5. SCAN CONTROL UNIT

5.1 GENERAL DESCRIPTION

The Lumonics HyperDYE-300 Laser Scan Control Unit System (SCS) provides total keyboard and/or computer control over the operation of the dye laser. Not only does it execute high-precision scans competently and reliably, but it has an easy-to-learn and easy-to-use keypad/display, a menu-driven software package for the host computer, and a flexible interface to the outside world, allowing it to be effectively integrated into almost any operational set-up.

The basic scan operation allows repeated scans between any set limits in continuous or burst mode. The scan can be linear in either frequency or wavelength, and the trigger for burst mode can be supplied from several different sources: internal timer, host computer or external device. Additional motor(s) (for example, for the second-harmonic generator) can be driven at the same time using any user-defined phase relationship with the mirror stage stepper motor.

The optional host computer menu program provides a user-friendly detailed menu-driven control of the Scan Control System, as well as providing disc-based storage of predefined set-ups. The host is connected to the SCS via an RS-232 link, with the data rates of 300 to 9600 bits per second. The host computer menu program is designed for any CP/M or MS-DOS based systems.

Other external control and/or datalogging devices can easily be incorporated into the system. The HyperDYE-300 has a control (or handshaking) facility with three status outputs and two trigger inputs, a chart recording interface consisting of a 0 to 10 volt ramp with marker pulse and pen up/down signal, and a trigger output to the pump laser. The serial interface can also be used to transmit status and current position data to, and transmit any commands from, an external device (e.g. a 'host' computer).

The HyperDYE-300 controls the motion of the tuning stage in the dye laser, and the resultant wavelength is a function of the groove spacing on the grating and the angles of incidence and diffraction of the light incident on the grating, viz:

$$n\lambda = d\,(\sin\theta + \sin\phi)$$

where λ = wavelength
d = groove spacing of grating (typically 416.7 nm)
θ = angle of incidence (fixed near 85°)
ϕ = angle of diffraction
n = order of diffraction

The vacuum wavenumber is the reciprocal of the wavelength (in units of cm) together with a vacuum correction term, which also depends on the wavelength.

Referring to Section 6, Reference Drawings, drawing 423AF10-B depicts the laser configuration with the mirror rotating about the grating.

Drawings 233AF12-C and 233AF13-C show the control system architecture, which is described more fully below.

5.2 SYSTEM BLOCK DIAGRAM

Drawing 233AF12-C gives a quick overview of the system components and their configuration. Note that some of the features may be optional. (A note on nomenclature: The Scan Control Unit (SCU) is the main processor box, and the Scan Control System (SCS) consists of the SCU plus the keypad/display plus the host computer.)

In more detail, the various aspects of the Scan Control System are as follows. The description is in three parts: the interface to the dye laser, the human interface, and the interface to the outside world.

5.2.1 Interface to the Dye Laser - The interface to the dye laser may be divided into five components.

1. The mirror stage drive is controlled by a 4000 step/revolution Berger-Lahr RDM 564/50 five-phase stepper motor. The mirror stage rotation is geared down to 1/35th of a degree per motor revolution, which results in a spectral step resolution of less than 5 x 10^{-5} nanometers (with a grating density of 2400 grooves per mm). The mirror stage may also be moved using the coarse and fine hand cranks.

2. The second harmonic generator (SHG) consists of two additional stepper motors driving a crystal and a prism, each geared to produce a resolution of 2000 steps per degree of rotation.

3. Each motor also has limit switch(es) to restrict its range.

4. The incremental shaft encoder consists of a 2000 transitions/revolution Datametric LC-23, connected to the mirror stage drive with a gear ratio of one transition for every 14 motor steps. The input to the SCS consists of the signals

A, B, M. The phase difference between channels A and B gives the direction of rotation, and M provides a market pulse once per revolution.

The incremental shaft encoder allows the SCS to detect and track any use of the manual cranks, and to detect and correct any errors (e.g. slippage or failure) in the control of the mirror stage drive stepper motor, and thus provides a closed-loop system.

5. The opto-electronic home sensor is used to provide a coarse indication of the absolute position of the mirror stage. This, together with the incremental shaft encoder, provides an absolute calibration of the system to within one encoder pulse.

Additional information may be found in Section 5.5.3. This completes the summary description of the interface with the dye laser.

5.2.2 Human Interface - The human interface has two components.

1. There is a keypad/display consisting of 13 numerical entry keys, 20 function keys, an eight-digit LED display, and 10 LED indicators (see Drawing 233AL12-C).

2. There is a menu-driven control program for a host computer (see Figures 5-1 and 5-2).

Section 5.4 gives a complete description of the use of the keypad/display and of the menus.

5.2.3 Interface to the Outside World - The interface to the outside world may be divided into four components.

1. The serial ports are used to communicate with the keypad/display and with the host computer, or with any other user-supplied control or data logging devices. The SCU polls each device several times each second to determine whether the device has a command to be processed. The SCU also continuously outputs the current position and status information.

2. The system provides a FIRE pulse which can be used to fire the pump laser.

3. The three status output and two strobe input lines provide handshaking for digital control of the SCU when scanning in burst mode. The NEXT POSITION input causes the system to move the amount specified by BURST INCREMENT, and the BURST FIRE activates the FIRE triggering to the pump laser, at the frequency and with the count specified by the user. (This handshaking can also be completely controlled using the serial port.)

4. The SCS can provide a chart recorder with a MARKER PULSE of user-selectable width and frequency. The width of the MARKER PULSE is adjustable with R2 on the User Interface Board. The frequency is entered as a scan parameter from the keypad or host computer. As well as the MARKER PULSE provided is a 4096-Step 0 to 10 volt RAMP and a PEN UP/DOWN signal.

   Because the MARKER PULSE and RAMP are controlled with feedback from the shaft encoder, in situations where the scan rate is slow and the marker increment is small, the marker pulse may appear in a non-linear fashion. This is due to the shaft encoder oscillating across a transition while travelling in a certain direction and the perhaps burstly characteristics of the shaft encoder gears. To prevent gross non-linearities, a lower limit on the MARKER PULSE is set at 0.01 nanometers or 0.5 wavenumbers.

   There is no lower limit check when the selected units is degrees. Also there is no lower limit check mode when converting from one set of units to another. This allows the user to select a marker increment below the lower limits in nanometers and wavenumbers by entering the small value in degrees mode and converting to the desired units.

5.3 UNPACKING AND INSTALLATION

5.3.1 Installation of Scan Control Unit and Keypad - Unwrap the SCU and keypad/display and save the packing material for possible future use or inspection by the carrier should any damage be discovered. Carefully inspect the units for damage; if any is found, notify the carrier immediately.

5.3.2. RS-232C Protocol for Lumonics Host Software - The host software for both CP/M and MS-DOS use the same serial protocol. When using a computer controlled host, set the format for the RS-232C port as follows:

9600 bits per second,
2 stop bit,
No parity,
and set the DTE/DCE switch at the top of the I/O User Interface board to DCE.

See Section 5.5.5 for information about DIP switch settings.

5.3.3 Installation of Host Computer Software - To install the host software, it is suggested that the following sequence of steps be followed.

Firstly, check that the disk format of the Lumonics disks matches that of your system. You should then make copies of the two originals, and store the originals in a safe place.

Secondly, you should ensure that your serial hardware, together with its driver software, is correctly installed. Set the SCU DIP switches into the special Serial Test Mode with the correct bit rate selected (see Section 5.5.5), and then power it on. Then run RXTEST on your host machine. RXTEST transmits bytes from 0 to 127, and the SCU echoes the successor of whatever it receives; for a complete description, see the listing in Section 6.

If RXTEST fails, there are two other routines which may be helpful in tracing the problem: TXTEST and READER. See Section 6 for a complete description and listing. Also included is an example of an appropriate driver for the Pure Data PDA232C serial card.

Additional Checks Required for CP/M Systems

Check that your Screen Control Characters are properly configured. Run the program SCRNTEST; this is a self-documenting program to test your display. The width of your display and the cursor control characters should be in the file CUSTOM.TXT.

Lastly, you should determine whether or not the data transmitted from the SCU to your computer should be in hexadecimal format (when in doubt, choose the hexadecimal format). This format is available because some CP/M operating systems do not, when waiting for a character to arrive on the serial port, distinguish between such characters and characters from the keyboard. You may determine whether this is true for your system with the programs READER and TESTPROG; again all the necessary documentation is in Section 6. The flag in the second line of the file CUSTOM.TXT should be set, and the appropriate switch of the SCU set if the hexadecimal format is selected, and cleared otherwise.

Now you can run the menu program: enter HYPERDYE followed by a carriage return.

5.3.4 A Primer - The basic function of the Scan Control System is to allow the user to scan the dye laser over any spectral region. The SCS is very flexible, allowing the user to select a scan format which exactly meets his requirements, yet is at the same time easy to use.

A scan can be initiated from either the main menu at the host computer or from the keypad, so let us first have a quick overview of these. (The exact function of each key or command will be described in detail in Section 5.4.)

