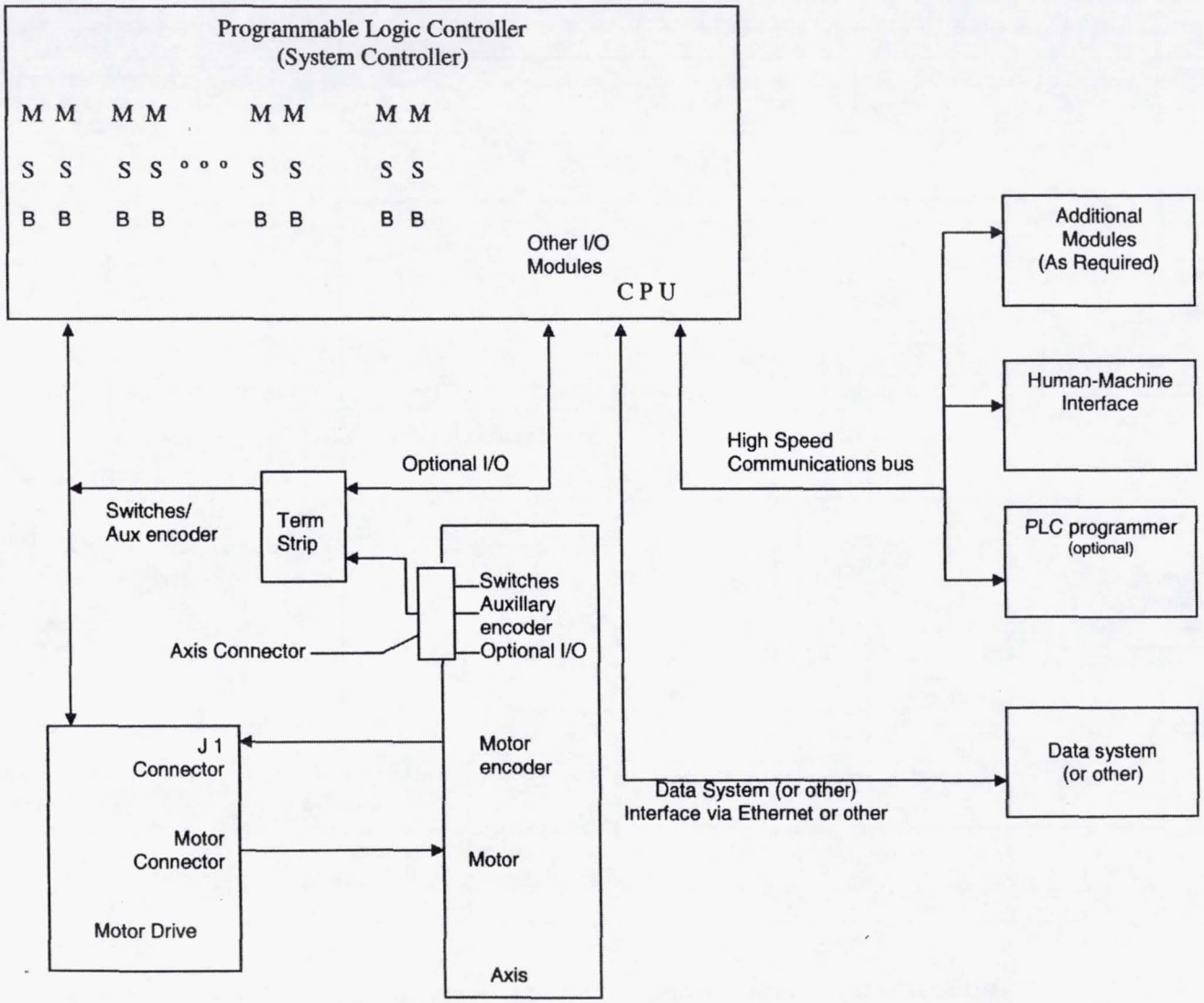
