Target Cell Heater and Controls

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1 Introduction

The target pumping cell must be kept at a temperature of about 170°C (340°F) for optical pumping of Rb to be effective. This is accomplished by flowing hot air through a special temperature-resistant enclosure around the pumping cell (the "oven") and regulating the temperature of the air using a process controller. The system is described in detail in the following.

2 Design

Figure 1 shows a schematic diagram of the heater system and the associated controls. Pressurized dry and filtered air at room temperature is provided by a dedicated compressor in the Hall. The air enters the system through a shut-off valve and a pressure regulator, which is typically set to an output pressure of 15 psi. The flow rate is measured with a gas velocity sensor (Omega model FMA-905) connected to a display unit (Omega DP41-E-S2R) that provides an alarm to indicate insufficient flow. The air then passes through a resistive heater element (120 VAC, 700 W) and continues through special temperature-resistant tubing (G-10) into the target oven. The oven material is Torlon and Vespel plastic which can withstand a temperature of at least 260°C continuously. The air finally exits the system through a several meters long exhaust pipe where it can cool down.

A 100Ω Pt RTD (Omega model F3105) measures the temperature inside the oven. A process controller (Omega CN77540-C2) operating in PID mode drives the heater via a solid-state relay (SSR) regulating the heater power dependent on the temperature detected by the RTD. The SSR (Omega model SSR240DC10) accepts a low-voltage (3-32 VDC) control signal of about 30 mA. A mechanical relay between the SSR and the heater allows interruption of the 120 VAC heater power in case of a malfunction (see section 3).

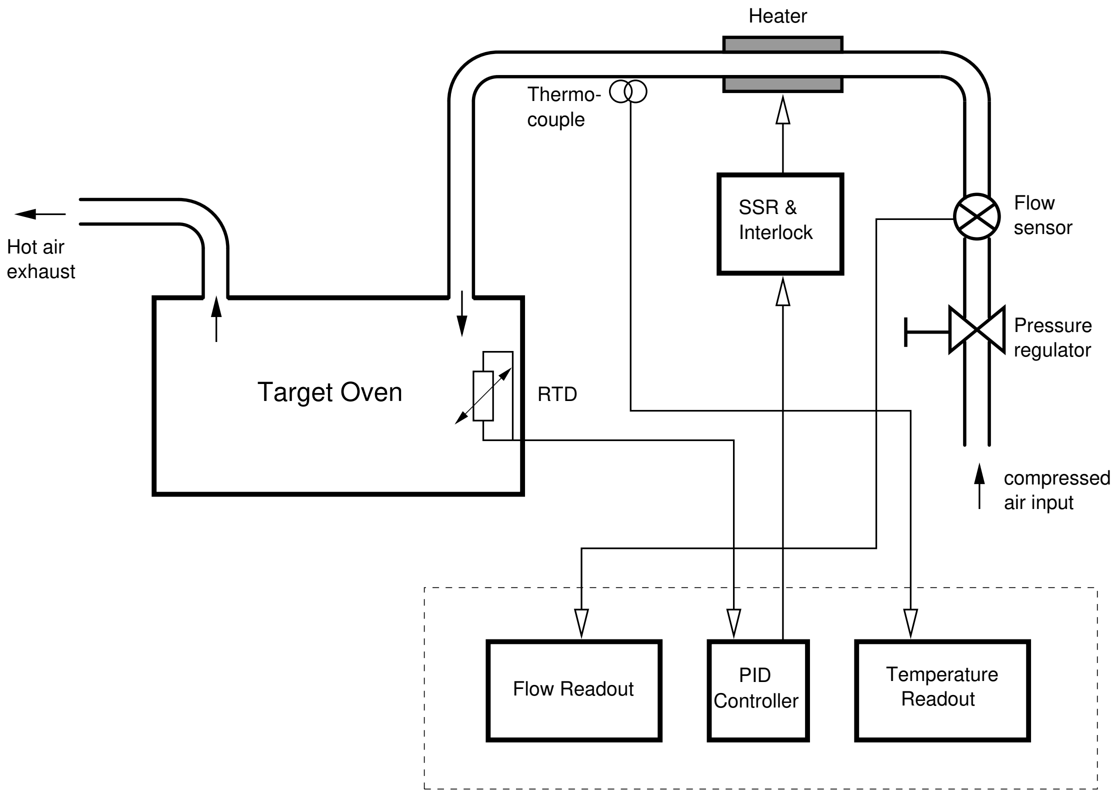

Figure 1: Schematic diagram of the target cell oven control system. The instruments in the dashed box are located upstairs, while the remaining components are located in the Hall in the vicinity of the target. For clarity, the interlock circuitry is not shown (see Figure 2).