The keypad is shown in Drawing 233AL12-B. The keys can be divided into three groups: the set-up keys (including PRES POS and UNITS SELECT), the numerical entry keys, and the control keys. As well, there is a thumbwheel switch on the right-hand side of the keypad's casing - this is used to change the functions of the set-up keys, and can be set to Normal Mode, Calibrate Mode or SHG Definition Mode. These modes are also initiated by different menus in the host computer menu program; Figures 5-1 and 5-2 illustrate the Main Menu and the Calibrate Menu.

From the main menu, or from the keypad in normal mode, we can change the values of the eight parameters which define a scan. Consider, for example, the first parameter - START POSITION. To display its value on the keypad, hit the START POSITION key. A value in the current units will be displayed, with a number "1" in the smaller left-most yellow digit. To change its value, simply key in the new number and hit the ENTER key; the keypad will revert to its usual display of the current position. To correct a keying mistake, hit CLR ENTRY, and to leave the parameter unchanged, hit any parameter key, STOP, or the CLR ENTRY key followed by ENTER. To change the START POSITION using the main menu, hit the "1" key on the host's console, and then in response to the prompt

Please enter start position:,

enter the new value followed by a carriage return. To leave it unchanged, simply enter a carriage return.

The SCAN command initiates a scan. The system first slews to the START POSITION, taking up backlash in the appropriate direction depending on the scan direction, and then waits there until the time given by SCAN DELAY has elapsed. What happens next depends on the scan mode and trigger selection.

In LINEAR mode, the system waits for a trigger, and then scans the dye laser smoothly to END POSITION at the speed SCAN RATE. At the same time, trigger pulses are being issued to the pump laser at FREQ, and marker pulses to the chart recorder at intervals of MARKER INCR. There are several possibilities for the trigger source. If the HANDSHAKE LOOPBACK flag in the calibration table has been set to 1, no trigger is necessary; the system starts as soon as SCAN DELAY has elapsed (but see also the PAUSE command below). Otherwise, the system requires a BURST FIRE strobe input in response to its IN POSITION output, or a BURST FIRE command on the serial link to the host computer.

In BURST mode, the scan does not proceed smoothly, but in steps. There are two types of triggers: BURST FIRE and NEXT POSITION, each of which can either be entered as a strobe on the handshaking facility or as a command on the serial link from the host computer. BURST FIRE causes trigger pulses to be issued to the pump laser at FREQ, the number being given by BURST QUANTITY. NEXT POSITION causes the system to slew the amount given by BURST INCREMENT, provided the END POSITION has not been reached. If, however, the HANDSHAKE LOOPBACK flag is 1, the system automatically generates its own triggers, alternating between BURST FIRE and NEXT POSITION, until the END POSITION is reached, starting and ending the sequence with BURST FIRE.

If the SCAN REPEAT COUNT parameter is 1, the system will stop at the end of this first scan. Otherwise, the running count is incremented from 0 to 1, and the scan (together with the necessary triggers) is repeated. The SCAN REPEAT COUNT parameter actually consists of two parameters separated by a decimal point, in the form XXX.YYY. The XXX refers to the total number of scans which should be done (i.e. the terminal count), while the YYY refers to the number of scans which have been done (i.e. the running count). When the SCAN command is given, YYY is set to zero, and the scanning is finished when YYY is equal to XXX.

The PAUSE command suspends the scan, or more accurately, it effects a suspension of the scan; this suspension can be removed and the scan resumed by the SCAN command. If the system is slewing to the START POSITION or waiting for SCAN DELAY to expire, the PAUSE command causes the system to complete any further slewing, to cancel any further SCAN DELAY, and to wait at the START POSITION for a resume command. If the system is in a linear scan, the PAUSE command causes the motors and pump laser trigger to be immediately halted; the scan can then be resumed using the SCAN command. The exact effect of the PAUSE command on a BURST scan is somewhat complicated, and is described in Section 5.4. While the system is paused, certain parameters may be changed; these are described in Section 5.4.

5.4 OPERATION

5.4.1 Calibration Parameters - There are eight parameters necessary to calibrate the scan control system, and they are stored in non-volatile RAM. The default values of these parameters are stored in EPROM.

The calibration parameters may be individually changed by the user by entering the data through either the keypad or the host computer, and the new values will be retained even when the system is powered down. The user may also reload the current calibration parameters with the default values by setting parameter 8 to "2", and then power the SCU down and up again.

The calibration parameters are:

PARAMETER	UNITS	TYPICAL VALUE	ALLOWABLE RANGE
1. Home location angle,	Encoder pulses	904192	700000 - 999999
2. Angle of incidence, θ	Encoder pulses	851397	650000 - 899999
3. Groove density of grating	Grooves/mm x 10	12002	500-50000
4. Mean air pressure	mbar x 10	10133	9000-12000
5. Order of diffraction	Order no.	1	1-6
6. Harmonic assumed for data display	Harmonic no.	1	1-4
7. Backlash	Full steps	200	1-1000
8. Loopback of handshaking/ reset to default		1	0-2

See Drawing 423AF10-B for definition of angles.

Parameters 1, home position, and 2, angle of incidence, will normally be entered in the following manner. Note that these parameters will differ slightly from unit to unit due to manufacturing variations, and that in particular the default values in EPROM are not likely to be correct.

1. With the grating removed, the tuning mirror is jogged to a position at which it will reflect an alignment laser beam back out the dye laser optical path. The user identifies this to the SCU as the zero angle by entering 0 for PRESENT POSITION (with DEGREES X 10000 selected as units).

2. The grating is installed and the tuning mirror is jogged to a position at which it will reflect the beam off of the plane surface of the grating back out the optical path. The user then takes the displayed angle (β) (in degrees x 10000) and calculates the angle of incidence (θ), which he enters into the system using the keypad in calibrate mode or the calibrate menu on the host computer ($\cancel{\beta} = 90° - \beta/2$).
   Θ

3. The HOME command from the host computer or keypad then causes the tuning stage to be driven to the home position, and the user should enter the displayed angle as the home position, again using the keypad or calibration menu. (In the Non-Motorized Model, a prompt tells the user which direction to manually crank the stage to home position; see below.)

5.4.2 Scan Parameters and Present Position - The following parameters, known as scan parameters, are stored in non-volatile RAM.

PARAMETER	UNITS	TYPICAL VALUE (SHOWING SIGNIFICANT DIGITS)	RANGE
Displayed units	= nm = cm^{-1} = nm, harmonic = cm^{-1}, harmonic = degrees x 10^{-4}	--	--
0. Displayed present position	As determined by units: units = nm units = cm^{-1}	560.317 21315.82	See following text
1. Start position	Same as present position	500.000	Same as present position
2. End position	Same as present position	600.000	Same as present position
3. Increment/Rate	Same as present position units=nm units=cm^{-1}	10.00000 1.000	.00005-50.00000 .002-1000.000
4. Marker increment	Same as present position units=nm units=cm^{-1}	10.000 1.000	.01-50.00000 .5-1000.000
5. Scan repeats	--	4	1-999
6. Scan delay	Seconds	30.0	0-1000.0
7. Laser trigger frequency	Hz	32.7	.1-1000.
8. No. of pulses	--	10	1-10000
Scan mode	Linear Burst	--	--

The present position is the wavelength or wavenumber corresponding to the present angle of the tuning mirror, as calculated by the CPU from the encoder reading and the calibration parameters. This value is displayed with an update frequency of approximately 10 Hz, and is also being continuously recorded in non-volatile RAM.

Once present position is calibrated, the system keeps track of present position by maintaining count of motor pulses (or motor pulse commands) with cross-checking to a maintained count of incremental encoder pulses. A new present position may be re-entered any time the motor is stopped.

Parameters 1 to 4, and the present position, are expressed in the currently selected units. These units may be cyclically changed by the UNITS SELECT command in the following order:

Nanometers
Nanometers harmonic
Vacuum wavenumber
Vacuum wavenumber, harmonic
Degrees x 10^{-4}

If the selected harmonic (as given by calibration parameter #6) is 1, then the second and fourth steps are omitted.

The UNITS SELECT command, as well as changing the displayed value of the present position, also performs an automatic conversion of the parameters.

START POSITION
END POSITION
INCREMENT/RATE, and
MARKER INCREMENT

Note that because of the reduced accuracy when the units are in degrees x 10^{-4}, the values of the start and end position may change slightly when converting from, say, nanometers to degrees, and then back to nanometers. The conversion of the increment and rate parameters is done at the start position, and round is applied for aesthetic reasons.

If a RANGE ERROR occurs (see Section 5.4.9.), then the system automatically selects as units DEGREES, with no automatic conversion of these four parameters and, moreover, the automatic conversion will continue to be disabled until at least one of these four parameters is re-defined. The display values of the four parameters, unless the system happens to have been cut back to the same units as when the error occurred, should be treated as being meaningless.

