CryoTel® Family
Free-Piston Stirling Cryocoolers

OPERATING INSTRUCTIONS

Model: CryoTel® GT
Version 5
Issued: November, 2010

Intellectual Property Declaration

SUNPOWER®

Athens, OH 45701 USA
www.sunpower.com

Manufactured by Sunpower, Inc., under the following patents: U.S. Pats 4,583,364; 4,602,174; 4,623,808; 4,649,283; 4,805,408; 4,864,232; 4,866,378; 4,912,409; 4,926,123; 5,003,777; 5,148,066; 5,342,176; 5,385,021; 5,450,521; 5,457,956; 5,461,859; 5,496,153; 5,502,968; 5,525,845; 5,537,820; 5,592,073; 5,642,088; 5,642,622; 5,715,693; 5,749,226; 5,775,273; 5,873,246; 5,941,079; 6,035,637; 6,038,874; 6,170,442; 6,199,381; 6,293,184; 6,446,336 B1; 6,536,326; 6,684,637; RE 38,337; 6,782,700; U.S. patents pending. Also: Australia Patents 676,805; 677,518; 680,770; 685,997; 701,785; 709,315; 753,580;754032. Brazil PI 950368-5; PI 960 8885-0; PI 9710742-5; PI 9713840-1; PI 9713840-1. Canada patent 2,184,473. EPO 0655120 1B issued in France, Italy, UK, Netherlands, Sweden and Germany (as DE 69329862.6-08). EPO 0693160 issued in Italy, UK, Netherlands France, Germany (as DE 69403468 T2); EPO 0754364 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69526217.3-08). EPO 0783618 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69518926.3-08). EPO 0878014 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69611387.2-08). EPO 0885413 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69627894.4-08). Italy 1297082. UK Patent No. 0,218,682; UK 2,334,307; UK 2,330,651. DBP No. 0,218,682 (Germany).
India Patents 177477, 178274, 185034; 185035. Republic of Korea patents 0202290; 0292453; 0301548; 0309486; 0320093. Mexico patents 184451; 194065; 197407; 201368. New Zealand Patents No. 263331; 282959; 319499; 302849; 517329. Singapore Patent P-No. 48360; 51842; 87422; 87423; 87424. Taiwan patent NI-77875.
Japan Patents 特許第3413658号
特許第1966438号特許 特許第3100163号
Patents pending in United Kingdom, Germany, Italy, France, Netherlands, Sweden, Brazil, Japan, Republic of Korea, India, China, Singapore.

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FIGURES

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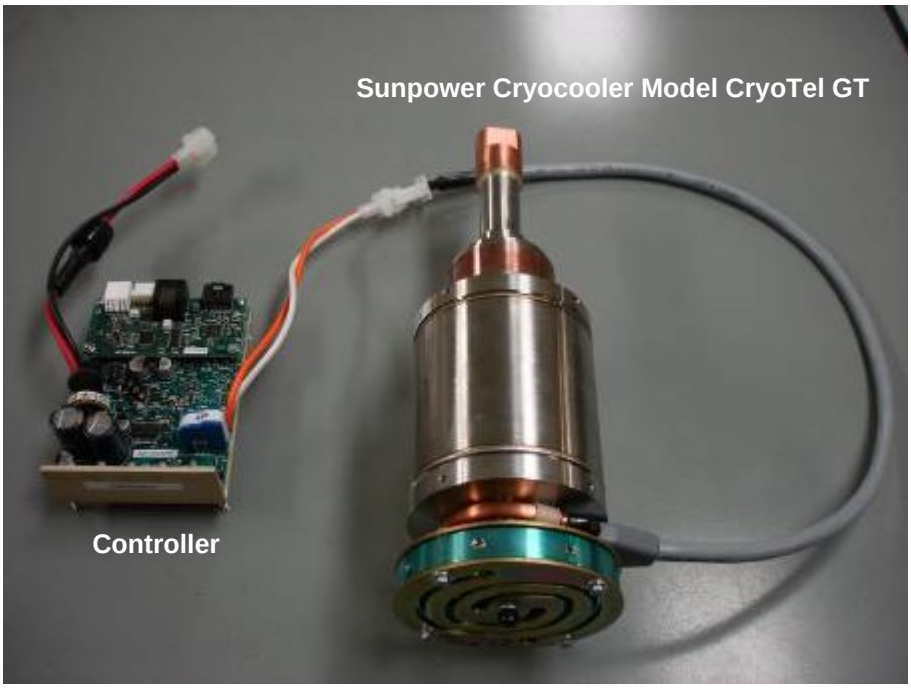
I. Introduction

Sunpower, Inc. is pleased to present this manual with your newly-purchased CryoTel® model cryocooler. As the world leader in free-piston Stirling cryocooling, Sunpower fully supports its products and is pleased to hear of any comments or concerns from new or existing clients.

CryoTel® GT Operating Instructions

The Sunpower cryocooler is a precision instrument; robust in many ways but fragile in others. This operating manual provides standard-use instructions and precautions. Please post where technicians will be working with the unit. Please do not assume that if a warning or instruction is not included here, a particular test or application of this unit is acceptable. It may not be. If you have any questions about this unit, or about any tests or applications you intend to perform, please contact Sunpower support service at phone (740)-594-2221;
email info@sunpower.com



CryoTel GT dimensions: length with balancer: 260 mm (10.2 in); length without balancer: 217 mm (8.5 in); diameter: 83 mm (3.3 in);
mass: 3.1 kg

Figure 1: CryoTel GT and Control Board

II. Precautions (Dos and Don'ts)

Although the CryoTel GT is mechanically robust, it can be damaged if not handled properly when in operation or when removing it from its packaging. The handling and operational **Dos** and **Don'ts** are listed below. Refer to the diagram of the CryoTel GT in Figure 2.