A thermocouple (Omega 5SC-GG-K-30-36) is mounted on the tubing right after the heater to allow monitoring of the temperature of the air exiting the heater. Another display unit (Omega DP41-TC-S2R) reads the thermocouple and generates an alarm if the temperature exceeds a preset threshold.

The PID controller as well as the two display units are installed in a 19" chassis in the electronics racks on the second floor of the counting house where they can be manually operated if necessary. All other components are located in the Hall in the vicinity of the target. The instruments can be monitored and programmed remotely via serial RS-232 communications, which allows convenient control via an EPICS/MEDM graphical user interface (GUI) in the counting house.

3 Safety Considerations

The heater system represents a significant fire hazard and therefore requires good failsafe protection. Possible failure modes include:

1. Insufficient air flow. Possible causes: Compressor failure; obstruction in filter; operator error. Possible harzards: Overheating of heater element, resulting in equipment damage and/or fire. Protection: Air flow is monitored; insufficient flow disables heater (and laser) via hardware interlock.

2. Heater overtemperature. Possible causes: Insufficient airflow; temperature controller failure; RTD failure; operator error. Possible hazards: Damage to heater element and/or tubing; fire. Protection: Heater temperature is monitored; excessive temperature disables heater (and laser) via hardware interlock.

3. Oven overtemperature. Possible causes: Temperature controller failure; RTD failure; insufficient air flow; excessive laser power; operator error. Possible hazards: Explosion of target cell; damage to oven enclosure and/or optical elements; fire. Protection: Temperature controller will generate alarm if RTD indicates excessive temperature, disabling heater via internal logic and and laser via hardware interlock.

A schematic diagram of the interlock system is shown in Figure 2. The instruments are programmed such that their dual alarm relays operate simultaneously if a value is out of range. An interlock condition disables the heater as well as puts the lasers in standby mode. Interlocking the lasers is

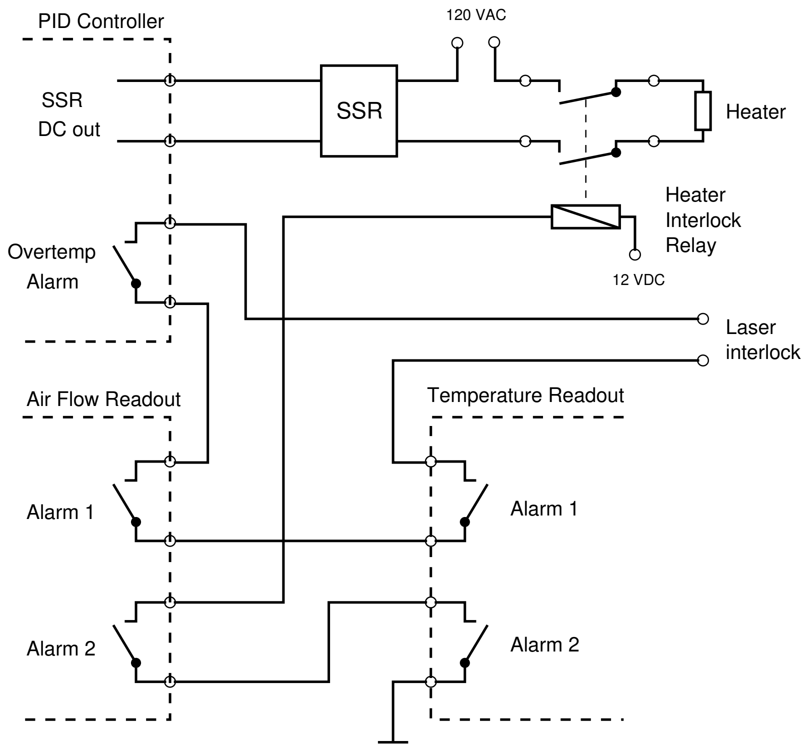

Figure 2: Schematic diagram of the oven heater interlock system. The switches represent relays. In normal operation, the relays are energized (contacts closed). An alarm condition (or instrument power failure) will de-energize (open) the corresponding relays, interrupting the interlock circuit. The instruments are programmed such that their dual alarm outputs operate simultaneously.

important as the laser light contributes significantly to the heating of the target oven.

4 Operation

The oven can be controlled from a GUI running on one of the Hall A counting house computers, or manually using the front panel controls. The GUI is not yet finalized, so we only give a brief description of the manual operating procedure here at this time:

1. The oven controller and temperature and flow displays are located in a 19" chassis in one of the racks upstairs. Make sure power to this chassis is on. The green light on the front panel should be lit.