Range checks are performed on values entered as the Present, Start, and End positions, with the allowable ranges:

Nanometers:	about 100.000 to 999.999
Wavenumbers:	about 10000.00 to 99999.99
Degrees x 10^{-4}:	0 to 200000H (about 0 to 210 degrees)

In addition, a check is made to ensure the entered values are realizable using the current grating density, angle of incidence, order of diffraction, and harmonic.

Note that if the entered linear scan rate requires too great a motor speed, an error will be reported during the scan. The present maximum motor rate is about 10,000 ministeps per second.

Parameter changes are allowed only when the system is STOPPED, excepting scan parameter numbers 4 to 8, which can be changed when the system is PAUSED. The keypad and the host menu program both check the current status before the user is allowed to key in the parameter; a parameter, however, can be displayed anytime.

5.4.3 Scanning - The SCU can operate in one of two scan modes: LINEAR, which is used to record data in analog fashion; and BURST mode which is designed for digital datalogging. As the name implies, linear mode will generate a scan that has position (wavelength or vacuum wavenumber) changing linearly in time at a programmable RATE.

The scan will proceed from START POS to END POS, with appropriate backlash take-up at the start of the scan, depending on whether the END POS is greater or less than the START POS.

The analog interface lines are Scan Status, 0 - 10 V Ramp, and Marker Pulse. The Scan Status line is simply to indicate that a scan is in progress, and can be useful as a pen up/down control on an X-Y plotter. The 0 - 10 V Ramp will output a DC voltage (from a 12-bit D/A converter) proportional to the position in the scan. The ramp idles at 0 V, is 0 V at the start of the scan, and increases linearly to 10 V at the end of the scan. This is intended to drive the X-axis of an X-Y plotter. The Marker Pulse is simply a 5 V signal output at regular increments during the scan. Refer to Section 6 for timing details.

When in BURST MODE*, the firing of the pump laser (and hence collection of data) is synchronized with the tuning drive motor. This ensures that the pump laser is triggered only at known wavelength (or wavenumber) positions, allowing reconstruction of all spectral data. Before the scan commences, the In Position and Firing Complete lines are both false (high). After the SCAN key is pressed, the SCU slews to the START POS then sets the firing complete line true and waits for the SCAN DELAY to expire. The SCU then makes In Position true. This is to be followed by a Burst Trigger low-going edge into the SCU which is acknowledged by Firing Complete line going false, and initiates a burst of pulses to the pump laser (BURST QUANTITY at the burst FREQUENCY). Once the burst is over, the SCU puts the Firing Complete line true. This is followed by receipt of a Next Position low-going edge, at which time the In Position line goes false and the position drive motor starts slewing (fastest mini-step rate) the length of the programmed increment (INCR). When slewing is complete, the In Position line goes true and the sequence repeats until the END POS is reached. The four I/O lines can be used as true handshake lines with an external control, or jumpered at the D-connector to have burst mode run under control of the SCU. One jumper would go from In Position to Burst Trigger, and another from Firing Complete to Next Position. This jumpering or loopback of the handshaking signals can also be done under software by setting the LOOPBACK calibration parameter to 1. Note that the burst mode scan position need not change linearly with time, since the data (signal intensity information) is logged against a known position.

The SCAN command is used to initiate a scan after at least START POS, END POS, and RATE have been entered for a linear scan, and INCR, START POS, END POS, BURST QTY, and BURST FREQ for a burst scan. The SCAN command causes the wavelength to be driven past the start position (by the number of steps defined by the backlash parameter) in the direction opposite the scan direction, then to approach the start position in the scan direction. The unit waits there for a time set by the SCAN DELAY and then commences the scan. The scan direction is determined by the relative values of the start and end positions.

The PAUSE command suspends the scan, or more accurately, it effects a suspension of the scan; this suspension can be removed and the scan resumed by the SCAN command. If the system is slewing to the START POSITION or waiting for SCAN DELAY to

* In this discussion, the four handshaking lines are referenced. They are all active low. See Section 5.5.4 for hardware and timing details.

expire, the PAUSE command causes the system to complete any further slewing, to cancel any further SCAN DELAY, and to wait at the START POSITION for a resume command. If the system is in a linear scan, the PAUSE command causes the motors and pump laser trigger to be immediately halted; the scan can then be resumed using the SCAN command.

The exact effect of the PAUSE command on a BURST scan is somewhat complicated, and is described in section 5.5.4.

While the system is PAUSED, the user is allowed to:

- Resume the scan with another SCAN command.
- Stop the scan with a STOP command.
- Change scan parameter #4 through to #8.

Any other command, or any attempt to change any other parameter, is invalid.

After a PAUSE command, the system will be in a PAUSING state until the stepper motors and pump laser trigger have stopped, at which time the system will go into a PAUSED state. The intermediate state is indicated on the keypad by both the PAUSE and SCAN LED's being lit, and during it, the resume command will be ignored and no parameters can be changed. (Handshaking signals, however, can be latched; see 5.4.4.)

The STOP command immediately halts motor motion and the pulse burst, and sends Firing Complete and In Position false. A subsequent SCAN command will restart at the beginning of the first scan.

The SCU will stop when it reaches the end position. If a repeat scan has been selected, the unit will slew to the start position (with backlash removal), wait for the scan delay to expire, and then commence another scan.

See Drawing No. 233AP01-B for complete timing details of the effects of SCAN, PAUSE and STOP keys on the handshaking lines.

5.4.4 Other Motor Commands - The JOG commands consist of FWD, REV, FAST and SLOW, allowing manual control over the mirror position, and may best be described in terms of the corresponding remote keypad buttons. The FWD and REV commands drive the output toward higher or lower values, respectively, when units are nanometers or degrees. If selected displayed units is wavenumber then the FWD command drives output to lower values, and the REV command towards higher values. The speed is controlled by the FAST and SLOW commands. Pressing one of the speed keys (FAST/SLOW) before a direction key (FWD/REV) will reset the speed to the upper or lower JOG speed limit. Pressing either speed key after the direction key (i.e. while JOGGING) will increase or decrease the speed by one step (within the JOG speed limits), with the available speeds being 2, 5, 15, 50, 144, 600, 2400 and 9600 steps/second. The JOG is stopped by pressing the FWD or REV key a second time. It may be resumed at the same speed by pressing only FWD or REV.

When the HG option is present, the jog commands can be modified so that they control only the crystal motor or only the prism motor. Normally, however, the JOG keys run both the wavelength and HG motors. See Section 5.4.5 for a more thorough description of the HG operation.

The SLEW command simply allows rapid position change to any accessible wavelength. With the system halted, the SLEW command is given, followed by a position and ENTER. The system immediately slews to the position entered with the motor full-stepping, with backlash taken up in a positive (i.e. low to high wavelengths) direction.

The HOME command immediately slews (full-stepping) the tuning stage to the home position, again taking up backlash from low to high wavelengths. The home position is at the shaft encoder marker pulse immediately after the home sensor transition point. The HOMING status is indicated on the keypad by the SCAN LED. N.B. At the conclusion of the homing operation, the current position is redefined as per the home sensor entry in the calibration table, except when the current units are DEGREES.

Closely related to the HOME command is the local homing function, which is executed automatically on power-up. The next shaft encoder marker pulse is located, and then the current position is redefined (except when the current units are again degrees) to be the nearest position consistent with the home sensor entry in the calibration table. This local homing function is necessary to handle any movement which may have occurred during power-down and -up.

5.4.5 Harmonic Generation - The crystal for SHG will double the frequency (halve the wavelength) of the fundamental output of the dye laser. The rotary stage for this crystal will be driven by a similar stepper motor system as that which drives the tuning mirror, but with reduced angular resolution. If geared 1:1 to the same rotary stage, the mini-step resolution will be 0.9 arc sec/step.

Since this option is still being developed, we will make some assumptions for the purposes of this discussion. We consider only the common rectangular crystal geometry. This then will require five different crystals to cover the wavelength range of interest. Potassium pentaborate (KPB) will be used to cover the lower wavelength ranges (434 - 490 nm), with the ends of the crystals cut at appropriate angles to the crystal axes so that the crystals are normal to the incident beam for different wavelengths. Either a third KPB crystal or a lithium formate monohydride (LFM) crystal will be used for intermediate wavelengths near 500 nm. Longer wavelengths (520 - 700 nm) will be covered by deuterated potassium dihydrogen phosphate (D-KDP or KD*P), with two different crystal cuts.

The curves which determine the positions of the harmonic generating crystal and prism are each defined by one or more points, evenly spaced in terms of the fundamental wavelength. The start point and the spacing of the definition points are selectable by the user for each pair of curves. The crystal and prism positions are determined from these points using four-point Langrangian interpolation, with the following exceptions:

- if the fundamental wavelength is between an end definition point and its neighbour (at either end of the curve), then three-point Langrangian (i.e. quadratic) interpolation is used;
- if the fundamental wavelength is slightly beyond either end definition point (or more precisely, the distance between the wavelength and the end point is less than or equal to the spacing of the curve definition points), then three-point Langrangian extrapolation is used;
- if only two points have been defined, then two-point Langrangian (i.e. linear) interpolation and extrapolation are used;
- if the fundamental wavelength is not within the above-mentioned range, the value of the curve is taken to be the constant value given at the nearest limit of the range; and
- if only one point has been defined, then the curve is taken everywhere as the defined constant value.