<u>CRITICAL!</u> – Do not operate the cryocooler without adequate cooling at the heat rejection site. Overheating the cryocooler <u>will</u> cause permanent damage.

DON'T

1. Pick up the cryocooler by the cold finger
2. Set the cryocooler on the cold tip.
3. Allow the cold finger to be dented. The slightest dent will render the unit inoperable.
4. Drill holes, or in any other way puncture, or attempt to modify, the pressure vessel.
5. Operate the unit without proper cooling. Heat must be removed from the copper heat rejection area of the cryocooler. If the cooler is provided with external cooling fins, air must be forced over the fins and the flow path should not be obstructed.
6. Puncture or otherwise damage the copper service tube.
7. Subject the electrical feedthroughs to mechanical stress; i.e. axial or radial movements, axial loads, blows, or the like.
8. Mount the cooler by suspending it from the balance absorber mounting bolt.
9. Apply clamping pressure to the pressure vessel (labeled in Figure 2).
10. Rigidly attach the absorber stud to "ground." Instead, let the cooler "float" via a rubber bushing or other means of articulation.
11. Remove the protective cover on the cold weld on the end of the copper service tube. Do not subject the cover to blows.
12. Control power to the cryocooler by making or breaking the power leads between the controller and the cryocooler.
13. Use an external, automatic, closed loop control system which attempts to control the cryocooler operation by varying the setpoint settings in the cryocooler controller.

DO

1. Check with Sunpower before making any modifications to the cryocooler
2. Note that if the control board is installed in an enclosure, cooling must be provided.
3. If the cooler is operating in a laboratory test mode with heaters providing the thermal load to the cold tip, interlocks should be provided so that the heater cannot operate unless the cryocooler is running. This will prevent accidental overheating of the cold tip.

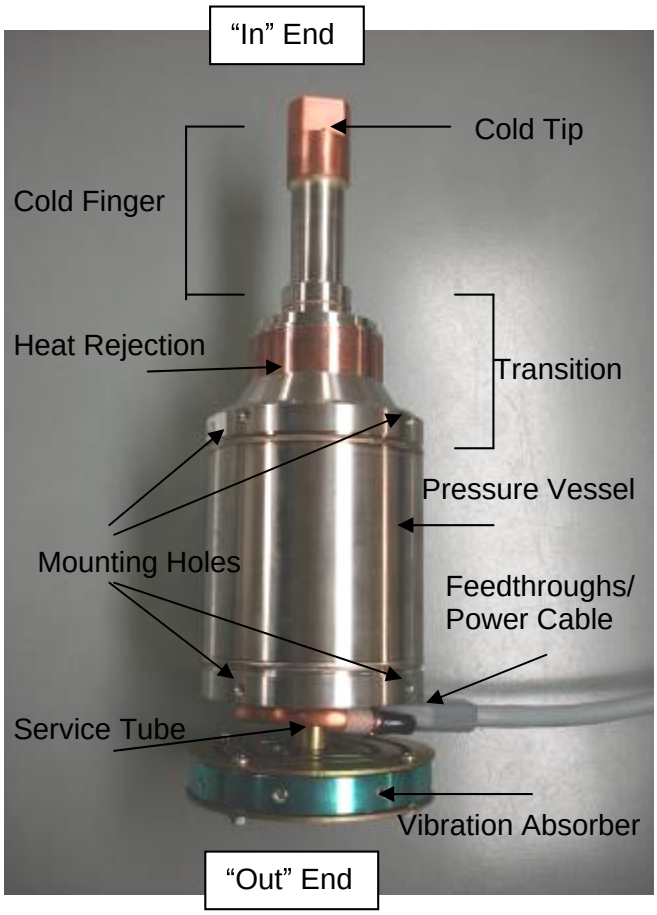


Figure 2: CryoTel GT Cryocooler

III. Unpacking

When unpacking or handling, only hold the cryocooler by the pressure vessel or the transition (see Figure 2). The CryoTel GT may sit horizontally on a level bench top or table, but the cooler must be supported to prohibit rolling. The cold finger must be protected from any contact as well.

IV. Mechanical Mounting

The CryoTel GT has a thick metal end plate on the "out" end of the pressure vessel nearest the passive vibration absorber. M4 threaded holes on the outer diameter of the transition and end plate are designed for attachment of the cooler to an external mechanical structure for testing or integration into the application. These can be seen in Figure 3.

On the face of the external copper ring that rejects heat from the cooler is a stainless steel plate. The plate has four M3 threaded holes that can be used for attaching a removable NW50 or customer specified vacuum flange (see Figure 4). A vacuum flange can also be welded to this plate, but must be done with a low energy weld such as plasma or micro TIG. It is recommended that, if needed, the customer allow Sunpower to perform the welding operation. The mechanical structure including the cryostat attachment plate, heat rejection copper, and transition have been designed to allow mounting the entire assembly by the cryostat and cantilevering the cooler and vibration absorber from the cryostat in a given application.

