

OPERATING INSTRUCTION MANUAL
FOR THE
MODEL TM-600
CRYOGENIC TEMPERATURE
MONITOR



CRYOMAGNETICS, INC.

INNOVATIVE SUPERCONDUCTING MAGNET SOLUTIONS

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WARNING!
DO NOT ATTEMPT TO OPERATE THIS EQUIPMENT BEFORE YOU
HAVE THOROUGHLY READ THIS INSTRUCTION MANUAL.

CE

MANUFACTURER'S DECLARATION OF CONFORMITY

According to ISO / IEC Guide 22 and EN45014

Manufacturer's Name: Cryomagnetics, Inc.

Manufacturer's Address: 1006 Alvin Weinberg Drive
Oak Ridge, TN 37830

Declares. the product

Product Name: Cryogenic Temperature Monitor
Model Number: TM-600
Product Options: All Options

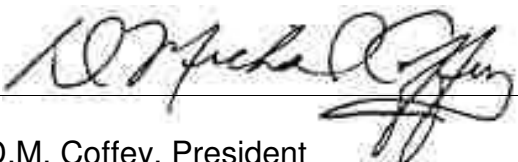
Conforms to the following Product Specifications:

Safety: EN61010-1 (95)
EN61326-1 (97)

EMC: EN61326-1 (97) Electrical Equipment for Measurement,
Control and Lab use – EMC Requirements
EN61000-4-2 (95) Electrostatic Discharge Immunity Test
EN61000-4-3 (96) Radiated Electromagnetic Fields
EN61000-4-4 (95) Electrical Fast Transient/Burst
EN61000-4-5 (95) Amendment A-Surge Immunity Test
EN61000-4-6 (96) Amendment A-Immunity to Conducted
Disturbances
EN61000-4-11 (94) Voltage Dips, Short Interruptions and
Voltage Variations

Application of Council Directives:

The product complies with the requirements of the Low Voltage Directive
73/23/EEC as amended by 93/68/EEC and the EMC Directive 89/336/EEC as
amended by 93/68/EEC.



D.M. Coffey, President
Cryomagnetics, Inc

Oak Ridge Tennessee May 27th, 2004

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1.0 Introduction

The TM-600 Cryogenic Temperature Monitor is a state of the art instrument for monitoring temperature in cryogenic environments with excellent accuracy and resolution. Its versatile architecture allows configuration to virtually any temperature sensor. This includes ruthenium oxide, platinum, Cernox™, carbon, germanium, silicon diodes, and others.

With the Two-Sensor option, the instrument has two independent input channels that are configurable to either the same or different sensor types. The unit is configured for use with four wire sensors, although two and three wire sensors may also be used.

The TM-600 has user-adjustable high and low setpoints that may be used to control other equipment based on the sensed temperature. With the Two-Sensor option, independent setpoints can be adjusted for each channel. This allows simultaneous control of temperature driven systems with a single TM-600. Also included is a fully adjustable audible alarm. The audible alarm will sound if the temperature falls below the low setpoint or above the high setpoint. Separate audible alarm setpoints are included with the Two-Sensor option.

Unique features of the TM-600 include factory installed standard sensor response curves with three point field calibration, and 40 point calibration tables for calibrated sensors. Both linear and spline interpolation functions are selectable by user menus. This allows optimal utilization of the calibration data for accurate results between calibration data points. A convenient Windows® 95 software program is provided to allow custom sensor calibration data to be read from or sent to the TM-600. Computer control via RS-232 is available in the standard configuration. Remote control via the latest IEEE-488.2 command set is available as an option. LabVIEW® virtual instrument drivers are available to allow computer control via a familiar, intuitive interface. A wide variety of other options are also available that allow the instrument to be upgraded and tailored to your particular requirements.

2.0 Factory Calibrations, Installed Options and Certification

TM-600 Serial Number: _____

Internal Reference: _____ Firmware Version: _____

Input Voltage: 100 VAC: _____ 115 VAC: _____ 230 VAC: _____

Input Channel 1:

Type: RuOxide __ PT-100 __ Carbon __ Other: _____

Calibration: Sensor Manufacturer / Serial No: _____

Maximum Resistance: _____

Excitation Current: _____

Three Point Cal: 4.20: _____ 77.35: _____ 273.0: _____

Control Output: TTL: _____ Open Collector: _____ Other: _____

Input Channel 2 (Option 3): Not Installed: _____

Type: RuOxide __ PT-100 __ Carbon __ Other: _____

Calibration: Sensor Manufacturer / Serial No: _____

Maximum Resistance: _____

Excitation Current: _____

Three Point Cal: 4.20: _____ 77.35: _____ 273.0: _____

Control Output: TTL: _____ Open Collector: _____ Other: _____

Analog Output (Option 1): Not Installed: _____

Type: 0-1 Volt: _____ 4-20mA: _____

Computer Interface Installed: RS-232: IEEE-488.2 (Option 2): _____

Notes: _____

Certified: _____

Date: _____

3.0 Setup

The TM-600 is delivered to you fully tested and ready to operate. This includes sensor calibration if Cryomagnetics supplied the sensor(s) with the instrument. Calibration will also be completed if the sensor calibration data was supplied at the time of order.

3.1 Line Voltage and Fuse

Unless otherwise specified, the TM-600 is configured for operation using 115 VAC +/- 10%, 50/60 Hz input power. The serial number tag on the rear panel of the unit indicates the factory voltage setting.

***** **WARNING** *****

Great care must be taken to avoid shock if any changes are being made inside the unit since line voltages will be exposed.
DISCONNECT THE POWER SOURCE BEFORE OPENING THE UNIT.

The line voltage setting can be changed to 230 VAC if desired. Always disconnect the power cord from the unit prior to opening the case. To open the TM-600, remove the two screws from the rear panel of the unit. Also remove the screws on the RS-232 and Sensor(s), I/O connectors. The rear panel can then be pulled back and the cover of the TM-600 can be slid off. Figure 3.0 indicates the changes in circuit board jumpers inside the unit used to make a change in line voltage.

Figure 3.0 - Line Voltage Jumper Settings

Transformer Primary Jumpers

Line Voltage	JP1	JP2	JP3	JP4
100V, 115V	Short	Open	Short	Open
200V, 230V	Open	Short	Open	Short

The fuse for the TM-600 is mounted on the main circuit board inside the unit. Should the fuse need to be changed, open the TM-600 as described above. Locate the fuse - it is a cylindrical device labeled F1 and can be found on the right side of the unit near the main transformer. Replace the fuse only with another fuse of the same type. Use only Wickmann part number 19374-035-K (250V, 0.25A, time lag). Never replace the fuse with a wire.