The SCU can store six pairs of curves, with each curve definition consisting of up to forty-five points. Additional curves may be stored on the host computer's disk and transferred to the SCU via the SETUP facility.

Generally, the SCU automatically ensures that the crystal and prism are positioned in accordance with the curves described above, using the shaft encoder position to obtain the fundamental wavelength. There are, however, two exceptions to this rule:

- the user can explicitly command the SCU to jog the motors independently, and
- when a different pair of curves is selected, the motor positions are not changed until a command requiring movement is given.

The status frame contains a code to indicate the status of the SHG subsystem, and this code can have one of four possible values:

- no SHG option present; that is, both motor cards are missing (or inoperative);
- only one of the crystal or prism motor cards is present;
- both crystal and prism motor cards are present and the fundamental wavelength is between the first and last definition point of the currently selected pair of curves; and
- one or both of the crystal and prism motor cards are present, but the fundamental wavelength is outside of the just-mentioned range.

This status information is displayed by the host menu program, but is not displayed by the keyboard.

The commands available to the user for the managing of the SHG curves allow him to perform the following five functions:

- homing-in on an existing curve;
- slightly modifying or extending an existing curve;
- defining a new curve;
- changing the currently selected curve; and
- transferring the curve information to or from the host computer for the SETUP facility.

The commands themselves are (as presented in the SHG menu of the host, and excluding the SETUP functions):

- Cancel jogging and RETURN to curve
- Aligned OK so fix curve & STEP FWD
- Aligned OK so fix curve & STEP REV
- Jog SHG CRYSTAL ONLY
- Jog SHG PRISM ONLY
- ALIGNED OK so redefine SHG position
- Select/Delete Curve

plus:

- STOP
- FAST
- SLOW
- JOG FWD
- JOG REV
- JOG FASTER
- JOG SLOWER

In more detail, these commands are as follows. The commands which specifically refer to the SHG (i.e. the first seven) are valid only when the system is STOPPED (except RETURN, which first stops any jogging).

The JOG FWD, REV, FASTER, SLOWER commands operate normally, and drive all three motors (if present) as per the currently-selected curve. These jog commands can also be restricted using the

Jog SHG CRYSTAL ONLY
Jog SHG PRISM ONLY

commands so that only a single motor is driven. These latter two commands are valid only when the system is STOPPED. The user can repeatedly change which motor is to be independently jogged. This independent jogging can be cancelled by any command (excluding the jog commands and the STEP FWD, STEP REV commands) which moves the main mirror stage motor, namely

SCAN
SLEW
and HOME,

and by the RETURN and ALIGNED commands. That is, any one of these five commands will restore the normal operation of the jog keys. While independent jogging is in progress, the FWD or REV light on the keypad will be on; no indication is given, however, of which motor is moving.

The RETURN command causes the crystal and prism, if they are not positioned according to the currently-selected pair of curves, to be driven to their correct position. Thus, this command can be used to cancel any changes in position caused by the independent jogging function, and as mentioned above, it also restores the jog keys to their normal operation. This command may also be useful in two other instances. If the STOP key is hit during backlash removal, then all three motors are immediately stopped, regardless of whether they are correctly aligned or not. The SCAN, SLEW, HOME, JOG FWD and JOG REV commands will all restore the correct alignment, but these also move the mirror stage; the RETURN command will restore the correct alignment and cause no movement of the mirror stage. The second instance is similar: if a different pair of curves is selected, the system will not initiate any motion required to put the system into correct alignment until the user gives a SCAN, SLEW, HOME JOG FWD, JOG REV or RETURN command, and the latter command will not move the main mirror stage motor.

When executing the RETURN command, the system status will be HOMING. (Note that on the keypad, the HOMING status is indicated by the SCAN LED.) The RETURN command does not cause any backlash in the SHG gearing to be taken up. The STEP FWD and STEP REV commands, however, do cause backlash to be taken up in the SHG gearing by virtue of the fact that the SHG motors will track the main mirror position as per the current curve as it has its backlash removed in the forward direction. Backlash is taken up similarly during the SLEW and SCAN commands.

The ALIGNED command is used to tell the system that it is correctly aligned and that the nominal positions of the crystal and prism should be changed so that they fall on their respective curves. This command also cancels, if necessary, the independent jogging. This command should not be confused with the RETURN command (which moves the crystal and prism so that their position is as per the existing curves), nor with the STEP commands (which, in part, redefine the curves so that the curves are as per the existing position). The ALIGNED command merely redefines the existing position so that it is as per the existing curves. This command may be used after changing crystals, and it may also be used to correct for any movement in the crystal and prism which may occur during power-up or power-down. Normally the user would independently jog the crystal and prism until he could see that the alignment was correct, and then he would inform the SCU of this using the ALIGNED command.

The STEP FWD and STEP REV commands are used to create a new curve and redefine or extend an existing curve. Their action can be divided into two cases depending on whether it is an initial step command or a subsequent STEP command. A STEP command is considered to be a subsequent step command if there has been a previous STEP command and there has not been any movement of the mirror stage motor since the previous STEP command, or if both curves of the current pair have just been deleted (see SELECT/DELETE command below), otherwise, it is an initial STEP command. An initial STEP FWD command will cause the system to move to the rightmost end definition point (that is, the definition point in the currently-selected pair of curves of longest wavelength actually containing valid data) with all three motors correctly aligned as per the definition point. And an initial STEP REV command will cause the system to move to the leftmost end definition point (also called the start point). Subsequent STEP commands perform two functions:

- the curve is extended or modified to reflect the current alignment at the current definition point, and
- the system is moved in the appropriate direction to the next curve definition point. (The STEP FWD command initiates movement in the direction of increasing wavelength.)

Thus, we see that a subsequent STEP command, by definition, can be given only at a curve definition point. And when the command is given, the current positions of the crystal and prism are saved in non-volatile RAM, thus modifying or extending the curves, depending on whether or not the point had been previously defined. In the latter case, if the user has not independently jogged the crystal or prism motors (or if he has cancelled the effects of any such jogging with the RETURN command), then the pair of curves is of course left unchanged.

As an example, suppose we wish to extend a curve in the direction of increasing wavelength. We first press STEP FWD. The system will then move to the last definition point, with either the FWD or the REV light of the keypad coming on while motion is taking place, and then with the STOP light on when the motion is completed. This last point is presumably correct, so we immediately press STEP FWD again to move to the first new point. All motors move, with the positions of the crystal and prism usually based on three-point Langrangian extrapolation of the last three valid definition points. If some adjustment is required to, say, the prism position, we press JOG PRISM ONLY, and use the jog keys to move the prism to a better position. Then we press STEP FWD again to store the current position and to move on to the next curve definition point. If we wish to double-check a previously-defined point, we can return to it by repeatedly pressing STOP REV.

The final user command to be described is the SELECT/DELETE CURVE parameter, which works as follows. The SCU stores six pairs of curves, labelled as 1,2,3,4,5 and 6. To display the number of the currently-selected pair on the keypad, the user should press SELECT/DELETE CURVE. To then change the selection, the user merely keys in the new curve number followed by ENTER, as with any parameter. The use of the host menu is similar.

To delete the currently-selected pair of curves, and to enter the present alignment as the first point in a new pair of curves, the keypad user should press the SELECT/DELETE CURVE key, which will display the currently-selected curve number. He should then key in the desired spacing between curve definition points for the new curve pair, as an integer in units of nanometers x 10^{-5}. The valid range is from 10000 to 1000000, i.e. from 0.1 nm to 10.0 nm. The user can now move to the second curve definition point with either a STEP FWD or STEP REV command, and so on.

What spacing should be used between the curve definition points? Analysis of the KDP crystal indicates that a 10 nm spacing is sufficient, although a lesser separation may be used to track any non-linearities in the gears which drive the crystal.

For a description of the final class of commands which are used to transfer curve data between the host computer and the SCU, see Section 5.4.7.

Regarding the definition points, all points after and including the first point, of which at least one of its two data values is undefined (i.e. equal to 2^{23}), are ignored. This is true even if only one SHG motor is present, and the undefined value belongs to the motor not present. If one motor is present, and a new pair of values is given to a definition point, the value will be assigned for the position of the non-existent motor. The first point is always considered valid.

If neither SHG motor is present or if the current units are degrees, all SHG commands except the curve select and data transfer commands will be considered invalid.

All SHG commands are valid only when the system is STOPPED, except the data display requests, which are valid anytime, and the RETURN command, which is valid while jogging. The RETURN command first puts the system into the STOPPED state before returning the motors to the correct alignment.

The IN POSITION signal will never be true unless all three stepper motors have stopped.