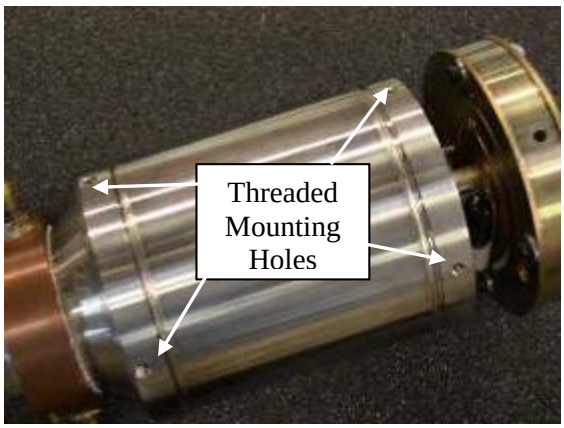


Figure 3: Pressure Vessel Mounting Holes

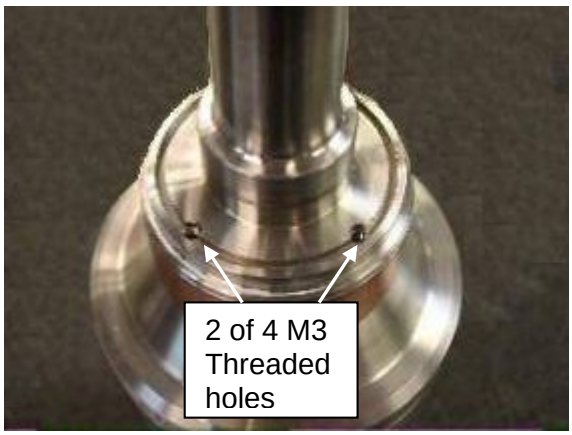


Figure 4: Weld Flange Holes

V. Attachment of Heat Load to Cold Finger

The copper cold tip at the end of the cold finger has a ¼"-20 threaded hole that can be used for mounting equipment to the cold tip for applications or tests (see Figure 5). The application of force to the cold tip must be handled with care and in accordance with these not-to-exceed limits:

- Cantilevered force, cooler **not** in operation: do not exceed a cantilevered force on the cold finger (static or shock) > 100 N (10.20kg).
- Cantilevered force, cooler **in** operation: do not permit the heat load apparatus to deliver force to the cold finger (static or shock) > 30 N (3.05 kg)
- Vertical loading: do not exceed a pure tension or compression load > 300 N (30.50 kg)
- Torque, cold finger: do not exceed a load >16 N*m (142 in*lbs)
- Torque-copper cold tip ¼-20 Thread: do not exceed a load of 10 N*m (88 in*lbs)

Figure 5: Cold Tip ¼”-20 Threaded Hole

VI. Cold End Vacuum

The cold finger of the CryoTel GT operates best in an insulated vacuum. The vacuum eliminates possible loading of the cold finger from convection or condensation of elements in the atmosphere such as water vapor and nitrogen. The vacuum is created by a customer provided vacuum Dewar or cryostat. As noted above, a flange can connect the cryostat and the stainless steel vacuum flange with an o-ring seal or welded attachment (Fig 2).

When using a mechanical vacuum pump it is appropriate to seal the flange with an o-ring and clamp. The vacuum pump will remove any residual gasses released by the o-ring and continue to maintain a vacuum inside the cryostat. However, an o-ring may corrode and become brittle over an extended period of time.

For customer applications requiring long-term vacuum without using a vacuum pump, it is recommended that the cryostat be welded to the CryoTel vacuum interface.

VII. Feedthroughs

The electrical pins on the metal plate at the end of the pressure vessel near the balance absorber are surrounded by glass, which acts as an insulator and prevents helium from leaking out of the pressure vessel. This arrangement is called a feedthrough. Because of the glass insulator, the feedthroughs should be handled cautiously. They are a permanent feature of the pressure vessel back end plate and should not be modified in any way.

The CryoTel GT is shipped with a power cable that attaches to the feedthroughs and the controller. This cable consists of orange and white 16 gauge wires with a molded plastic connector for the feedthroughs at one end and a plastic connector housing that plugs directly into the controller output cable of the same wire colors. This harness is shown in Figure 6.

Figure 6: Power Cable

It is necessary to remove the balance absorber in order to install the power cable. The balance absorber is attached with the center M5 screw. Remove this screw and the balance absorber will be free from the cryocooler.

Install the power cable by aligning the cryocooler feed through pins with the holes in the cable connector and pressing down. Insert the retaining screw into the connector and tighten.

Install the balance absorber by re-installing the M5 screw.

Important assembly notes:

- The heads of the four screws that fasten the balance absorber assembly together should be facing towards the cryocooler. The nuts for these screws will be on the "top" of the balance absorber.
- The screw heads of the four balance absorber assembly screws need to be positioned so that none of them are directly over either the power cord connector or the service tube elbow. This is to ensure that the screw head does not impact either of these features during large amplitude displacements of the balance absorber.