3.2 Connecting Sensors

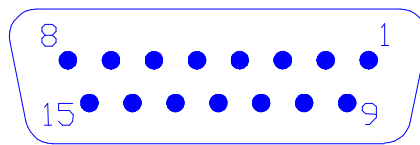
Sensors connect to the TM-600 through the rear panel DB-15F connector labeled "Sensor(s), I/O". This connector provides service not only to the sensors, but also to the control output signals

generated by the TM-600 and the 4-20mA analog output signal. Figure 3.1 indicates the pin designations for the connector.

******* IMPORTANT *******

Connections should NEVER be made directly to the connector on the rear panel. Always solder to a mating connector that is not attached to the unit. Connections should be double-checked for accuracy prior to attaching to the TM-600 and powering the unit ON.

Figure 3.1 - Sensor Connector Wiring - DB-15F



View Facing Rear Panel Connector

<u>Pin #</u>	<u>Function</u>	<u>Pin #</u>	<u>Function</u>
1	Sensor 1: I+	9	Sensor 2 (Optional): I+
2	Sensor 1: I-	10	Sensor 2 (Optional): I-
3	Sensor 1: V+	11	Sensor 2 (Optional): V+
4	Sensor 1: V-	12	Sensor 2 (Optional): V-
5	Analog Output (Optional) 4-20 mA I-	13	Sensor 2 (Optional): Control Output
6	Analog Output (Optional) 4-20 mA I+	14	Sensor 1: Control Output
7	Analog Output (Optional) Sensor Select	15	GND
8	N/C		

Cryomagnetics, Inc. temperature sensors have four (4) lead wires and use either #30 AWG Teflon insulated lead wires or color coded phosphor-bronze lead wires (either option may be specified when the sensor is ordered). The standard color code for lead wire is shown in Figure 3.2.

Figure 3.2 - Temperature Sensor Color Codes

<u>Lead Function</u>	<u>Teflon Color</u>	<u>Phosphor-Bronze Color</u>
I+	Red	Clear
I-	Black	Black
V+	Blue	Yellow
V-	Yellow	Green

If a temperature sensor has 3 lead wires, the I- and V- leads are typically combined into a single black lead. If a sensor has 2 lead wires, the I- and V- leads are combined into a single black lead and the V+ lead is not used. The V+ connection at the input to the TM-600 should be connected to the I+ terminal in this case.

Cabling between the temperature sensor and the TM-600 should be of appropriate size such that high voltage drop across the I+ and I- leads does not occur. Since sensor excitation currents are typically less than 200 microamps, #30 AWG copper wire should be adequate for most applications where the cable is 30 meters or less. Unshielded cable may be used where no significant use of SCR-controlled equipment or intense electrostatic field sources are present. Otherwise, it is recommended that shielded cable be used.

3.3 Sensor Calibration

Calibration of sensors using standard curves is performed through the front panel keypad of the TM-600, and can not be performed through the TM-600 computer interfaces. If custom sensor calibration data is available, it is downloaded using the RS-232 interface by a calibration support tool that runs under Windows® 95.

To calibrate a sensor, connect the sensor and power ON the TM-600. Allow the instrument to warm up for a few minutes for best results. If the Two-Sensor option is installed, use the UP or DOWN arrow keys to highlight the sensor channel to be calibrated and press the MENU key. Again use the UP or DOWN arrow keys to select CAL from the opening menu. When CAL is highlighted, the TM-600 will show the present sensor selection on the second line and the selected interpolation algorithm (linear or spline). Press ENTER to access the calibration menu:

Sensor Calibration
Ohms Sensor Fit

The "Sensor" option selects the sensor type and the standard curve for the sensor. The "Ohms" option

allows sensor resistance to be measured or set at 4.2 degrees Kelvin, 77.35 degrees Kelvin, and 273.0 degrees Kelvin. The readings at the three calibration points can be used to shift the standard curve for the attached sensor. The "Fit" option selects the interpolation algorithm used when converting from measured resistance to temperature.

3.31 Sensor Selection

Select the type of sensor from the Sensor menu and press ENTER. If the sensor type is changed a confirmation will be required before the active calibration data is changed.

Load Default Curve? No Yes

If "Yes" is selected the active calibration data will be replaced by the standard curve for the selected sensor. It should be noted that "Update Cal Table" under the "Ohms" option must be selected before the standard curve data is shifted to match the three calibration data points.

3.32 Three Point Calibration

Three point calibration should be used if custom calibration data is not available for the attached temperature sensor.

***** **IMPORTANT** *****

This procedure overwrites the active calibration data by applying measured or entered data to standard curves. It does not use the active calibration data, and will overwrite any custom calibration data that has been loaded. Do execute this procedure if you want to use custom calibration tables.

Resistances can be measured or entered at the temperatures of liquid helium, liquid nitrogen, and ice water. The values are then used to adjust the standard curve.

Select "Ohms" in the Sensor Calibration Menu.

Cal Temperature (°K) 4.20 77.35 273.0
--

Select the calibration temperature.

273.0°K Calibration Measure Adjust

"Measure" should be selected if the sensor is at the selected calibration temperature. Otherwise select "Adjust". If "Measure" is selected the measured resistance can be monitored until the sensor stabilizes in the environment:

273.0°K Calibration 100.07Ω

If "Adjust" is selected, a known resistance or the resistance from standard curve data may be entered by using the UP/DOWN buttons.

CH 1 273.0°K Cal ↑↓ 100.00Ω

Press the MENU button to abort the measurement/adjustment or press ENTER to accept it. In either case the active cal table can be updated using the values of the three calibration points.

Update Cal Table? No Yes

The resistances at the three calibration points are stored in EEPROM and are retained until changed using these menu options. This allows any one point to be changed at any time without regard to when power is removed from the instrument.

3.33 Calibration Data Interpolation

Spline interpolation should normally be selected since it will provide superior performance. See section 6.2 for further information regarding the algorithms. Select the preferred algorithm using the "Fit" option of the Sensor Calibration menu.

Cal Interpolation Linear Spline

3.34 Custom Calibration Data

Custom calibration data is easy to use with the TM-600. The sensor type should first be selected in the Sensor Calibration menu. The accompanying disk provides example calibration data and software that can be used to smooth the calibration data, download the data to the TM-600, or upload the active calibration data from the TM-600. Detailed information is found in the software's online help.

Step 1: The data must be in a standard text file with two columns. Temperature is in the first column,

resistance in the second column. If the calibration data is in voltage form it must be converted to resistance by dividing each voltage by the excitation current. The excitation current is recorded in Factory Calibrations on page 2.

Step 2: Execute TM600CAL.exe either from the distribution floppy or from the hard drive where it is installed. Use the File/Open menu to load the calibration data.