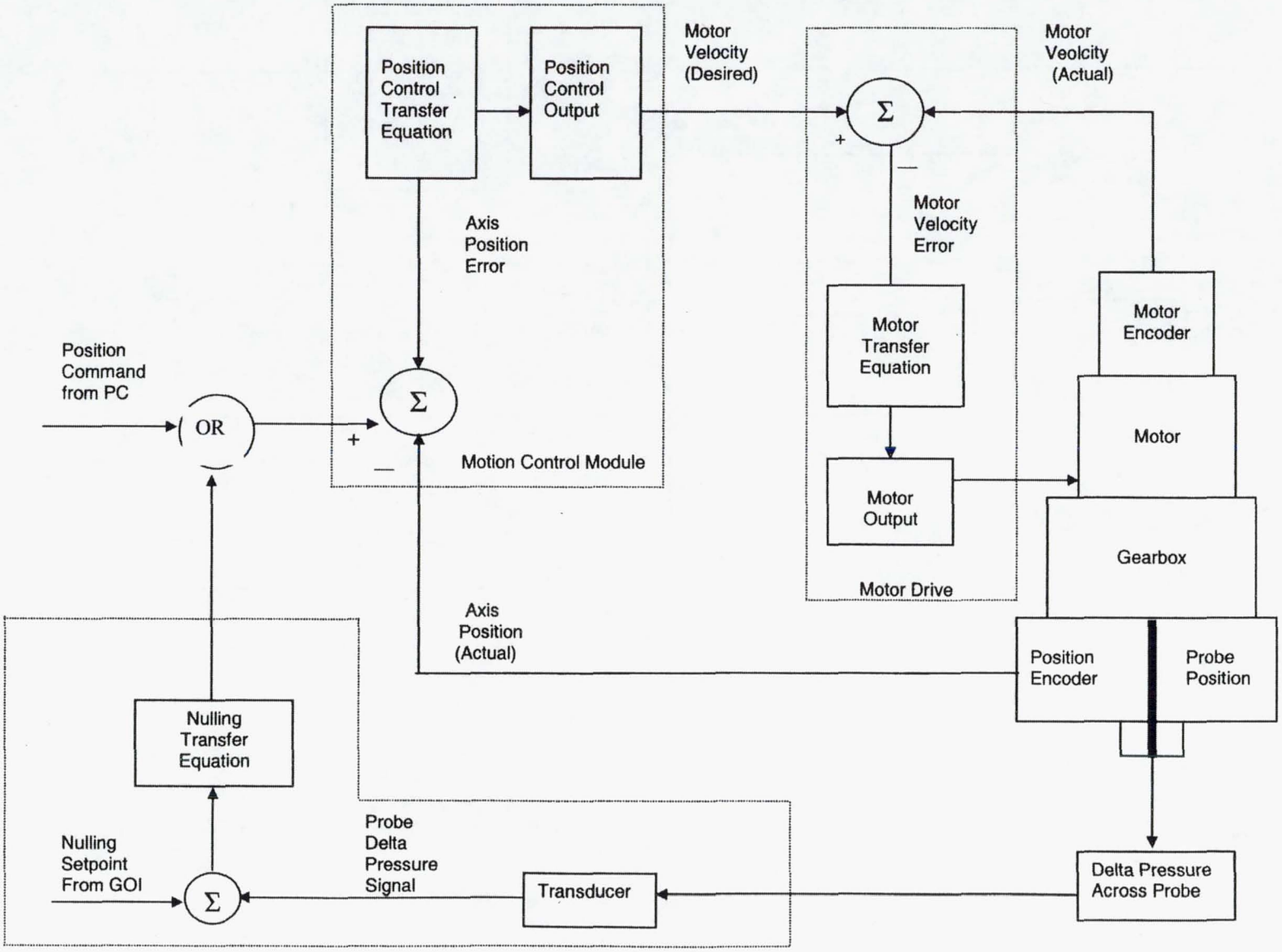