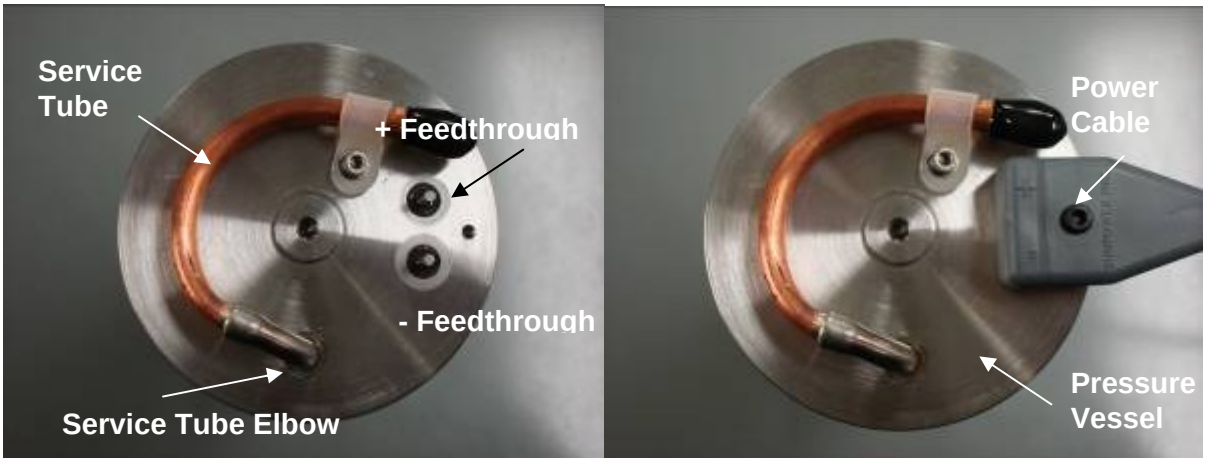


Figure 7: Rear Pressure Vessel End Plate and Power Cable Wire Harness

VIII. Temperature Sensor

For proper operation of the CryoTel controller it is necessary to mount a temperature sensor to the object being cooled. The sensor allows the controller to measure and control the cooled object's temperature. The sensor feedback also controls the cooler's power ramp-up. If the sensor is not installed properly, the cooling capacity of the cryocooler will be severely limited and temperature control will not function.

The controller is designed to us a Lakeshore PT-111 platinum RTD or equivalent. Sunpower packages the PT-111 in a copper disk so that the sensors are identical in size, shape and wiring. Figure 8 shows the sensor and the cable connecting the sensor to the controller.

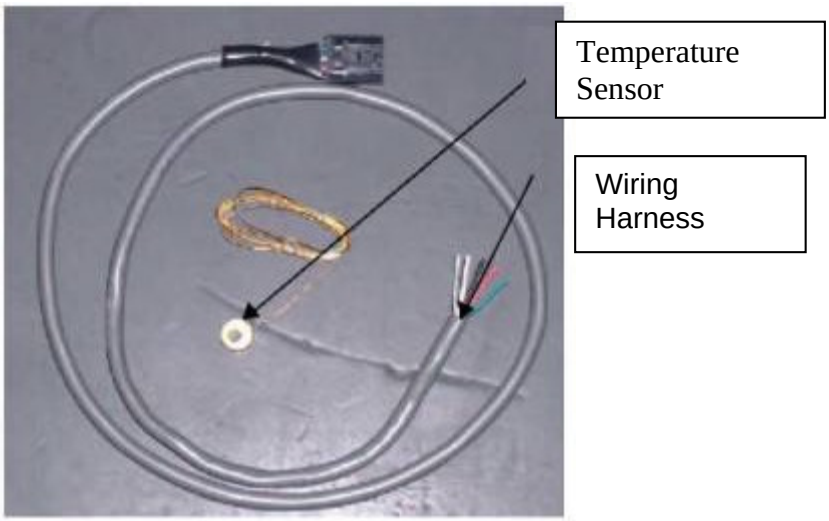


Figure 8: Temperature Sensor and cable

The temperature sensor is encased in a small copper slug. Use an M3 screw in the 3mm drilled hole to attach the sensor to object being cooled. Use a thin layer of Indium, Apiezon grease, or similar thermal grease between the sensor and the object to ensure proper thermal conduction.

Laboratory testing can be accomplished with a test cap arrangement similar to the one shown in Fig 9. The test cap is used to supply a specified heat load to the cold tip. The test cap consists of a copper cap with two resistors, a through hole with ¼"-20 clearance for connection to the copper tip, and a copper clamp ring with M3 clearance holes to clamp temperature sensors around the circumference of the cold tip. Calculate the heat load (power in Watts = current x voltage) by providing a known voltage and current across the resistors on the test cap. Mount the control sensor using one of the M3 mounting holes on the clamp ring. If using a second sensor, mount it to the clamp ring for independent temperature measurement. If not, simply clamp the other half of the ring snuggly with an M3 screw. Apply an appropriate thermal grease to the bottom faces of the test cap and inside surface of the clamp ring in order to maximize conduction between them and the cold tip. Mount the test cap to the cold tip using the ¼"-20 threaded hole on the cold tip being sure not to apply more than 10 N*m of torque.