Step 3: Smooth the calibration data by selecting the Tools/Smooth menu option.

Step 4: Set TM-600 Channel, Sensor Type, Sensor ID, and set units to Kelvin

Step 5: Save the smoothed calibration data to a file using File/Save As.

Step 6: Select the COM port and Baud Rate using Tools/Options. Verify that the selected baud rate matches the baud rate in the TM-600 "Ports" menu option. Connect the TM-600 RS-232 port to the selected COM port. Place the TM-600 in its operating mode (not in menu).

Step 7: Download the smoothed calibration data using the Tools/Download option. This takes about four seconds.

Step 8: If spline interpolation is to be used, select "Spline" in the "Fit" option of the Sensor Calibration menu. The TM-600 will verify the spline algorithm with the new calibration data before accepting the selection. This takes about a minute.

The TM-600 will now use the downloaded calibration data points to compute temperatures from the measured resistances. If any of the calibration data needs to be adjusted, TM600CAL.exe may be used to upload the calibration table, modify it, and download the new data.

4.0 Menus

Setup of the TM-600 can be performed either through the front panel keypad and simple menu instructions or through remote computer interface (RS-232 or IEEE-488.2 if installed). Calibration is only supported through the front panel keypad. In the following sections there are detailed descriptions of how to recalibrate for different sensors, set the audible alarm, and configure the controller functions.

Before connecting any sensors or other cabling to the TM-600, connect the power cord provided with your TM-600 to an appropriate power source. Power the instrument ON and familiarize yourself with the display. If your TM-600 is configured for dual sensor inputs, the first line of the display will indicate Sensor #1 and the second line will indicate Sensor #2.

>T1	4.357 °K
T2	20.45 °K

If your TM-600 is configured for a single sensor input, the display will only indicate one temperature.

Temperature
21.36 °K

If the control output for a sensor is active, it is indicated by a diamond to the right of the temperature display. If an alarm condition is present, it is indicated by an "A" to the right of the temperature display.

For dual input units, you will notice an arrow directly to the left of the Sensor #1 display line. Using the UP or DOWN arrow keys on the front panel, this arrow can be toggled between the two display lines (sensors). To change the display units, alarm points, control output limits, computer communication parameters, calibration, or any other user-settable options, you must press the MENU key. The menu function will be displayed on the first line and present setting for the item on the second line. Pressing the DOWN key will select the next menu item to the right. Pressing UP will select the next menu item to the left. The display will scroll left or right and display three menu items in each scroll position.

>Units<	Alarm	Limits
	°K	

Pressing MENU again returns the instrument to normal display and operations. Be aware that some computer interface commands are not available while the menu system is active (see Appendix A).

There are numerous user-adjustable options available. The following outline indicates options and the menu headings under which they are found.

4.1 Units

The Units menu item allows the user to set the display units of the TM-600 for this particular channel. Available options are degrees Kelvin (°K), degrees Centigrade (°C), degrees Fahrenheit (°F), or ohms (Ω). Note that settings entered or displayed under the other menu items will follow the selection for the channel in the Units menu. If ohms is the unit of display for the first channel the limits will be displayed as resistance in ohms.

4.2 Audible Alarm

The TM-600 has an internal audible alarm which can be set to activate when the temperature falls outside of user setpoints. The setpoints for the high and low alarm limits are set in the "Alarm" menu. The alarm function gives a front panel display indication when it is activated - "A" appears on the right side of the active display line to indicate an alarm condition. The audible alarm can be silenced by pressing any front panel key on the TM-600; however, the visual indication of the alarm condition, "A" on the display, is maintained until the measured temperature is between the alarm setpoints. Separate indicators are displayed for each channel if the Two-Sensor option is installed. If the alarm is silenced after a channel 1 threshold is exceeded and channel 2 exceeds its threshold, the alarm will sound again. The audible alarm function can be disabled for a channel if the low setpoint is set higher than the high setpoint.

4.3 Limits

The TM-600 has an independent control output for each channel which will activate when the measured temperature falls outside of user setpoints. The setpoints for the high and low control output limits are set in the "Limits" menu. The control output function gives a front panel display indication when it is activated - a diamond pattern appears on the right side of the active display line when the control output is activated. The control output will remain active until the measured temperature is between the setpoints.

4.4 Ports

The Ports menu item allows the user to set the analog output mode of the TM-600 (if this option is installed), select the computer interface which is active (RS-232 or IEEE-488.2 - if installed), and to set up the parameters of the computer interface such as baud rate, address, etc. When the Ports menu item is highlighted, the current setting of the analog and computer interfaces are displayed on the second line. To change any of the Port options, press ENTER when "Ports" is highlighted. Then select the option that is to be changed:

RS-232 Baud rate may be set to 9600, 4800, 2400, or 1200. Factory default is 9600.

IEEE-488.2 Device address may be selected from 0 - 31. Factory default is 1.

AO The sensor input channel controlling the analog output port is selected. The analog output of the TM-600 may be configured to driven from Channel 1, Channel 2, or remote selection. The Remote setting allows the user to supply a digital signal to the TM-600 to select which channel is controlling the analog output. This allows the user to monitor both channels without computer commands.

4.5 Calibrate

Under the Calibrate (Cal) menu item the user can set the type of sensor being used on this channel, select an interpolation algorithm, or perform a three point calibration using standard temperature sensor response curves. When "Cal" is highlighted a summary of the present settings is shown on the second line of the display. Pressing ENTER while "Cal" is highlighted allows the user to perform the calibration functions. Refer to section 3.3 for temperature sensor calibration procedures.

4.6 Analog Output Limits (Option 1)

The analog output limits (AnlgOut) menu item enables the user to set the lower and upper limits for the analog output. If the measured temperature is less than the lower limit, the minimum analog output value will be set on the analog output port. If the measured temperature is above the upper limit, the maximum analog output value will be set on the analog output port. If the measured temperature is between the lower and upper limits, a linear interpolation will be used to set the value on the analog output port.

5.0 Interfacing

The TM-600 comes standard with an RS-232 computer interface. All front panel functions, except calibration functions, may be accessed using the corresponding command string over the RS-232 port. In addition, an IEEE-488.2 port is available as an option. This port conforms to the IEEE-488.2-1992 standard.

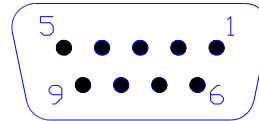
5.1 RS-232 Computer Interface

An RS-232 computer interface port is provided as standard equipment on all TM-600s. The port is accessed through the DB-9F connector on the rear panel of the instrument. The interface is factory configured for 9600 baud, 8 data bits, 1 stop bit, no parity. Figure 5.0 indicates the proper pin designations for the port. Figure 5.1 details available RS-232 port commands.