5.4.6 Keypad Description - This section describes what is displayed by the keypad and what action is taken by the SCU after pressing each key on the keypad. The keys are divided into the following groups: numerical entry, parameter, command, scan mode, and units. The display itself is an eight-digit, seven-segment LED display - refer to Drawing 233AL12-B. On power-up, all LED indicators should be momentarily lit, and the buzzer should sound.

NUMERICAL ENTRY KEY GROUP This group is fairly straightforward, consisting of the digits 0 to 9, a decimal point, an ENTER key and a CLEAR ENTRY key. The value of a parameter will not be changed unless the ENTER key is pressed. The numeric keys have no effect unless the left-hand prompting seven-segment digit is on.

PARAMETER KEY GROUP The parameter keys are the eight parameter entry keys in the SCAN SET-UP group, plus the PRES POS key. When any of these is pressed, the left-most seven-segment display (which is amber and smaller than the other seven) will indicate which key is pressed by displaying the number found in the lower right corner of the parameter key. The remaining digits will show the current value of that parameter.

If ENTER is pressed, there is no change in that value, and the display reverts to show present position in current units.

If a numeral key or the decimal point key is pressed, the display clears and the corresponding entered character is displayed in the least significant position. Subsequent numerals are shifted in from the right until ENTER is hit, at which point the entry is accepted, and the display reverts to show present position in current units. During numerical entry, the decimal point key will have no effect if a decimal point has already been entered and is on the display. Once all seven digits are full, no further numerical entry is permitted. If ENTER is pressed with the display clear, the stored parameter remains unchanged, and the display reverts to show the present position.

If another (or the same) parameter key is pressed (without ENTER being pressed), that new parameter is prompted for entry.

If any other key is pressed (except SLEW), the display reverts to displaying position, and the newly-depressed key results in its normal function being activated. SLEW will behave as a parameter key if pressed during numeral entry.

SCAN MODE KEY AND LED'S This key toggles the scan mode between BURST and LINEAR; the mode is indicated by the respective LED. Scan set-up parameters remain unchanged, but the value of INCR/RATE is in currently displayed units in BURST mode, and in currently displayed units/second in LINEAR mode.

SCAN CONTROL KEY AND LED GROUP There are three keys in this group: SCAN, PAUSE and STOP. Each has an LED associated with it.

The SCAN key is valid only if the system is STOPPED or PAUSED.

If STOP is pressed during a scan, the SCU causes the motor to stop immediately and to immediately stop sending trigger pulses to the pump laser; the SCAN LED goes out and the STOP LED comes on.

If the SCAN LED is on and PAUSE is pressed, the SCU causes the motor and trigger pulses to pump laser to stop immediately (if LINEAR scan), or to finish the current increment or pulse burst (if BURST scan). The PAUSE LED comes on immediately; the SCAN LED goes out immediately (LINEAR scan) or after the current increment or pulse burst (BURST scan).

When the PAUSE LED is on, pressing the SCAN key will resume the scan where it was left off, using whatever scan set-up parameters are now current. (These may have been changed during the pause.)

JOG KEY AND LED GROUP The FWD and REV keys toggle their respective LED's and corresponding motor motions. When both LED's are off, pressing REV turns the REV LED on. The REV key again will turn it off. Similarly, the FWD key turns the FWD LED on, and the FWD again will turn it off. Both lights may not be on at the same time. Pressing FAST or SLOW while either LED is on causes an increment to the next higher or lower speed respectively, in the current direction. When a FWD or REV LED is toggled off, then on again (or the other LED is toggled on), motor speed resumes at the last value active when the LED was turned off. However, pressing FAST or SLOW while both are off will reset the stored speed value to the fastest or slowest of the available speeds. Power-up default jog speed is 144 ministeps per second.

HOME KEY The HOME key initiates the homing action described in Section 5.4.4. While it is in progress, both the SCAN and LED come on. In the homing mode, pressing STOP will cancel the homing and cause the motor to ramp to a halt.

SLEW KEY The SLEW key, when pressed, behaves as a parameter key, except that no stored value is displayed on the display. All that appears is the prompting number and a display of seven dots. As far as numerical entry goes, the system now behaves as if a parameter key and CLEAR ENTRY had been pressed.

If ENTER is pressed, the display reverts to present position display and no action occurs. If a number is properly entered first, pressing ENTER will result in the tuning stage slewing to the wavelength or wavenumber whose value was just entered.

DISPLAY UNITS The UNITS SELECT key operates in a cyclic fashion to display NM (nanometers), a selected HARMONIC of NM, CM^{-1} (vacuum wavenumbers), and a harmonic in CM^{-1}, degrees x 10000, then back to NM. An exception is if current calibration displayed harmonic is 1. In this case, the UNITS SELECT key will cycle between NM, CM^{-1} and degrees x 10^{-5}, with the HARMONIC LED never coming on.

When using NM, the display will show six digits, with three to the right of the decimal place. In CM^{-1} mode, there will be seven digits, with two to the right of the decimal place. If degrees x 10^{-5} are displayed, there can be seven digits, with no decimal point.

A change in the display units will cause an internal (SCU) conversion of the current scan set-up parameters, and present position.

KEYPAD MODE SWITCH (i.e. Thumbwheel Switch)

Position 0 is normal mode.

Position 1 is ~~configure~~ calibrate mode, and Position 2 is SHG mode; either of these states is indicated by the blinking of both the BURST and LINEAR LED's. In these modes, the functions of the Scan Parameter keys are changed as per the following tables. All other keys retain their normal function (excepting that the JOG function can be modified by the JOG CRYSTAL ONLY and JOG PRISM ONLY commands).

HOME POSITION 1	INCIDENCE ANGLE 2
GRATING DENSITY 3	AIR PRESSURE 4
ORDER OF DIFFRACTION 5	DISPLAYED HARMONIC 6
BACKLASH 7	HANDSHAKE LOOPBACK 8

Set-up keys in Calibration Mode. Note that these are all parameter keys; that is, after the operator presses one, the current value is displayed and a new value can then be entered.

CURVE SELECT/ DELETE 1	not used 2
RETURN 3	ALIGNED 4
STEP FWD 5	STEP REV 6
JOG CRYSTAL ONLY 7	JOG PRISM ONLY 8

Set-up keys in SHG Mode. Note that only the first is a parameter key; the others are single-key commands.

5.4.7 <u>The Host Computer Menu Program</u> - The host computer menu program contains five menus:

- the MAIN menu
- the CALIBRATION menu
- the HARMONIC generation definition menu
- the SETUP menu for stored setups, and
- the three-page HELP menu,

with the first three mimicking the corresponding modes of the keypad. To invoke the menu program, the user need only insert the appropriate diskette, power-on the host computer, and type HYPERDYE<CR>. All user commands are generally single-key; a carriage return is required only when entering a parameter. The last line is reserved for echoing commands and prompting. PLEASE NOTE: ALL LETTERS ENTERED MUST BE UPPER CASE.

The MAIN menu, in addition to the standard commands of the keypad, contains the commands NEXT POSITION and BURST FIRE which duplicate the function of the handshaking lines, as well as commands to select one of the four subsidiary menus or to exit to the operating system.

The parameters of the CALIBRATION menu are all integers with no decimal point. To return the system to the factory default configuration, set calibration parameter #8 to 2, and then power the SCU down.

The functions of the HARMONIC menu and the SETUP menu are described in Section 5.4.5 and 5.4.8.

The HELP menu may be invoked from any other menu. The current page may be changed by simply entering the new page number, or the user may return to the previous menu with an X.

<u>CP/M Host Menu</u>

The diskette for the CP/M host computer menu program contain the following files:

HOST.DOC	- A short documentation file
TXTEST.COM	- Can be used to test serial transmission
TXTEST.ASM	- Documentation and source code for TXTEST
READER.COM	- Can be used to test serial reception
READER.ASM	- Documentation and source code for READER
RXTEST.COM	- Can be used to test serial reception and transmission
RXTEST.ASM	- Documentation and source code for RXTEST
SCRNTEST.COM	- Self-documenting program to test screen function
SCRNTEST.TXT	- MBASIC source code for SCRNTEST

SERIAL.HEX	- Hexadecimal version of serial driver used by HYPERDYE
SERIAL.ASM	- Source code for serial driver
TESTPROG.COM	- Test program to display data from SCU and keyboard
TESTPROG.TXT	- MBASIC source code for TESTPROG
AUTOTEST.COM	- Automatic motor movement program looping through commands in AUTOTEST.DAT
AUTOTEST.TXT	
AUTOTEST.DAT	
HYPERDYE.COM	- Menu program
HYPERDYE.BAS	- Version of HYPERDYE which can be run under BASIC
HYPERDYE.TXT	- MBASIC source code for HYPERDYE
CUSTOM.TXT	- Contains configuration parameters and documentation
NOCOMMNT.TXT	- MBASIC program used to create HYPERDYE.BAS
MRUN.COM	- Microsoft run-time library (to be eliminated)
PDAPATCH.ASM	- Driver for Pure Date PDA232C serial card
TEMPLATE.SET	- Text file used by setup facility

To run the menu program, the following files must be on the active disk drive:

HYPERDYE.COM
CUSTOM.TXT
TEMPLATE.SET

MS-DOS Host Menu

The diskette for the MS-DOS Host Computer contains the following files:

HOST .DOC	- A short file to document changes to the host for the IBM
HYPERDYE.COM	- HyperDYE host menu program
RXTEST .COM	- Can be used to test serial transmission/reception
LUMTIT .GRS	- A graphic title page for the host

A fully functional host diskette need only include the following files:

HYPERDYE.COM
LUMTIT .GRS

This leaves plenty of disk space for other utilities that the user may also require during a session (i.e. A desk utility such as the SIDEKICK program).