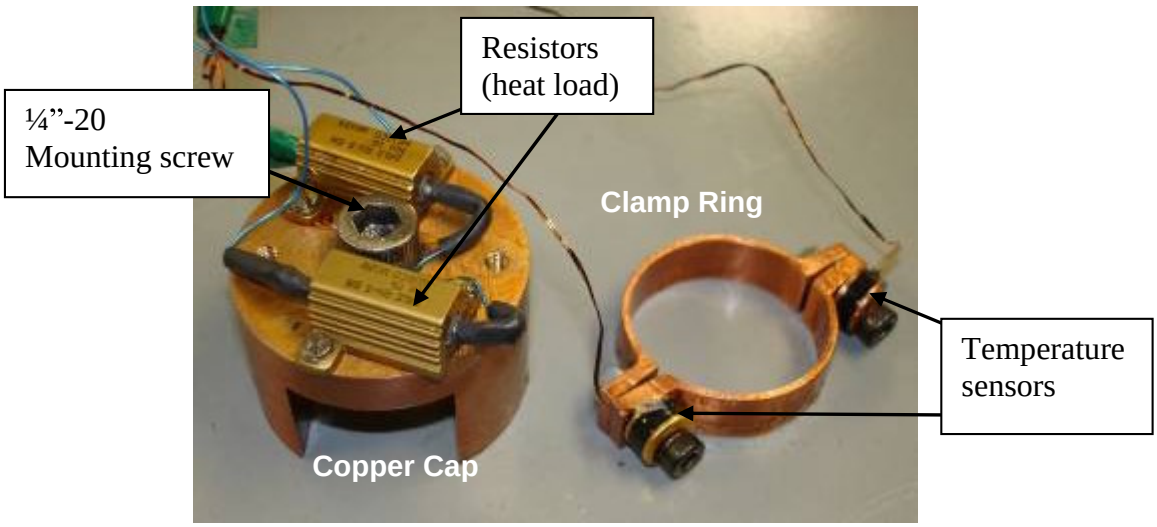


Figure 9: Test Cap Assembly

When the cold tip is contained in a vacuum vessel, use feedthroughs to connect the sensor input cable to the sensor wires. Use at least four conductors connecting the feedthrough to the control temperature sensor. Use additional feedthroughs if employing a test cap or other sensors inside the cryostat. All wires inside the cryostat should be as small as possible in order to minimize parasitic loading on the cooler. The wires of the sensor and cable are color coded to help insure proper connection. Table 1 shows the proper connection of the wires. Figure 10 and Table 2 describe proper connections of the cable to the CryoTel Controller.

RTD Wire Color	Cable Color
Black	Black
Red	Red
Clear	White
Green	Green

Table 1

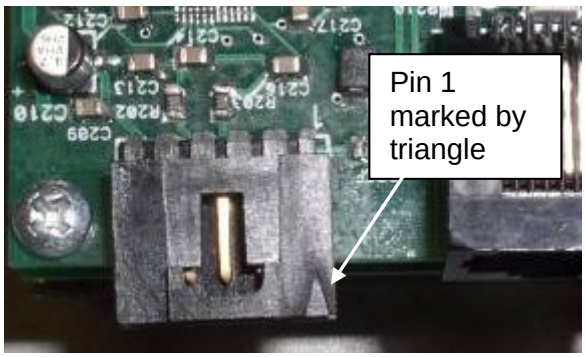


Figure 10: Controller Temperature Sensor Connector

Mating connector for temperature interface cable is DigiKey part # WM2903.

Terminals are DigiKey part # WM2554.

PIN	Function	RTD Wire Color	Harness Wire Color
1	I+	White (Clear)	White
2	I-	Red	Red
3	V+	Black	Black
4	V-	Green	Green
5	Shield		

Table 2

IX. Heat Rejection

Proper heat rejection is crucial to the operation of a cryocooler. Some CryoTel heat rejection options are a water jacket, copper fins, or a conducting solid.

CRITICAL! – Do not operate the cryocooler without adequate cooling at the heat rejection site. Overheating the cryocooler will cause permanent damage.

A. Water Jacket

Sunpower can provide a permanent or removable water cooling jacket with the CryoTel GT (Fig. 11 –*both are identical in appearance*). Use a suitable thermal grease to maximize conduction between the heat rejector and the water jacket if using a removable unit (the permanent unit is installed at the factory and does not require thermal grease). The thermal grease should be refreshed periodically as it will dry out over time. After connecting the water supply to the water jacket for heat rejection, ensure that air is removed from the water jacket. This can be done by flowing water through the cooling system for several minutes prior to the run. If it appears that air is still trapped in the water jacket, try carefully tilting the cooler in the direction away from the cooler discharge tube. This will raise the level of the discharge tube and allow any trapped air to escape. Trapped air will decrease heat rejection and cooler performance. Water should be flowing through the jacket at approximately 15mL per second (0.24 gallons per minute).

Figure 11: Water Jacket Heat Rejection

B. Copper Fins

Copper fins are also available in a permanent or removable form. If copper fins are used for heat rejection (Fig. 12-*permanent fins are pictured*), use a fan with a rating of 100 cubic feet per minute (1.6e-3 m^3/min) for air through-flow. Sunpower recommends mounting the fan to a cylindrical shroud that can be placed around the fins in order to direct the air through the fins. Note that some heat rejection also occurs from the walls of the pressure vessel. Therefore avoid permitting any containment structure for the cryocooler to hinder the heat rejection from any part of the cooler. It is also recommended to electrically interlock the cooling fan and the controller in order to ensure that the cooler cannot operate without also turning on the fan. For additional cost, Sunpower is able to provide a fan, shroud, and controller that are suitable for laboratory testing.