Figure 5.0 - RS-232 Port Connector Wiring

<u>Pin #</u>	<u>TM-600 Pin Function</u>
--------------	----------------------------

1, 4, 6, 7, 8, 9	N/C
2	RS-232 Transmit
3	RS-232 Receive
5	Ground



View Facing Rear Panel Connector

Commands available to the TM-600 operator over the RS-232 computer interface are given in Appendix A. The commands available through RS-232 are identical to those available through IEEE-488.2; however, some commands may be IEEE-488.2 specific and may not provide responses consistent with the RS-232 interface.

Command strings are normally limited to 30 characters when the RS-232 interface is used. A <RETURN> will be generated internally when a line longer than the maximum is encountered, and any valid commands in the received line will be processed. An output buffer of 32 characters is used although longer responses can be successfully generated. All remote commands are case insensitive, allowing upper or lower case to be used without affecting operation of the commands.

When the RS-232 interface is selected, all commands sent to the instrument will be echoed including the ASCII <RETURN> character. A <NEWLINE> character will be sent when command processing is complete. The host computer should wait for the <NEWLINE> before sending additional commands.

5.2 IEEE-488.2 Computer Interface

The TM-600 may have an optional IEEE-488.2 computer interface (Option 2). The TM-600 implements SH1, AH1, T6, L4, SR1, RL0, PP0, DC1, DT0, C0, and E1 options. The commands are compliant with the IEEE-488.2 standard.

Reference: IEEE Standard Codes, Formats, Protocols, and Common Commands (IEEE Std 488.2-1992) provides a detailed description of the IEEE common commands (identifiable in the command list by the asterisk as the first character.)

The command list and structure is identical to the RS-232 command set. Reference Appendix A for a detailed description.

5.3 Analog Output

An analog output from the TM-600 is available as an option (Option 1). This output can be specified at the time of purchase to be either 4-20mA or 0-1V. If the 4-20 mA option is installed, the signal is found on the TM-600 rear panel DB-15F connector, pins 5 and 6 (see Figure 3.1). If the 0-1V analog output option is installed, the signal is found on the TM-600 rear panel BNC connector. In either case, the analog output signal is linear and proportional to the measured value between the analog output limits (see paragraph 4.6). If the Two-Sensor option is installed, the sensor having control of the analog output may be selected through the TM-600 rear panel DB-15F, pin 7 (see Figure 3.1). This is a TTL compatible (0-5V nominal) input. A low level on this pin selects Sensor 1, and a high level or an open connection selects Sensor 2. The analog output in the PORTS menu must be set to "Remote" if external selection is to be used.

5.4 Audible Alarm

A user-adjustable audible alarm is standard on the TM-600. The alarm may be set through the front panel menu system (see section 4.2). The alarm gives the user an audible indication if the measured temperature falls below the low alarm setpoint or exceeds the high alarm setpoint. If the Two-Sensor option is installed, the audible alarm will activate if either threshold is exceeded. Once the alarm is activated, it may be silenced by any front panel keystroke. It will only be reactivated after a normal reading (i.e., one between the alarm setpoints) is detected by the TM-600, followed by another reading in which an alarm condition again exists. The audible alarm may be disabled by setting the low threshold above the high threshold.

5.5 Control Outputs

The TM-600 in its standard configuration is capable of generating control signals to be used with remote equipment. If your TM-600 has the Two-Sensor option installed (Option 3), two totally independent systems can be under automatic control by a single TM-600.

The control outputs may be set to be either “open collector” or “0-5V”. Refer to Section 2.0 of this manual for the factory settings of your particular TM-600. Figure 3.1 indicates the output pins designated to carry the Control Output signals, and Figure 5.1 indicates the jumper setting to change the configuration.

Figure 5.1
Control Output Format Setting

Sensor / Jumper	TTL Compatible	Open Collector
Sensor 1 / JP22	Short	Open
Sensor 2 / JP20	Short	Open

If the output will consequently be driving a solenoid valve or relay, the output will typically be configured as open collector. If the control output is simply being monitored by other equipment (e.g., a computer), the output should be configured as TTL Compatible (0-5V).

When the TM-600 is used in conjunction with Option 5, the Line Voltage Controller Module, the unit is capable of driving solenoid valves requiring 115V/230V AC. Option 5 provides the user with a fused and opto-isolated line voltage output. Refer to Appendix C for a technical description of Option 5.

6.0 Theory of Operation

Depending upon how your TM-600 is configured, it may be compatible with ruthenium oxide, platinum, Cernox™, carbon, germanium, silicon diodes, and other sensors. It can be configured for a single sensor input or dual sensor inputs. The TM-600's high accuracy is achieved by a precision, self-calibrating, 24-bit sigma-delta analog-to-digital converter and the topology of its analog-to-digital reference circuits. The TM-600 generates the reference voltage for the analog-to-digital converter by sensing the excitation current through a precision resistor. This eliminates one of the largest errors normally found in precision instrumentation since any drift or uncertainty in excitation current is removed in the digitization process. This approach requires that a precision current sense resistor be selected to generate an adequate reference voltage at the excitation current chosen for the sensor. Excellent results are achieved if the reference voltage falls between 1.0 and 2.5 volts. For example, a PT-100 platinum temperature sensor operating at 200 microamperes uses a 12,100Ω current sense resistor and generates 2.42 volts as an A/D reference. A 100K ruthenium oxide temperature sensor operating at 10 microamperes uses a 250K current sense resistor and generates 2.50 volts as an A/D reference. Selection of an appropriate current sense resistor and installing appropriate calibration data allows a wide range of sensors to be used with the TM-600.

6.1 Temperature Sensing

Temperature sensing involves sending a known current through a sensor that has a predictable resistive or voltage response to temperature changes. The TM-600 uses an accurate programmable current source that drives the sensor, and a precision A/D converter to detect the voltage across the sensor. The instrument uses the measured voltage to compute the resistance of the sensor, and using the selected interpolation algorithm, it finds the temperature required for the sensor to exhibit the measured resistance.

6.2 Interpolation Algorithms

The TM-600 converts measured resistances or voltages to temperature by locating two resistance/temperature points in the 'active calibration table' where one resistance is higher than the measured resistance and one is lower. If linear interpolation is selected the temperature is computed on a straight line between the two points. If spline interpolation is selected, two additional points on each side are used to provide a better estimate of the actual temperature by generating a curve that passes through the nearest four points. Each algorithm has advantages and disadvantages. Figure 6.1 illustrates the two algorithms but exaggerates the linear fit errors by limiting the number of calibration points used.