Software Differences Between CP/M and IBM Versions

As previously stated, the new IBM version of the host software is 100% compatable with the older CP/M version; however, some software improvements have been made to the IBM host.

The old version of the host, although infinitely more versatile than the HD-50 keypad/display, was slow to react to the computer keyboard, and screen refreshing was equally cumbersome. This was due in part to the speed of compiled code produced by Microsoft's Basic Compiler. To remedy this problem, the HyperDYE-300 host software was rewritten in Turbo Pascal 3.0. This permitted a program execution speed many times faster than before and a special keyboard procedure allowed for better key response from the computer.

5.4.8 Predefined Set-Ups - The SETUP menu on the host computer menu program allows the transfer of selected data between the SCU and the host's disk.

The selection of information to be transferred from the SCU to the host is determined by the file TEMPLATE.SET, which should be residing on the host's currently-selected disk. The first line of this text file is a header, which is ignored; the remainder consists of a data request to be sent to the SCU - one request per line. When the user wishes to transfer data from the SCU to host, the menu asks him for the name of the file into which the data should be stored, and it also asks him for a header line for this file. The default extension of the file name is ".SET". The program then sends the requests from TEMPLATE.SET to the SCU, and stores the SCU's responses in the user-specified file. This file can now be saved, edited, printed, etc., and can be sent back to the SCU at any time.

The syntax of the requests and responses is specified in Section 5.5.1, and the meaning of the data values should be clear, except perhaps for the 900 command and the SHG curve data.

The parameter following the 900 command allows the host to directly specify the units and mode as follows with bit 0 the least significant bit:

Bit 0:	units = selected harmonic if set
Bit 1:	units = wn if set, and nm otherwise
Bit 2:	units = degrees if set, overriding bits 0 and 1
Bit 3:	mode = linear if set, and burst otherwise
Bit 4-7:	not used.

With regard to the SHG data, there are two types of data to be transferred:

- the start position and definition point spacing of each pair of curves, and
- the value of each definition point.

For example, to specify that the second pair of curves should start at 400.00000 nanometers with a point separation of 10.00000 nanometers, the host computer would send to the SCU the message

200:40000000:1000000.

(NB: This command also has the side effect of erasing all data but the first point in the second curve pair.) And the host could request the same information from the SCU by sending the message

200.

To specify that the fifth position on the second curve pair should be at 300 ministeps for the crystal, and at -400 ministeps for the prism, the host would send

205:300:16776816

where a two-complement representation is used:

$$16776816 = 2^{24} - 400.$$

To request the same data, the host would send

205.

If the fifth definition point happened to be invalid, the SCU would reply back with

205:083888608:08388608;

where the last two numbers are simply 2^{23}.

5.4.9 Error Codes - After any error, except invalid entry, the system will stop. Also note that the errors are additive, e.g. the common occurrence of errors 200 and 400 will be indicated by an error code of 600.

1 - POSITION RANGE ERROR (RANGERR) The current position cannot be expressed in the current units. This error can occur:

- while jogging
- while homing
- when the current units are changed from degrees
- when a calibration parameter is changed.

The system will automatically select as units degrees, but with no automatic conversion of START, END, RATE, MARKER, and the automatic conversion will continue to be disabled until at least one of these parameters is changed.

If this error occurs without the presence of error code 2, then it simply means that the current position is beyond the valid 100-999 nm or 10000-99999 cm^{-1} range.

ACTION: Use PRES POS, JOG, SLEW or HOME commands to return to a valid position or a valid reading, and then correct START, END, RATE, MARKER.

2 - CONVERSION ERROR (ARITHERR) An error occurred with converting a value from current units to degrees, or vice versa. This error could occur when calculating the current position (in which case it would be combined with an error code #1). It could also occur when converting the START and END positions,

- while changing the current units from degrees
- while changing a calibration parameter.

This error could also occur if START + INCREMENT and/or START + MARKER are invalid during a change in units, and could also occur at the start of a scan if a previous conversion error or position range error had been ignored.

ACTION: Check that START, END, INCREMENT/RATE, and MARKER parameters are all valid.

4 - MOTOR TIMER OVERRUN (OVERRUN) The error indicates that the step rate is too high, and should only occur when the scan rate selected for a linear scan is too high.

ACTION: Reduce RATE/INCREMENT.

10 - PUMP TRIGGER TIMER OVERRUN (PUMPERR) This error, if it occurs, indicates that the interrupt 0 input to the CPU chip is active too much of the time. This problem could be caused by:

- excessive shaft encoder jitter and/or bad signals (e.g. poorly grounded) from shaft encoder;
- similar problems with handshake input lines.

ACTION: Disconnect handshake lines and select internal loopback of handshake signals. If problem still present, trace signals using scope, or call serviceman.

20 - SERIAL INPUT BUFFER OVERFLOW (OVERFLOW) An input line of more than 25 characters was received.

ACTION: Retransmit command line.

40 - UNEXPECTED INTERRUPT FROM LUMO BUS (INTERR) This is perhaps caused by noise, or an incorrectly jumpered board. This error often occurs on power-down.

ACTION: If problem is repeatable, trace it with scope.

The next five errors are concerned with the shaft encoder. Their possible causes include:

- excessive jitter (possibly caused by motor problems)
- poor signals and/or interference
- slippage of gear attached to motor shaft
- insufficient number of steps in backlash removal

After any shaft encoder error, the user should execute the HOME command, or at least effect a local home by powering down and up again.

100 - NO SHAFT ENCODER INDEX PULSE DETECTED (HOMERR) This can only occur during the local homing function on power-up, and indicates that no index pulse was received while going forward 60,000 ministeps (i.e. more than two revolutions of the shaft encoder).

200 - NO SHAFT ENCODER INCREMENT DETECTED (INCRERR) This error occurs when the motor position is being synchronized with the shaft encoder, and indicates that no shaft encoder step occurred while issuing 20 ministeps.

400 - SHAFT ENCODER AND MOTOR POSITION DISAGREE (POSTNERR) The tolerance is 2.4 encoder steps while ministepping, and 4.8 encoder steps while full-stepping. This error can only occur while:

- slewing
- scanning, or
- homing,

and will not occur:

- during backlash removal
- while jogging
- during power-up local homing function, or
- when system is stopped.

1000 - ABRUPT CHANGE IN SHAFT ENCODER POSITION (SHAFTERR) The shaft encoder position changed by more than two between servicing of interrupts; this can be caused either by poor signals or noise, or by too high a rate on a linear scan.

2000 - EXPECTED OVERSHOOT ON SLEW DIDN'T OCCUR (SLEWERR) The number of steps in backlash removal is possibly too small.

4000 - NOT USED (reserved for system development).

The next three error codes are concerned with the motor driver(s).

10000 - MOTOR ERROR #1: LIMIT SWITCH DETECTED OR MOTOR CABLE INTERLOCK

20000 - MOTOR ERROR #2: MOTOR TIMEOUT A motor card did not respond to a command from the CPU. This error, in conjunction with 40000, will occur if it is attempted to issue a motor movement command (e.g. JOG FWD) in the Non-Motorized Model, which does not have any motor driver assembly.

40000 - MOTOR ERROR #3 Protocol Error: An error was detected in the interface between the CPU card and a motor card.

100000 - ENTRY ERROR This can be caused by

- a meaningless command
- a parameter change request with an invalid parameter
- a command disallowed as per the current machine state, as follows.

COMMAND	SCU STATE					
	SCANNING	HOMING	SLEWING	JOGGING	PAUSED	STOPPED
Scan	Ignore	X	X	X	OK	OK
Pause	OK	OK	OK	OK	Ignore	Ignore
Stop	OK	OK	OK	OK	OK	Ignore
Home	X	Ignore	X	X	X	OK
Jog Commands	X	X	X	OK	X	OK
Mode	X	X	X	X	X	OK
Units	X	OK	OK	OK	X	OK
Next Pos, Fire	OK	X	X	X	OK	X
Display Parameter	OK	OK	OK	OK	OK	OK
Change Parameter	X	X	X	X	See Note	OK

X = Results in entry error
Ignore = Command is ignored
OK = Command will be executed

Note: During HOMING, SLEWING or JOGGING, the PAUSE command is the same as STOP.