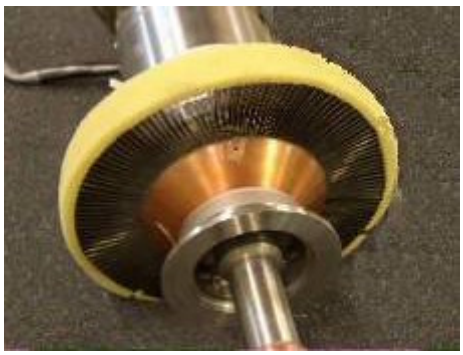


Figure 12: Cooling Fin Heat Rejection

C. Conducting Solid

Use of any other means of heat rejection necessitates ensuring that the proper amount of heat is being transferred away from the rejector and that the reject temperature is suitable. It is recommended to involve Sunpower with the design of a conduction heat exchanger.

X. CryoTel Operation

<u>CRITICAL!</u> – Do not operate the cryocooler without adequate cooling at the heat rejection site. Overheating the cryocooler <u>will</u> cause permanent damage.

A. Preparation

1. Attach application apparatus or test cap assembly to cold tip of cold finger.
    a. Apply a thin layer of Apiezon thermal grease or Indium to the copper tip of the cold finger in order to maximize conductivity.
2. Attach the customer-provided cryostat by appropriate means if a vacuum is required for the application.
3. If using a vacuum, make wire connections from temperature sensor and any other measuring devices inside the cryostat through Dewar feedthroughs.
    a. For maximum performance, wires should not touch the walls of the Dewar. Contact with walls will increase the heat loading (conduction) during use and will yield lower available cooling power.
4. Seal the cryostat vacuum except for the connection to the vacuum pump (if using vacuum).
5. Mechanically attach the cryocooler assembly to the customer provided mounting device.
6. Connect the wiring from the cryostat feedthroughs to the appropriate test and measurement devices.
    a. The cold tip temperature sensor must be connected to the controller's mating connector as described previously using the provided cable and connector (See Figure 13 for controller connections).
7. Attach the vacuum pump to cryostat, start the vacuum and allow it to reach a vacuum of 10^{-4}Torr or better.

B. Beginning Operation

1. Prepare the CryoTel GT for testing as described above.
2. Connect the power cables for the CryoTel GT to the controller's mating connector (controller connections in Fig. 13).
    a. Verify the correct polarity is observed with respect to the CryoTel GT – orange power cable wires are positive, white wires are negative.
    b. Attach the included wire harness to the cooler as shown in Figure 6 then attach the plastic connector at the other end to the connector with orange and white wires on the controller (Fig 13).
        i. Note: The connector attached to the cooler wires is an AMP Mate-N-Lok® plug housing, 1-480698-0; with AMP Mate-N-Lok® contacts, 3505471-1 (available from Mouser Electronics, part numbers 571-14806980 and 571-3505471 respectively).
        ii. Note: The connector attached to the controller wires is an AMP Mate-N-Lok® cap housing, 1-480699-0 with AMP Mate-N-Lok® contacts, 350550-1 (available from Mouser Electronics, part numbers 571-14806990 and 571-3505501 respectively).
3. Connect the controller to a $48V_{DC}$ power outlet.
    a. Note: The input power connector attached to the control board is an AMP Mate-N-Lok® cap housing, 1-480699-0 with AMP Mate-N-Lok® contacts, 350547-1

(available from Mouser Electronics, part numbers 571-14806990 and 571-3505501 respectively).

b. Note: Use a suitable connector for the power supply such as the same AMP Mate-N-Lok® plug housing used for the cryocooler power cables, AMP part number 1-480698-0 with AMP universal connector socket, 350550-1.
c. The controller has a startup sequence that positions the piston in the axial center. This sequence takes approximately 7-10 seconds once the controller is turned on.
d. The controller then applies a 60 Hz AC voltage to the motor, creating the oscillating motion of the piston that begins the cooling process.
e. The controller increases the power input to the cryocooler based on cold end temperature and predetermined time constants. The maximum draw by the controller is approximately 300 W_E.

4. Allow cold tip temperature to stabilize at desired cold end temperature
   a. Proper operation of the CryoTel GT requires a minimum loading of 6 Watts. If minimum load requirements are not met, the stabilized temperature will be below 77 K.