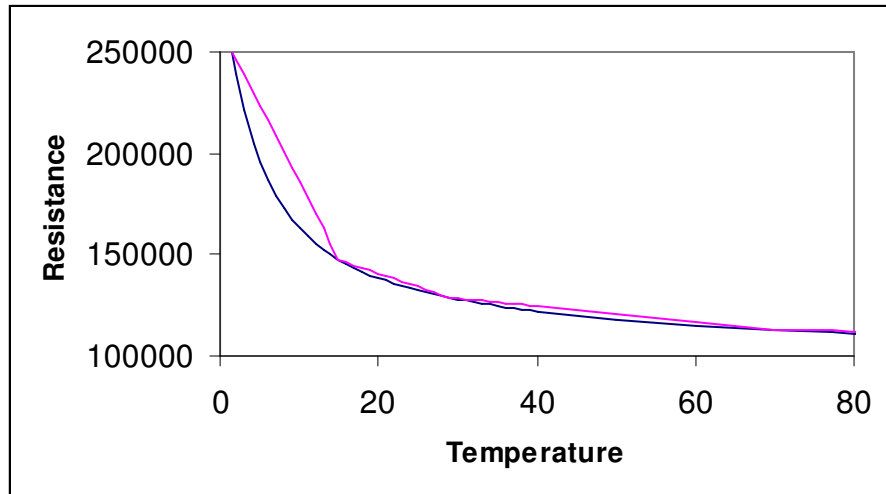


Figure 6.1 - Spline vs Linear Interpolation

If the calibration data is 'smooth', the spline fit is well behaved and will provide better estimates of the temperature between standard curve or custom curve data points than the linear fit. The linear fit has inherent errors between data points for any real sensor since sensor response is never a straight line. However, if arbitrary or poorly measured data is used for custom calibration data, it is possible for the spline fit to generate a curve that is not constantly increasing or decreasing, which would result in significant measurement errors. The software tool shipped with the TM-600 will smooth calibration data to avoid problems with the spline fit.

The spline algorithm is checked to ensure that the resulting curve is constantly increasing or constantly decreasing whenever custom calibration data is downloaded or a user calibration is performed. Linear interpolation is selected if errors are detected.

6.3 TM-600 Circuit Description

The TM-600 is a 68HC11 microprocessor based instrument. This microprocessor has built-in EEPROM that is used to hold factory calibration and configuration data, as well as user entered calibration and setup information. Consequently, it is not possible to simply change the processor with another 68HC11. The unit will not work properly with a new processor until it has been initialized by the factory.

The processor controls virtually all aspects of the TM-600 including the display, keypad, precision current sources, and the high stability 24-bit analog-to-digital converter used to monitor sensor voltages. Due to the flexibility and stability of the TM-600's circuits, very high resolution and accuracy is achieved.

The TM-600's display is a bright, vacuum fluorescent unit having high contrast. It is capable of full alphanumeric and can clearly be read from a significant distance.

Great care must be taken to avoid shock if any changes are being made inside the unit since line voltages will be exposed. Disconnect the power source before opening the unit.

7.0 Limited Warranty Policy

Cryomagnetics, Inc. warrants its products to be free from defects in materials and workmanship. This warranty shall be effective for one (1) year after the date of shipment from Cryomagnetics.

Cryomagnetics reserves the right to elect to repair, replace, or give credit for the purchase price of any product subject to warranty adjustment. Return of all products for warranty adjustment shall be FOB Oak Ridge, TN, and must have prior authorization for such return from an authorized Cryomagnetics, Inc. representative.

This warranty shall not apply to any product which has been determined by Cryomagnetics, Inc. inspection to have become defective due to abuse, mishandling, accident, alteration, improper installation or other causes. Cryomagnetics, Inc. products are designed for use by knowledgeable, competent technical personnel.

In any event, the liability of Cryomagnetics, Inc. is strictly limited to the purchase price of the equipment supplied by Cryomagnetics, Inc. Cryomagnetics, Inc. shall not assume liability for any consequential damages associated with use or misuse of its equipment.

8.0 Technical Specifications

The following specifications reflect the electronic performance of the TM-600 measuring the resistance of an RTD sensor. The accuracy of the measured temperature will be a function of the electronic accuracy, sensor accuracy, sensor calibration data, sensor sensitivity, and accuracy of the selected interpolation algorithm. Achievable accuracies include 0.001 °K at 4.200 °K using a 100K ruthenium oxide sensor, and 0.070 °K at 77.2 °K using a PT-100 platinum temperature sensor.

Electronic Accuracy	Limited to 15 ppm FSR + Reference Stability
Resolution	24 bit analog to digital converter
Bandwidth	2.62 Hz digital filter
Averaging	0.5 Second
Reference Stability	5 ppm/°C standard, 0.2 ppm/°C optional
Electronic Noise	1 uV RMS
Display update interval	0.5 seconds (single channel) 4 seconds (dual channel)
Interpolation/Conversions	Single precision floating point (six digit accuracy)
User Calibration Tables	40 points/channel
Current Source(s)	Programmable/Configurable 1uA to 100 mA
Current Source dependent errors	Removed by A/D reference configuration
A/D Input Current	1 nA max
A/D Gain, Drift, and Offset errors	Removed by A/D self-calibration
50/60 Hz Rejection	100 dB min
Control Outputs	
TTL configuration	2.6 mA Source at 2.4 V, 250 mA Sink at 0.8 V
Open Collector configuration	40 Volts Maximum, 250 mA Sink at 0.8 V
Analog Output Accuracy	+/- 0.05 percent FSR
0-1 Volt Analog Output	8 mA source capability into 120 ohms
4-20 mA Analog Output	15 V internal source, operable with 1V to 50V external source

Appendix A

Computer Interface Command Reference

Commands available over the computer interface are separated into commands that are IEEE 488.2 specific, commands that are inhibited when the operator menu is accessed, and commands that are always available. All command mnemonics that elicit a response from the instrument end with a question (?) character. The general command format is as follows:

```
<subcommand1>;<subcommand2>;<subcommand3><RETURN>
```

where a subcommand is formatted

```
<Command Mnemonic><SPACE><Parameter>
```

Example:

```
*IDN?;CHAN 2;UNITS F;UNITS?<RETURN>
```

Responses to each subcommand are separated by semicolons. The above example would return:

```
Cryomagnetics, TM-600, 2002, 2.08; F<RETURN><LINEFEED>
```

where the serial number is 2002 and the firmware version number is 2.08.