An entry error can also result when a scan parameter entry, or a PRES POS or SLEW command, fails a range check. Note that no range check is performed on PRES POS, START, END, RATE, MARKER and SLEW when the current units are degrees.

77777 – **BATTERY ERROR** One (or perhaps both) of the two lithium cells in the non-volatile RAM has been depleted. Note: See also Power-Fail Error error.

ACTION: The system is still completely operational, but the user should first verify that the current scan and calibration parameters are still valid before proceeding.

77777 – **POWER-FAIL ERROR** The power supply board had signalled that the power was about to fail, but the power never did fail. Note: See also Battery Error; the two errors have the same code, but they cannot be confused since they occur at different times.

ACTION: Perhaps there was a glitch in the power supply, so the SCU should be manually powered down and then up again to ensure that everything is in a valid state.

5.4.10 Non-Motorized Model -

GENERAL DESCRIPTION The Non-Motorized Model contains no motor drivers: all movement of the mirror stage is made using the handcranks. On power-up, the system checks whether the mirror-stage motor card responds to its commands, and if not, it assumes a non-motorized configuration with no motor card present.

The following commands are valid in the non-motorized configuration:

PRESENT POSITION
UNITS SELECT
SCAN
HOME
STOP

PRESENT POSITION and UNIT SELECT commands operate as usual. The remaining commands are used for scanning or homing, as described below.

SCANNING WITH THE NON-MOTORIZED MODEL The SCAN command allows the system to generate the following output signals:

- 0 to 10 volt ramp
- Marker pulse
- Trigger pulse
- Scan status/pen down

(Note that either of the two pulse signals can be used to trigger the pump laser.) The SCAN command is only valid when:

CURRENT < START < END
or CURRENT > START > END

After the user gives the SCAN command and moves the mirror stage past the START position towards the END position, the 0 to 10 volt ramp will be increased as per the mirror stage position, and a marker pulse will be issued each time the mirror stage is moved by the amount given by MARKER INCREMENT. The SCAN STATUS/PEN DOWN signal will also go active, and trigger pulses will be issued continually at frequency FREQ.

When the user eventually moves the mirror stage past the END POSITION, or if the user gives the STOP command, scan mode is immediately terminated and the above-mentioned output signals return to their inactive state. The SCAN light, which goes on when the SCAN command is given, will go off.

Note that if the user moves the mirror stage in the wrong direction, the value of the 1 to 10 volt ramp will remain fixed and will not decrease, and no marker pulses will be issued.

But if the user again reverses direction, the ramp and marker pulses will resume operation once the previously obtained position is reached.

After giving the SCAN command, if the user has not moved the mirror stage past START position within 10 seconds, the scan will be terminated. This timeout helps ensure that the pump laser is not inadvertently activated by merely turning the handcrank.

HOMING WITH THE NON-MOTORIZED MODEL The HOME command is used:

- To find the home location (when the current units are DEGREES), and
- To re-define the current position using the position of the home location stored in non-volatile RAM (when the current units are not DEGREES).

The home location is the first shaft encoder index pulse following the home sensor transition, when moving in the forward direction. When the HOME command is given, the user should move the mirror stage in the direction indicated by the FORWARD and REVERSE LED's on the keypad (or by using the corresponding information on the host menu program).

There are only two cases:

- If the REVERSE light is on, the user should move the mirror stage in the reverse direction until the REVERSE light goes out and the FORWARD light goes on, and
- If the FORWARD light is on, the user should move the mirror stage in the forward direction until the FORWARD light goes out and the STOP light goes on: that is, until the home location has been found.

Moving the mirror stage in the wrong direction has no effect. The homing mode may be terminated at any time with the STOP command.

FEATURE NOT USED IN NON-MOTORIZED MODEL The following are either ignored or invalid in the Non-Motorized Model.

Scan parameters	- INCREMENT/RATE - SCAN REPEAT - SCAN DELAY - BURST QUANTITY
Calibration parameters	- BACKSTEP (number 7) - LOOPBACK (number 8)
Commands	- All SHG commands - The four JOG commands - SLEW - NEXT POSITION - BURST/LINEAR

5.5 INTERFACES

5.5.1 Serial Message Formats - The SCU (the main processor) can issue four types of messages on the serial bus:

Status and Position:	(status) (unit and mode) (SHG status) (position)
Error:	EE (error code)
Data:	(data code) : (data)
SHG Curve Data:	(point code) : (crystal position) : (prism position)

(The protocol related messages, such as polls and acknowledgements, are excluded here. Refer to section 5.5.2.) And a remote station or terminal can send four types of commands to the SCU:

Basic Command:	(command code)
Slew Command:	(command code) : (new position)
Data Request:	(data code)
Data Change Command:	(data code) : (data)
SHG Curve Data:	(point code) : (crystal position) : (prism position)

Here (status) is a single letter indicating the current system status, (unit and mode) is a single letter indicating current units and scan mode, and (SHG status) is a single character giving the SHG motor(s) status, as follows:

(Status):

- @ - scanning, with IN POSITION true and FIRING COMPLETE true
- A - scanning, with IN POSITION false and FIRING COMPLETE true
- B - scanning, with IN POSITION true and FIRING COMPLETE false
- C - Scanning, with IN POSITION false and FIRING COMPLETE false
- P - paused
- Q - pausing
- S - stopped
- F - jogging or slewing in forward direction
- R - jogging or slewing in reverse direction
- T - retracing
- D - waiting for SCAN DELAY to expire
- E - error
- H - homing

(Units and Mode):	N	- nanometers, burst mode
	n	- nanometers, linear mode
	W	- wavenumbers, burst mode
	w	- wavenumbers, linear mode
	M	- nanometers, harmonic, burst mode
	m	- nanometers, harmonic, linear mode
	V	- wavenumbers, harmonic, burst mode
	v	- wavenumbers, harmonic, linear mode
	D	- degrees x 10,000, burst mode
	d	- degrees x 10,000, linear mode
	E	- error (i.e. EE)

(SHG Status):	(blank)	- no SHG motors present
	- (minus)	- SHG crystal motor present
	= (equals)	- both SHG motors present
	# (no. sign)	- one or both motors present, but current position outside range of SHG curve

The (position), (error code), (data code), and (data) are all positive numbers in decimal ASCII notation, with the most significant digit first and perhaps with a decimal point. The (position) is the current position in the current units. The (error code) is a six-digit code, as described in Section 5.4.10. The various (command codes) are single letters, as follows:

(Command Code):	G	- scan
	P	- pause
	S	- stop
	H	- home
	9	- slew
	F	- jog forward
	R	- jog reverse
	Q	- faster jog
	Z	- slower jog
	B	- change scan mode
	U	- change scan units
	L	- burst fire
	N	- next position
	C	- SHG: return
	K	- SHG: aligned
	D	- SHG: step forward
	E	- SHG: step reverse
	I	- Jog SHG crystal only
	J	- Jog SHG prism only
	Y	- SHG: reserved for future use

The slew command (9) requires the new position data. The (data code) is a one or three-digit code defining the type of data, as follows:

(Data Code): 0 - present position
1 - start position
3 - incr/rate
4 - marker increment
5 - scan repeat count
6 - scan delay
7 - frequency
8 - burst quantity
900 - select current units and mode
901 - home location angle
902 - angle of incidence
903 - groove density of grating
904 - order of diffraction
905 - mean air pressure
906 - harmonic assumed for data display
907 - backlash
908 - internal loopback/factory default reset
909 - select/delete current SHG curve

The SHG curve data has the following format.

Let X be the curve number, from 1 to 6. Then in the message

X00:YYYYYYYY:ZZZZZZZZ,

the Y field gives the position (in nanometers x 10^{-5}) of the start of the crystal curve #X and the prism curve #X, while the Z field gives the spacing between the curve separation points (also in nm x 10^{-5}). And for NN from 01 to 45, the message

XNN:CCCCCCCC:PPPPPPPP

gives the positions (in ministeps) of the crystal and prism at the NNth definition point on the Xth curve. A position of 2^{23} indicates an undefined value.

For display purposes, it is sometimes necessary to know the exact representations of the messages, which are as follows. Let

D = digit 0 to 9
N = digit or possibly leading blank
X = digit or decimal point or leading blank
b = blank
S = status byte

Then a status or error frame has one of the formats

SSSbDDD.DDD
SSSDDDDD.DD
SSSbNDDDDD
EEDDDDDD,

and a parameter frame has one of the formats

D:XXXXXXXD (with at most seven digits)
90D:bNNNNNND
DDD:DDDDDDDD:DDDDDDDD.

5.5.2 Serial Protocol - The following describes the serial protocol used by the SCU to communicate with the keypad and any external host computer. (A simpler protocol is given below in Section 5.5.5.) The keypad or host will just be referred to as the "terminal".

The SCU initiates a data transfer sequence by polling the terminal; it sends an

<ENQ>.

The terminal should respond with either an

<ACK>

or a

<message> <checksum> <CR>.