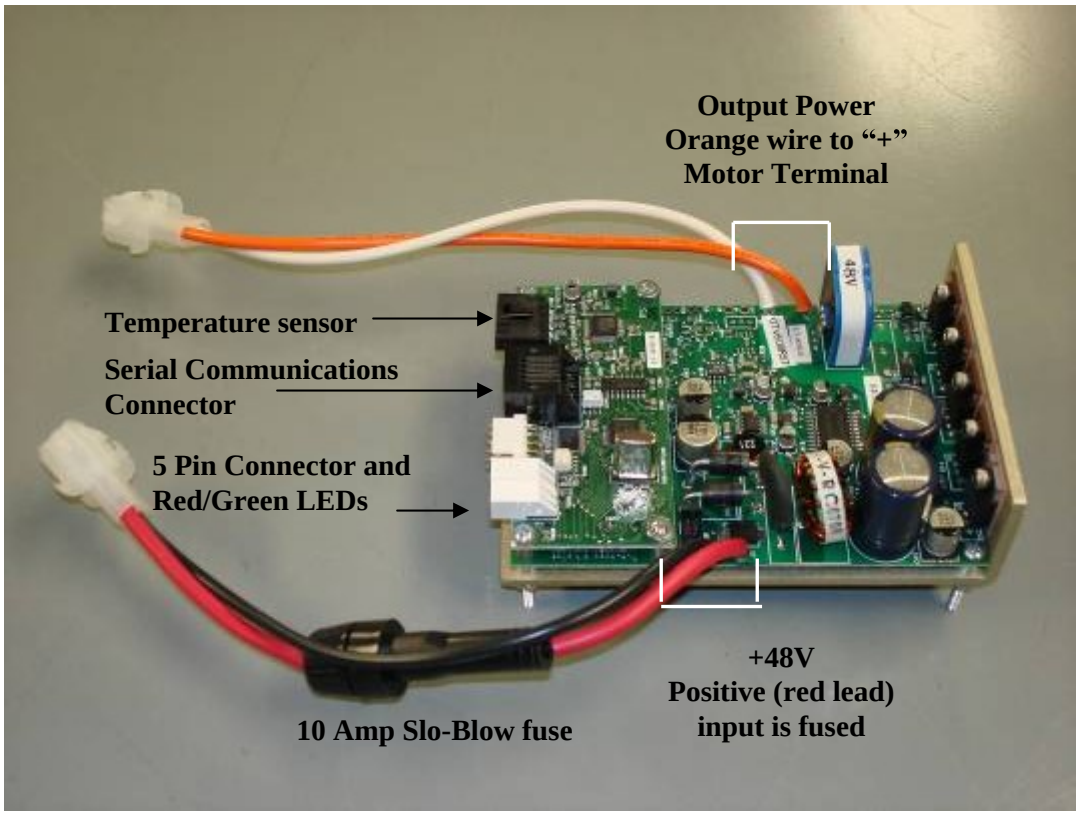


Figure 13: CryoTel GT Control Board

C. Operation Shutdown

1. Turn off the controller.
    a. The quick rattle heard when power is cut off from the CryoTel is due to the stored energy in the vibration absorber being dissipated.
    b. In rare cases where the operating temperature was below 60 K, it has been observed that the cooler can energize itself during shutdown and become an engine. To prevent this, allow the cold tip to reach a temperature above 60 K before shutting down.
2. Allow the cold tip and the rest of the cryocooler temperature to rise to room temperature before opening the vacuum in order to prevent the vapor outside the cryostat from condensing and freezing on the cold tip.
    a. Applying a heat load to the cold tip during the warming process reduces the time needed to reach room temperature.
    b. Sunpower recommends using a relay in conjunction with the temperature sensor to ensure that the power supply to the heat load shuts off when the cold tip temperature reaches 300 K.

XI. LED and 5 Pin Connector Summary

The two LED's, shown in figure 13, indicate whether the cooler has reached its set point temperature or if the cooler is still in cool down mode. The red LED will be on as long as the cooler is in cool down mode. When the cooler reaches its set point temperature within 0.5K the green LED will turn on.

The 5-pin connector is connected to an optocoupler circuit as shown in Figure 15. When the green LED is on, current is able to flow from pin 1 to pin 5 through the Darlington Phototransistor. When the green LED is off, the current flow through the phototransistor is blocked. This would be useful if the user wanted switch an externally powered indicator light or control system input on when the cooler reaches the set point temperature. Pins 2, 3, and 4 on the 5 pin connector are not used.