Error Handling and Command Availability

The ERROR command allows error messages to be enabled or disabled when the RS-232 interface is used. The IEEE-488.2 status mechanisms may always be used to determine if an error occurred processing a command, and the category of the error. Some commands are unavailable if the instrument menu is being accessed by an operator at the instrument. If a command available only in operate mode is received while the menus are being accessed, a device dependent error is reported in the Extended Status Register (ESR), and the message "Blocked by menu" will be returned if error reporting is enabled when using the RS-232 interface.

The following table lists the TM-600 commands, shows the TM-600 mode and channel where the command may be used, and provides a short command description. Command details are provided in the reference that follows.

Command	Available	Description
CHAN	Operate	Select instrument channel for computer commands
CHAN?	Operate	Query selected channel
CURVE	Operate	Set a calibration curve data point
CURVE?	Operate	Query a calibration curve data point
ERROR	Operate	Set error response mode for RS-232 interface
ERROR?	Always	Query error response mode
HIGH	Operate	Set high threshold for control output activation
HIGH?	Operate	Query high threshold for control output activation
H-ALM	Operate	Set audible alarm high threshold
H-ALM?	Operate	Query audible alarm high threshold
LOW	Operate	Set low threshold for control output activation
LOW?	Operate	Query low threshold for control output activation
L-ALM	Operate	Set audible alarm low threshold
L-ALM?	Operate	Query audible alarm low threshold
MEAS	Operate	Start measurement on selected channel
MEAS?	Operate	Query last completed measurement on selected channel
OUT	Operate	Select channel for analog output
OUT?	Operate	Query selected channel for analog output
TYPE?	Operate	Query sensor type for selected channel
UNITS	Operate	Select units for selected channel
UNITS?	Operate	Query selected units for selected channel
*CLS	Always	Clear Status Command
*ESE	Always	Standard Event Status Enable Command
*ESE?	Always	Standard Event Status Enable Query
*ESR?	Always	Standard Event Status Register Query
*IDN?	Always	Identification Query
*OPC	Always	Operation Complete Command
*OPC?	Always	Operation Complete Query
*RST	Always	Reset Command
*SRE	Always	Service Request Enable Command
*SRE?	Always	Service Request Enable Query
*STB?	Always	Read Status Byte Query
*TST?	Always	Self-Test Query
*WAI	Operate	Wait-to-Continue Command

CURVE? Query a calibration curve data point
Availability: Operate Mode
Command Syntax: CURVE? <Point #>
Response: <Temperature> <Resistance>
Response Example: 273.00 100.00 **Response Range:** Temperature: 0.0 to 327°K
Resistance 0.0 to 250000.0

Description: The **CURVE?** query recalls a data point in the active calibration data table for the selected channel. Temperature is in degrees Kelvin. This command is intended for use by TM600CAL.exe.

Related Commands: CHAN, CHAN?, CURVE

ERROR Set error response mode for RS-232 interface
Availability: Operate Mode
Command Syntax: ERROR <Error Mode>
Example: ERROR 1
Parameter Range: 0 or 1 (0 - disable error reporting, 1 - enable error reporting)

Description: The **ERROR** command enables or disables error messages when the RS-232 interface is used. It is much easier to handle errors under program control when using the RS-232 interface if error messages are disabled, but it is desirable to enable error messages if a terminal program is used to interactively control and query the TM-600.

Related Commands: ERROR?

ERROR? Query error response mode
Availability: Always
Command Syntax: ERROR?
Response: <Error Mode>
Response Example: 0 **Response Range:** 0 or 1

Description: The **ERROR?** query returns the selected error reporting mode.

Related Commands: ERROR

HIGH Set high threshold for control output activation
Availability: Operate Mode
Command Syntax: HIGH [Temperature]
Example: HIGH 65.0
Default Parameter: 0.0 **Parameter Range:** Calibration Range

Description: The **HIGH** command sets the high threshold for the control output activation in the present units for the selected channel. If the temperature exceeds the threshold the control output will be activated.

Related Commands: CHAN, CHAN?, HIGH?, H-ALM, H-ALM?, LOW, LOW?, L-ALM, L-ALM?

HIGH? Query high threshold for control output activation

Availability: Operate Mode

Command Syntax: HIGH?

Response: <High Temperature > <Units>

Response Example: 65.00 K **Response Range:** Calibration Range

Description: The **HIGH?** query returns the high threshold for control output activation in the present units for the selected channel.

Related Commands: CHAN, CHAN?, HIGH, H-ALM, H-ALM?, LOW, LOW?, L-ALM, L-ALM?

H-ALM Set audible alarm high threshold

Availability: Operate Mode

Command Syntax: H-ALM [Alarm Temperature]

Example: H-ALM 65.0

Default Parameter: 0.0 **Parameter Range:** Calibration Range

Description: The **H-ALM** command sets the high threshold for the audible alarm in the present units for the selected channel. If the temperature exceeds the threshold the audible alarm will sound.

Related Commands: H-ALM?, CHAN, CHAN?, L-ALM, L-ALM?, UNITS, UNITS?

H-ALM? Query audible alarm high threshold

Availability: Operate Mode

Command Syntax: H-ALM?

Response: <Alarm Temperature > <Units>

Response Example: 4.220 K **Response Range:** Calibration Range

Description: The **H-ALM?** query returns the audible alarm high threshold in the present units for the selected channel. If the temperature exceeds the threshold the audible alarm will sound. The alarm is disabled if the threshold is set to 0.

Related Commands: H-ALM, CHAN, CHAN?, L-ALM, L-ALM?, UNITS, UNITS?

LOW Set low threshold for control output activation

Availability: Operate Mode

Command Syntax: LOW [Temperature]

Example: LOW 45.0

Default Parameter: 0.0 **Parameter Range:** Calibration Range

Description: The **LOW** command sets the low threshold for the control output activation in the present units for the selected channel. If the temperature falls below the threshold the control output will be activated.

Related Commands: CHAN, CHAN?, HIGH, HIGH?, H-ALM, H-ALM?, LOW?, L-ALM, L-ALM?

LOW? Query low threshold for control output activation

Availability: Operate Mode

Command Syntax: LOW?

Response: <Low Temperature > <Units>

Response Example: 45.0 K **Response Range:** Calibration Range

Description: The **LOW?** query returns the low threshold for control output activation in the present units for the selected channel.

Related Commands: CHAN, CHAN?, HIGH, HIGH?, H-ALM, H-ALM?, LOW, L-ALM, L-ALM?

L-ALM Set audible alarm low threshold

Availability: Operate Mode

Command Syntax: L-ALM [Alarm Temperature]

Example: L-ALM 65.0

Default Parameter: 0.0 **Parameter Range:** Calibration Range

Description: The **L-ALM** command sets the low threshold for the audible alarm in the present units for the selected channel. If the temperature falls below the threshold the audible alarm will sound.