If no response is received within a 45-character period, then the SCU gives up and polls the other terminal. (To measure this period, the SCU transmits up to 45 NULs, which should be ignored by the terminal.)

If the terminal had sent an <ACK>, the SCU will respond with a status or error frame:

<status message> <checksum> <CR>,

or

<error message> <checksum> <CR>

and then go on to poll the other terminal.

If the terminal had sent a message, the message would have been either a command or a data request. If the former, the SCU will execute or initiate execution of the command and respond with a status or error frame as above. If the latter, the SCU will send a data message to the terminal,

<data message> <checksum> <CR>

and then go on to poll the other terminal.

If the checksum in the terminal's message has been incorrect, the SCU will send an

<NAK>

and go on to poll the other terminal. When the first terminal receives a <NAK> (or any invalid character), it should wait until it is polled again, and re-transmit its message.

The <checksum> consists of the sum (module 256) of the ASCII characters in the message, represented as a two-digit hexadecimal number (with the least significant digit first), with the hexadecimal digit N (for N between 0 and 15 inclusive) encoded as the character whose ASCII value is 96 + N.

Some CP/M operating systems, when told to get a character from the reader device, do not distinguish between a character from the reader and from the keyboard. Since it is essential that the host software be able to make this distinction, the data transmitted from the SCU to the host (but not vice-versa) can be encoded in hexadecimal format.

This hexadecimal format is the same as that used for encoding the checksum, and is applied to all printable (that is, with ASCII codes 32 to 127) characters sent by the host. Thus the host can assume that when it has obtained a character from the CP/M reader device

- if the character has ASCII code 96 to 111, or is NUL, ENQ, NAK or CR, then it came from the SCU
- any other printable character is from the keyboard
- and any other non-printable character is an error.

5.5.3 Dumb Terminal Format - The dumb terminal format is designed so the user can conveniently drive the SCU using only a so-called "dumb" CRT terminal, and has the following features which distinguish it from the usual protocol described above.

- no polling is done by the SCU: a command can be given at any time, and status frames will be continually issued whenever the SCU is not STOPPED or PAUSED
- no checksums are used
- basic commands (that is, those whose codes are a single letter from A to Z) do not require a carriage return
- error messages are prefaced by a LF and terminated by a CR, LF, BEL
- parameter displays are terminated by a CR, LF.

5.5.4 Handshaking Lines - The handshaking lines operate, when the system is in burst mode, as follows.

A command on the handshake line is latched when the system accepts it and stores it for later execution, and the handshaking response is the changing of the corresponding handshake status line from true to false. These three events can occur at separate times.

The status line IN POSITION being true means:

- stepper motor not moving, and
- the system will latch another NEXT POSITION command.

The system will execute a latched NEXT POSITION command if (or when) FIRING COMPLETE is (or becomes) true, with the following exception:

- after a PAUSE command followed by a BURST FIRE command and after the burst has been fired, FIRE COMPLETE will remain false but a NEXT POSITION command can be executed.

IN POSITION goes false (or remains false):

- on power-up
- when retracing begins
- at completion of last scan
- after STOP command
- when stepper motor starts moving
- when a NEXT POSITION command is latched and FIRING COMPLETE is true

and it goes true (or remains true):

- when SCAN DELAY ends
- when stepper motor stops moving, except when PAUSE command has been issued
- when SCAN command following a PAUSE command is issued.

Note that retracing will begin when a NEXT POSITION command is executed, and the system is already at or beyond the END POSITION, and likewise for the completion of the scan.

The handshaking response will occur within 100 microseconds of the command (provided the above conditions are satisfied), and the execution will begin within 10 milliseconds.

The BURST TRIGGER command is entirely similar to the NEXT POSITION command in the obvious sense, with the following exceptions:

- If retracing begins, or the scan is completed, any latched BURST Trigger command will be rejected.
- FIRING COMPLETE goes true when SCAN DELAY begins.
- FIRING COMPLETE goes true one full period after last laser trigger in burst, except when a PAUSE command has been issued.

Note that if the BURST TRIGGER and NEXT POSITION commands are issued almost simultaneously, the order of execution may be reversed. Also note that the system will actually be able to latch a command a few microseconds before the corresponding status line goes true.

SCAN STATUS goes false:

- on power-up
- when retracing begins
- at completion of last scan
- after STOP command

and goes true:

- at the end of SCAN DELAY.

When the system is in linear mode, the handshaking lines operate as follows.

SCAN STATUS is the same as in burst mode.

IN POSITION is the same as SCAN STATUS, except that it also goes false after a PAUSE command, and then true after a SCAN command following a PAUSE.

FIRING COMPLETE goes false on power-up, on completion of last scan, and after stop command, and true when SCAN or SCAN DELAY begins.

NEXT POSITION is ignored.

BURST TRIGGER becomes the scan trigger, and is latched when FIRING COMPLETE is true, and executed when IN POSITION is true. If, however, the scan already has been triggered, the command is ignored.

Note that no additional trigger is required following PAUSE, SCAN command sequence.

Also note that no handshaking is performed, i.e. the external machine receives no acknowledgement of its trigger command.

5.5.5 Dip Switch Setting and Serial Format - The first three DIP switches on the I/O card select the external devices present and the protocol to be used:

Switch 1: Keypad is present (ON = yes, OFF = no)
Switch 2: Terminal is smart (ON = smart, OFF = dumb)
Switch 3: Terminal requires hex format (ON = yes, OFF = no)

These options are described in more detail below. The bit rate for the serial transmission to the terminal is determined by the next two switches:

Switch 4 OFF, Switch 5 OFF:	9600 bps
Switch 4 ON, Switch 5 OFF:	2400 bps
Switch 4 OFF, Switch 5 ON :	1200 bps
Switch 4 ON, Switch 5 ON :	300 bps

The bit rate for the keypad is always 9600 bps.

Certain combinations of the protocol selection switches, namely

- keypad with dumb terminal, and
- dumb terminal with hexadecimal format,

do not make sense. These are used for the following special functions:

- Keypad, with dumb terminal, no hex format = keypad with no terminal (XXXXX001).
- Keypad, with dumb terminal, with hex format = reserved for future use (XXXXX101).
- No keypad, with dumb terminal, with hex format = special serial test mode (XXXXX100).

5.5.6 Pinout for the SCU User Interface - The Scan Control Unit is equipped with a User Interface which is accessed through a fifteen pin D-Connector at the front of the enclosure. This connector supplies the following signals:

Pin	Function
1	Ground
3	Burst Trigger
4	Marker Output
7	+ 5V
8	Ground
9	0-10V Ramp Output @ 5mA
10	Next Position
11	Scan Status - Pen up/down
12	In Position
13	Fire Complete
14	+ 5V
15	Cable Shield

1. Pins 2, 5, 6 are not used and should not be connected.
2. With the exception of pin 9, all pins require TTL voltage and current levels.

```
                Current Status      =  STOPPED
          > 0.  Current Position    =  415.000 <
            1.  Start Position      =  400.000
            2.  End Position        =  430.000
            3.  Increment or Rate   =   .10000
            4.  Marker Increment    =  5.00000
            5.  Scan Repeat Count   =        1
            6.  Scan Delay          =      0.0
            7.  Pump Laser Freq     =     32.7
            8.  Burst Quantity      =       10

Units =           Harmonic =        SHG =      Mode =
NANOMETERS        FIRST             NONE       LINEAR
G.  Scan          9.  Slew          F.  Jog Forward
P.  Pause         H.  Home          R.  Jog Reverse
S.  Stop                            Q.  Jog Faster
                                    Z.  Jog Slower
B.  Burst/Linear                    N.  Next Position
U.  Units Select                    L.  Burst Fire

C = Calibrate         ? = Help      A = SHG Alignment
X = Exit to CP/M                    D = Setup Select

Please enter Start Position:
```

FIGURE 5-1

MAIN MENU OF HOST COMPUTER MENU PROGRAM

```
    Current Status                          =  STOPPED
0.  Current Position                        =  415.000
1.  Home Position    (deg x 10000)          =   900000
2.  Incidence Angle (deg x 10000)           =   850000
3.  Grating Density (grv/mm x 10)           =    24000
4.  Air Pressure     (mbars x 10)           =    10133
5.  Order of Diffraction (1 - 6)            =        1
6.  Displayed Harmonic    (1 - 9)           =        1
7.  Backlash Removal (full-steps)           =      128
8.  Handshake Loopback/Default              =        1

 Units =        Harmonic =    SHG =     Mode =
 NANOMETERS     FIRST         NONE      BURST

   ********** CALIBRATION MENU **********

  S.  Stop       9.  Slew       F.  Jog Forward
                 H.  Home       R.  Jog Reverse
                                Q.  Jog Faster
  U.  Units Select              Z.  Jog Slower

  X.  Exit to main menu         ?.  Help
```

FIGURE 5-2

CALIBRATION MENU OF HOST COMPUTER MENU PROGRAM