FIGURE 2 – TYPICAL MOTION SYSTEM AXIS CONTROL DIAGRAM



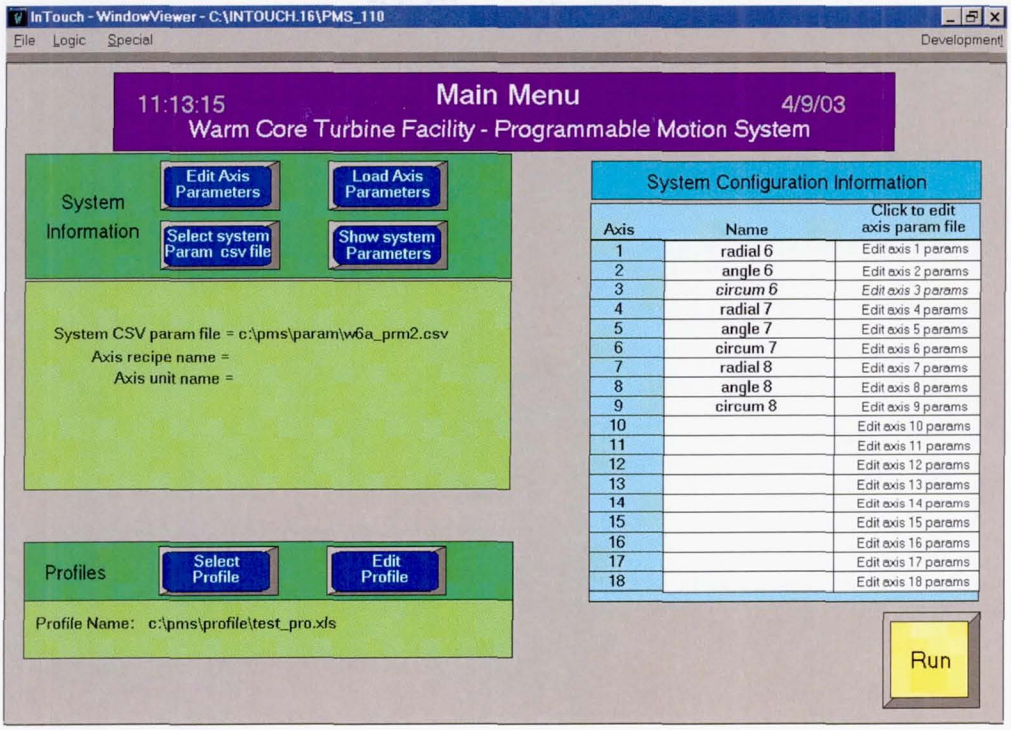


FIGURE 3 – MAIN MENU

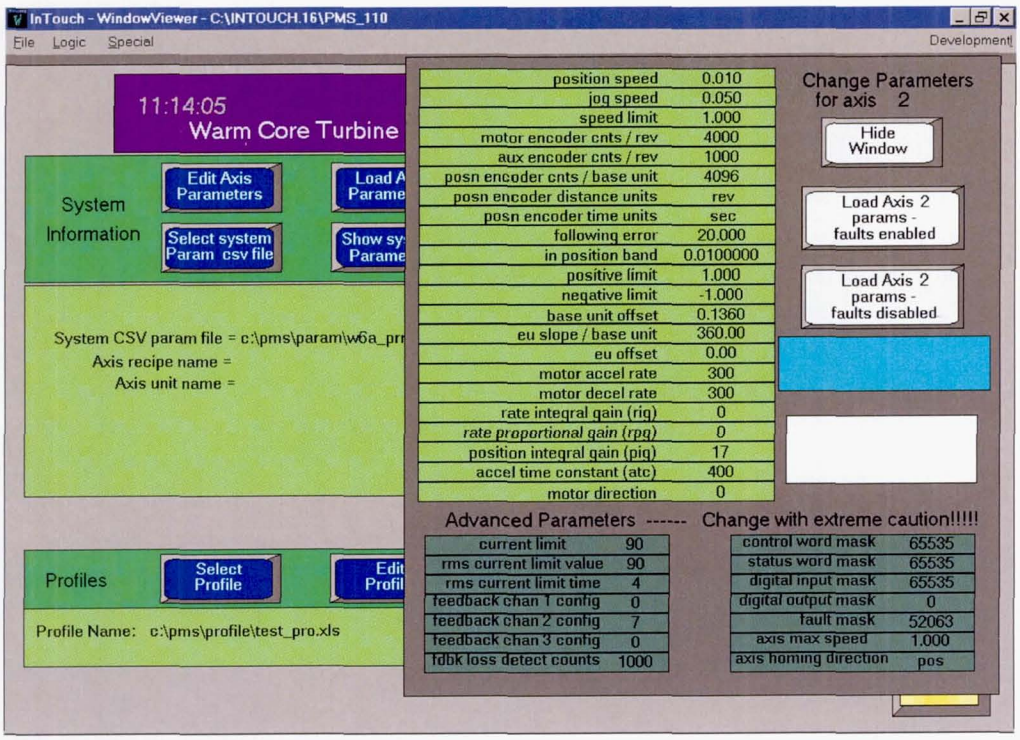


FIGURE 4 – MAIN MENU WITH AXIS PARAMETER EDIT WINDOW OPEN

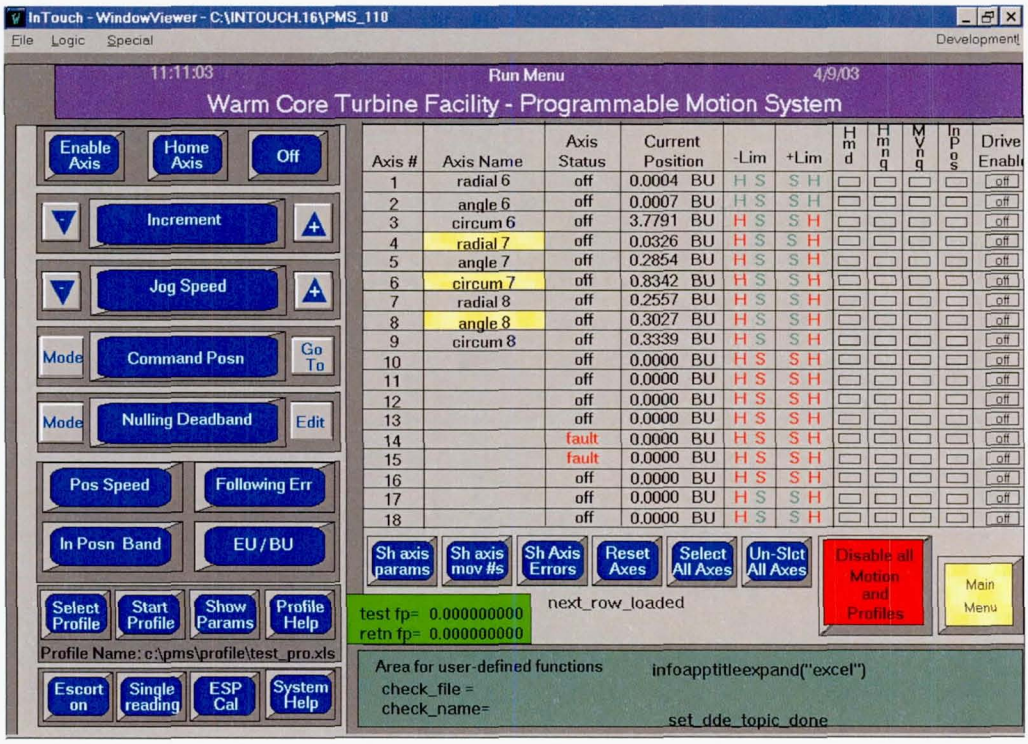


FIGURE 5 – RUN MENU

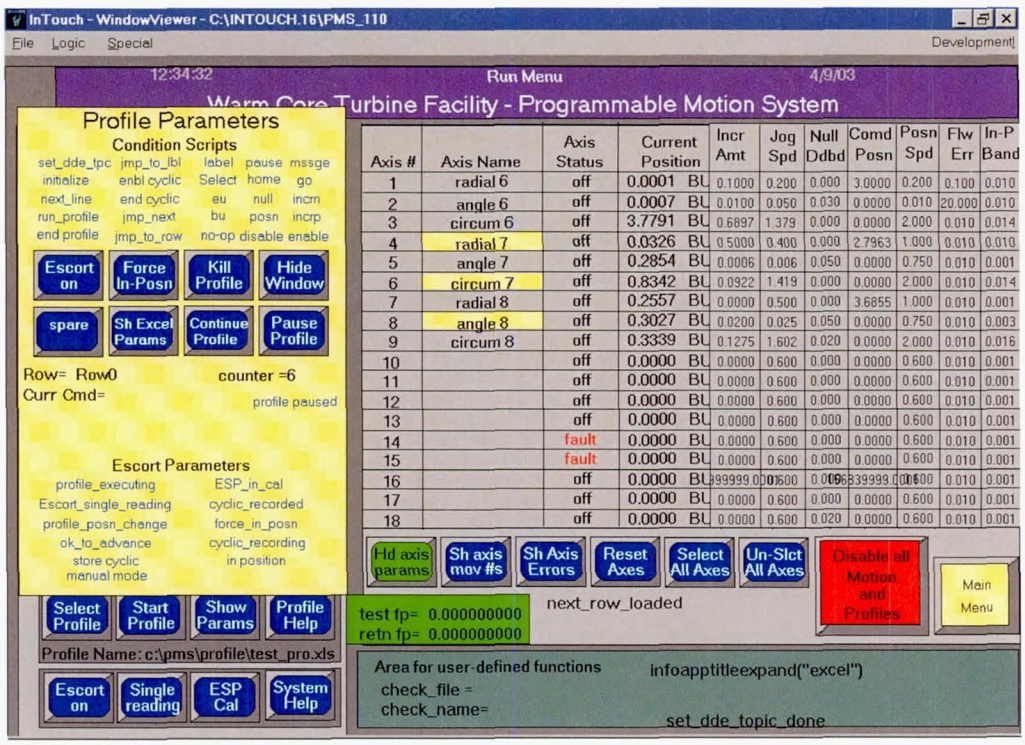


FIGURE 6 – RUN MENU WITH PROFILES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 2003	Technical Memorandum

4. TITLE AND SUBTITLE

A Programmable System for Motion Control

5. FUNDING NUMBERS

Cost Center 2275000007

6. AUTHOR(S)

Brent C. Nowlin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–13954

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—2003-212377

11. SUPPLEMENTARY NOTES

Prepared for the 49th International Instrumentation Symposium cosponsored by the Aerospace Industries and Test Measurement Divisions of the Instrumentation, Systems, and Automation Society, Orlando, Florida, May 4–8, 2003. Responsible person, Brent C. Nowlin, organization code 7545, 216–433–2675.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 09 Distribution: Nonstandard

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The need for improved flow measurements in the flow path of aeronautics testing facilities has led the NASA Glenn Research Center to develop a new motion control system. The new system is programmable, offering a flexibility unheard of in previous systems. The motion control system is PLC-based, which leads to highly accurate positioning ability, as well as reliability. The user interface is a software-based HMI package, which also adds flexibility to the overall system. The system also has the ability to create and execute motion profiles. This paper discusses the system's operation, control implementation, and experiences.

14. SUBJECT TERMS

Motion control; Programmable; Motion profile; Programmable logic controller; Servomotors; Digital command systems; Positioning; Automatic control

15. NUMBER OF PAGES

24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	