Related Commands: H-ALM, H-ALM?, CHAN, CHAN?, L-ALM?, UNITS, UNITS?

L-ALM? Query audible alarm low threshold

Availability: Operate Mode

Command Syntax: L-ALM?

Response: <Alarm Temperature > <Units>

Response Example: 4.220 K **Response Range:** Calibration Range

Description: The **L-ALM?** query returns the audible alarm low threshold in the present units for the selected channel. If the temperature falls below the threshold the audible alarm will sound.

Related Commands: H-ALM, H-ALM?, CHAN, CHAN?, L-ALM, UNITS, UNITS?

MEAS Start measurement on selected channel

Availability: Operate Mode

Command Syntax: MEAS [Channel #]

Example: MEAS 2

Default Parameter: Default Channel (See CHAN) **Parameter Range:** 1 to 2

Description: The MEAS command starts a measurement on the selected channel. This command is unnecessary since the TM-600 samples continuously, but is included for completeness of a standard IEEE 488.2 command set.

Related Commands: CHAN, CHAN?, MEAS?

MEAS? Query last completed measurement on selected channel

Availability: Operate Mode

Command Syntax: MEAS? [Channel #]

Example: MEAS? 2

Default Parameter: Default Channel (See CHAN) **Parameter Range:** 1 to 2

Response: <Measured Temperature > <Units>

Response Example: 15.000 K

Description: The **MEAS?** query returns latest reading in the present units for the selected channel. If a reading for the selected channel is in progress, the previous reading is returned.

Related Commands: CHAN, CHAN?, MEAS, *STB?

OUT Select channel for analog output

Availability: Operate Mode with Dual Channel Analog Output Option

Command Syntax: OUT <Selection>

Example: OUT 2

Parameter Range: 0, 1, 2

Description: The **OUT** command sets the channel to be placed on the analog output port. If <0> is selected the digital input select (remote select) will be used to select the channel. Otherwise <1> or <2> selects the respective channel.

Related Commands: OUT?

OUT? Query selected channel for analog output

Availability: Operate Mode with Dual Channel Analog Output Option

Command Syntax: OUT?

Response: <Select Value>

Response Example: 0

Description: The **OUT?** command returns the channel placed on the analog output port, or 0 if the digital input select (remote select) is used to select the channel.

Related Commands: OUT

TYPE? Query sensor type for selected channel
Availability: Operate Mode
Command Syntax: TYPE? [Channel]
Example: TYPE? 2
Default Parameter: <Default Channel> **Parameter Range:** 1 or 2
Response: <Channel Type> <Sensor ID>
Response Example: 2 PT-100 **Response Range:** 2-5, 11-13

Description: The **TYPE?** query returns a code for the sensor type of the designated channel, or the sensor type of the default channel set by the CHAN command if a channel is not specified.

<u>Sensor Type</u>	<u>Sensor ID</u>
2 - Platinum temperature sensor	PT-100
3 - Carbon temperature sensor	Carbon
4 - 10K Ruthenium Oxide temperature sensor	Ru-102
5 - 100K Ruthenium Oxide temperature sensor	Ru-104
11 - Silicon Diode Type type Si-410	Si-410
12 - Germanium Diode type N1G	Ge-N1G
13 - Custom	Custom ID

Related Commands: CHAN, CHAN?

UNITS Select units for selected channel
Availability: Operate Mode
Command Syntax: UNITS <Unit Selection>
Example: UNITS F
Parameter Range: K, C, F, or Ohms
Description: The **UNITS** command sets the units to be used for all input and display operations for the default channel selected by a prior CHAN command. Units may be set to degrees Kelvin, Centigrade, or Fahrenheit, or sensor resistance in ohms.

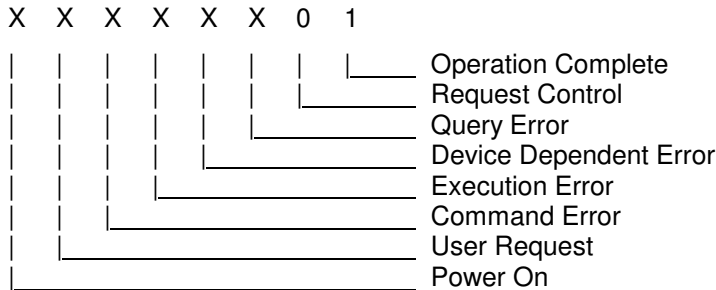
Related Commands: CHAN, CHAN?, HIGH, HIGH?, H-ALM, H-ALM?, LOW, LOW?, L-ALM, L-ALM?, MEAS, MEAS?, UNITS?

UNITS? Query selected units for selected channel
Availability: Operate Mode
Command Syntax: UNITS?

***ESR?** Standard Event Status Register Query
Availability: Always
Command Syntax: *ESR?
Response: <Standard Event Status Register>
Response Example: 128 **Response Range:** 0 to 255

Description: The *ESR? command operates per IEEE Std 488.2-1992 by returning the contents of the Standard Event Status Register and then clearing the register.

Status Byte Bit Allocations:



Related Commands: *ESE, *ESE?

***IDN?** Identification Query
Availability: Always
Command Syntax: *IDN?
Response: <Manufacturer>,<Model>,<Serial #>,<Firmware Level>
Response Example: Cryomagnetics,TM-600,2002,2.08
Serial # Range: 2000 to 9999 **Firmware Level Range:** 1.00 to 9.99

Description: The *IDN? command operates per IEEE Std 488.2-1992 by returning the TM-600 manufacturer, model, serial number and firmware level.

Related Commands: None

***OPC** Operation Complete Command
Availability: Always
Command Syntax: *OPC
Description: The *OPC command operates per IEEE Std 488.2-1992 by placing the Operation Complete message in the Standard Event Status Register (ESR). The TM-600 processes each command as it is received and does not defer any commands for later processing.

Related Commands: *OPC?

***OPC?** Operation Complete Query
Availability: Always

Command Syntax: *OPC?

Description: The *OPC command operates per IEEE Std 488.2-1992 by placing an ASCII character "1" in the output queue since the TM-600 does not defer any commands for later processing.

Related Commands: *OPC

***RST** Reset Command

Availability: Always

Command Syntax: *RST

Description: The *RST command operates per IEEE Std 488.2-1992 by returning the TM-600 to its power up configuration. This selects channel 1 as the default channel and resets any active control output.

Related Commands: None

***SRE** Service Request Enable Command

Availability: Always

Command Syntax: *SRE <mask>

Example: *SRE 255

Default Parameter: 0 **Parameter Range:** 0 to 255

Description: The *SRE command operates per IEEE Std 488.2-1992 by setting the specified mask into the Service Request Enable Register (SRE).