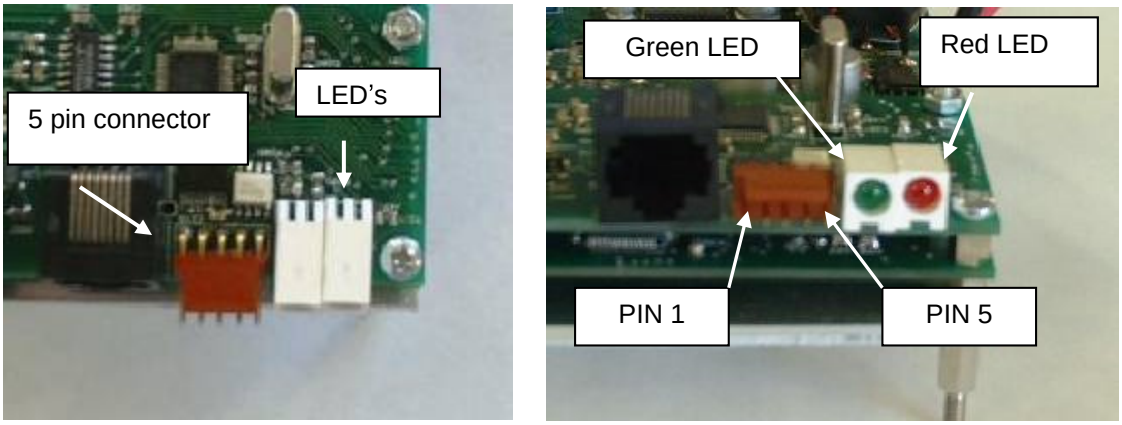


Figure 14: Controller LED's and 5 pin Connector

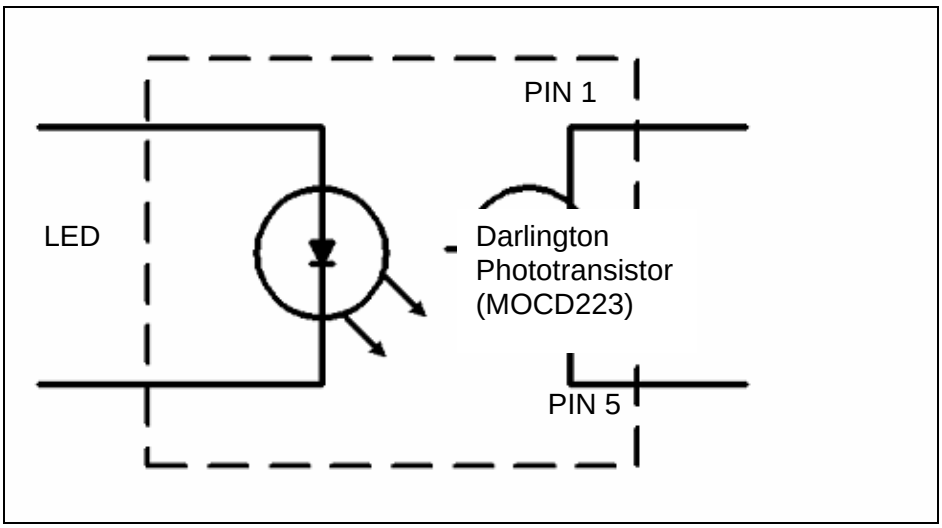


Figure 15: Optocoupler Circuit.
Phototransistor is on when green LED is on.

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XII. CryoTel Serial Communications Command Reference

Control the CryoTel GT with any terminal emulator program. A common choice is Hyperterminal, as it is included with Windows. The connecting cable and computer adapter are included.

Caution: Use of an external program, such as LabVIEW™, to establish closed loop control of the cryocooler via serial communication, may cause controller malfunction. This malfunction condition requires the controller to be returned to Sunpower, Inc. for reprogramming. Manual setpoint adjustments may be made as required without problem.

A. Serial Interface Specifications

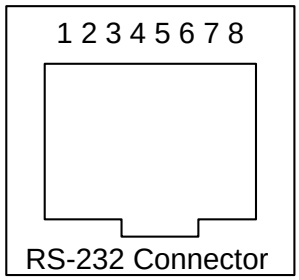
RS-232

Baud Rate:	4800
Flow control:	none
Data bits:	8
Stop bits:	1

B. Controller Connector Wiring Information

Pin Numbering of RJ-45 connector and Pin-out of RS-232 Connector on CryoTel Controller

Pin	Function
1	RX
2	GND
3	Do not connect
4	GND
5	Do not connect
6	GND
7	TX
8	GND



C. CryoTel GT Terminal Emulator Commands

The following pages show an explanation of each of the terminal emulator commands and display examples.

1. Display temperature sensor value in Kelvin
   a. Command: **TC<CR> (<CR> means "press Enter key")**

```
TC
330.00
```

2. Show the current controller mode
   a. Command: **SET PID<CR>**
   b. The value returned will be a two or a zero. If it is a zero, the controller will maintain a constant power as commanded by **SET PWOUT**. If it is a two, the controller will try to maintain a constant temperature as commanded by **SET TTARGET**.

```
SET PID
002.00
```

3. Set controller Mode
   a. Command: **SET PID=V<CR>**
   b. V may be a two or a zero as shown before. Two is for temperature control and a zero is for power control.
   c. When this command is entered, the return display is equivalent to using SET PID without a specific value.

```
SET PID=0
000.00
SET PID=2
002.00
```

4. Display target temperature in Kelvin
   a. Command: **SET TTARGET<CR>**
   b. This command shows the target temperature of the controller when in mode 2

```
SET TTARGET
077.00
```

5. Set target temperature in Kelvin when in mode 2
   a. Command: **SET TTARGET=V<CR>**
   b. V corresponds to the target temperature. This value is stored in flash so it is retained in the controller at power up.

```
SET TTARGET=86.42
086.42
```

6. Display command power when in mode 0 control.
   a. Command: **SET PWOUT<CR>**

```
SET PWOUT
170.00
```

7. Set command power when in mode 0 control
   a. Command: **SET PWOUT=V<CR>**
   b. V corresponds to the target power in watts. While any number from 0.0 to 999.99 can be input, the controller will only command a power that will not damage the cryocooler.
   c. The minimum power is 70W @ 77 K.
   d. The maximum power is a function of cold head temperature and increases as the cold temperature decreases.

```
SET PWOUT=160
160.00
```

8. Display current command power and power limits
   a. Command: **E<CR>**
   b. The top value is the maximum allowable power for the current temperature. The middle value is the minimum allowable power. The bottom is the current command power. All values displayed with this command are in watts.

```
E
230.00
070.00
170.00
```

9. Remote ON-OFF feature:
   There is a control feature available that allows the power output to the cryocooler to be disabled while keeping the controller powered up. The controllers are shipped with this function disabled because the majority of our customers do not need it and would not want to make the wiring changes to the standard RJ45 connector. Pins 3 and 5 on the RJ45 serial communications port are used as the signal input. Shorting these pins together enables the controller output; open circuit disables the controller output.

You can enable this feature by sending these commands to the controller:
Unlock <enter>
SSTOP=1 <enter>
Lock <enter>

<<Caution>> It is imperative that the "Lock" command be entered at the end of the sequence to prevent the software being compromised during controller operation.

Note: after you enable this function, pins 3 and 5 must to be connected in order to drive the cryocooler.

D. Allowable Number Formats

When using the terminal emulator to command the controller, all input numbers should be in one of the following formats. X is a digit from 0 to 9.

X	XX	XXX
X.X	XX.X	XXX.X
X.XX	XX.XX	XXX.XX

End of CryoTel® GT Operating Instructions Version 5