Related Commands: *SRE?

***SRE?** Service Request Enable Query

Availability: Always

Command Syntax: *SRE?

Response: <SRE Mask>

Response Example: 255 **Response Range:** 0 to 255

Description: The *SRE? command operates per IEEE Std 488.2-1992 by returning the mask set in the Service Request Enable Register (SRE) by a prior *SRE command.

Related Commands: *SRE

***STB?** Read Status Byte Query

Availability: Always

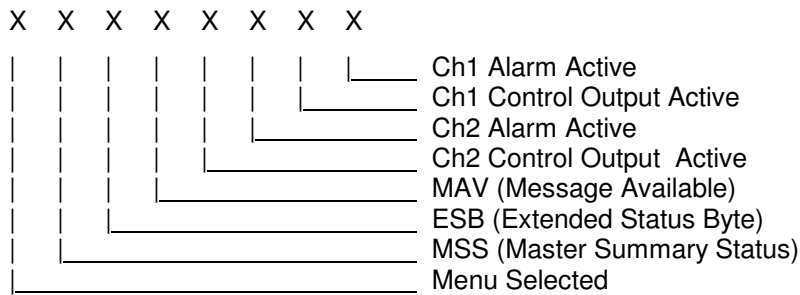
Command Syntax: *STB?

Response: <Status Byte>

Response Example: 65 **Response Range:** 0 to 255

Description: The ***STB?** command operates per IEEE Std 488.2-1992 by returning the Status Byte.

Status Byte Bit Allocations:



*** TST?** Self-Test Query

Availability: Always

Command Syntax: *TST?

Response: <Self test status>

Response Example: 1 **Response Range:** 1

Description: The ***TST?** command operates per IEEE Std 488.2-1992 by returning the self test status. Explicit tests are not performed in response to this command, but a 1 is returned for compliance with the specification.

Related Commands: None

*** WAI** Wait-to-Continue Command

Availability: Always

Command Syntax: *WAI

Description: The ***WAI?** command operates per IEEE Std 488.2-1992 by accepting the command without generating an error. Since the TM-600 only implements sequential commands the no-operation-pending flag is always TRUE.

Related Commands: OPC, *OPC?

Appendix B

Factory Calibration

The TM-600 Factory Calibration is used to establish sensor excitation levels and hardware calibration. If these procedures are not carefully performed the instrument may not function properly. Factory assistance is recommended.

***** WARNING *****

Load resistors and/or Sensors must be attached to perform the calibration.

Power MUST be removed while making ALL connections.

The factory calibration menu is invoked by holding the MENU and ENTER keys while power is applied to the unit. The display will show

Instrument Cal >Abort< Ch1 Ch2

or,

Instrument Cal >Abort< Ch1 Ch2 Anlg
--

if the analog output option is installed. If the analog output is installed, it *must* be recalibrated after the Ch1 factory calibration is performed. Use the UP and DOWN keys to select the calibration to be performed, and press ENTER to begin the calibration.

B.1 Factory Calibration of a Temperature Sensor Channel

Factory calibration of a temperature sensor channel (or sensor input) requires a precision reference resistor to be placed between I- and I+, and jumpers connected from I- to V- and from I+ to V+. Refer to Figure 3.1 for connection details. A reference resistor value equal to the largest sensor resistance to be measured will produce the best results. After the connections have been made, enter the factory calibration menu as described in the preceding paragraph.

Select the sensor channel to be calibrated (Ch 1 or Ch 2) using the UP or DOWN arrow keys and press ENTER. The value of the TM-600's internal current sense resistor will be displayed. The value should not need to be changed unless R30 (Ch1) or R29 (CH 2) has been changed to support a different sensor type. Press ENTER to accept the value of the current sense resistor.

The value of the sense current will be displayed next. Use the UP or DOWN arrow keys to display the desired excitation current and press ENTER to accept the value.

The TM-600 will display:

CH 1 Max RTD Value xxx.xx Ω

Select the maximum resistance that the sensor will exhibit. This value is used to select an operating gain. A value higher than necessary may result in more instrument noise while a value too low may limit the temperatures that can be measured. Review the calibration data for the sensor and enter the largest resistance shown for the temperature range that is to be measured.

The TM-600 now will display:

Ch 1 Cal Resistor xxx.xx Ω

Adjust the displayed value to the value of the precision calibration resistor connected to I+/I-/V+/V- and press ENTER. The display will prompt for the calibration resistor to be attached. Check the connections and press ENTER after verifying that the connections are correct.

Attach Cal Resistor <Enter> when ready

After a few seconds the channel calibration will be completed and the factory calibration menu will be redisplayed.

B.2 Factory Calibration of the Analog Output Option

The TM-600's Analog Output must be recalibrated whenever the Ch 1 factory calibration is changed. In preparation for calibrating the analog output, the sensor or a dummy load must be connected to the Channel 1 sensor inputs. If the Analog Output is configured for 0-1 Volt Output, no load is required at the analog output. If the Analog Output is configured as 4-20mA Output, either a load resistor of less than 600 ohms or the actual current loop itself must be attached to pins 5 and 6 of the rear panel DB15 connector since current must be able to flow in order for the calibration to be made. The value of the resistor is not important.

Select ANLG on the Factory Calibration Menu and press ENTER. The Analog Output calibration is automatic and will be completed in about 3 seconds.

Appendix C

Line Voltage Controller Module – Option 5

Overview

The Line Voltage Controller Module enables the TM-600 to control one or two 115 VAC (or 230 VAC if specified) loads up to 1 Amp each using the TM-600 Low and High setpoints. The outputs are labeled channel 1 and channel 2, and are controlled by the respective channels of the TM-600.

Connections

An interconnection cable is provided with the Line Voltage Controller Module to connect the TM-600 to the Line Voltage Controller Module and to the sensors. The DB-15M connector attaches to the TM-600, the DB-9F attaches to the Line Voltage Controller Output Module. Individual sensor connectors on the cable for channel 1 and channel 2 are labeled.

Output connections are standard 110V output sockets.

DB-9M Pinout

Pin 1 - Channel 1 control input (0V - enabled, open - disabled)

Pin 3 - Channel 2 control input (0V - enabled, open - disabled)

Pin 6 - +15V input (10 ma max)

Pin 9 - Ground

Fuses

Each output is individually fused on the rear panel of the module with a user replaceable 2 amp 250VAC fuse. Slow blow fuses should not be used.

Theory of Operation

The 'hot' side of each output is individually switched using an opto-isolated solid state switch rated for 20-500Hz operation. These switches exhibit a 1 mA off-state leakage current which will be observed as 90-100 VAC if the output is checked with a voltmeter with no load attached to the output.