2. Verify the alarm set points for the flow meter and temperature indicator. Press the `SETPTS` button until the display shows `SP3`. After about 1 second, the setpoint value appears. It should be 250 for the air flow display and 220 for the temperature display. Press `SETPTS` again and check setpoint `SP4`. It should be identical to `SP3`.

   To change any of the values use the `MIN` and `MAX` buttons. The `MIN` button selects the digit to be changed whereas the `MAX` button changes the value of the currently selected digit. Press `SETPTS` again to store the new value. When finished, press `SETPTS` until `RUN` appears in the display.

3. Verify the current temperature of the oven. It is shown in the upper (red) display of the temperature controller and is labeled `PV` for "Process Value". The units are °C. The value should be reasonable, *e.g.* around room temperature if the oven has been off for several hours or more. If the value does not make sense, either the controller is misconfigured (see below) or the RTD in the oven is broken or incorrectly connected. Do not proceed before you have a sensible reading.

4. (Optional) Verify the correct configuration of the controller. Use the `MENU` button on the controller to scroll through the various configuration menus. To inspect parameters within a menu, press `ENTER` followed by `MENU` again. The suggested default parameters are listed in Tables 1 and 2. This step is time-consuming and can be skipped if you are relatively certain that the configuration is ok. A detailed description of the controller parameters is given in the controller manual.

5. Verify that air is flowing. The air flow readout should indicate a value of 350–450. These are arbitrary units. As long as the heater is off, the reading should not fluctuate by more than about ± 10 units.

6. Verify the current temperature of the heater. It should be close to room temperature. If the value is unreasonable, either the readout is misconfigured or the thermocouple is broken. Do not proceed before the problem is corrected.

7. Verify that alarms are reset. Underneath the main display there are four LEDs, one for each alarm 1–4. If either LED `3` or `4` is on on either instrument, it indicates that an alarm has been triggered and that the system is interlocked. You must reset the alarms before you can continue. To do so, first correct the problem (*e.g.* turn the air flow on) then press `RESET` once on the affected instrument(s). If the LEDs stay on despite correct setpoints and readings, the instrument is probably misconfigured.

8. Begin heating. To avoid damage to the oven, the temperature must be increased to the final value slowly. A good final operating temperature is 170°C, and a good ramping rate is 60°C/h, *i.e.* heating of the oven will take about three hours to complete.

   In manual mode, you must enter a new temperature setpoint by hand at fixed time intervals. ("Ramp and Soak" does not seem to work reliably with this controller.) You should increase the value by 10°C every 10 minutes. For example, if the current oven temperature is 35°C, start with a setpoint of 45°C and increase this value by 10°C in approximately 10 minute intervals.

   To enter a new setpoint, do the following

   (a) Press `MENU` on the temperature controller. A little green light marked `SP1` in the upper left corner of the display will start to blink. Also, the first digit of the green numerical display, labeled `SV` for "Setpoint Value", will blink.

   (b) Use `MIN` to select the digit you wish to change and `MAX` to modify the value.

   (c) When done, press `ENTER`. The display will briefly show `run` when the controller enters normal operating mode. This starts the heating process.

9. Check correct operation of the controller. A little green light marked `SP1` in the upper left corner of the temperature controller display indicates that the heater is active. This light should blink slowly, being mostly on while the oven is heating up and being mostly off (or even completely off for periods of up to a few minutes) when the oven temperature has reached the setpoint.

   The heater temperature should increase proportionally to the fraction of time that the `SP1` indicator is on. Note that the temperature reading is *not* directly related to the oven temperature. In particular, the heater may become significantly hotter than the oven, and its temperature might fluctuate from almost room temperature to high values over short periods of time as the heater power is automatically cycled on and off by the controller. As long as the temperature stays below the alarm threshold (220°C) there is no reaason for concern.

10. Check stability of the final temperature. The temperature might overshoot slightly. If the overshoot is less than about 5°C then this is normal. If the stability is poor it is probably due to incorrectly set PID parameters in the controller. Changing these parameters is best done by an expert since this requires in-depth understanding of the system.

    The laser contributes significantly to the heating of the oven. Therefore, you will notice sudden temperature instabilities when the laser is turned off or on. It will take several minutes for the controller to compensate for such changes.

11. The air flow rate is slightly dependent on the heater power applied (conductance varies with temperature). Therefore, the flow rate will fluctuate by some 10-20%. This is normal.

12. At any time you can place the controller in standby mode by pressing `ENTER` twice. The display will show a blinking text `STBY`. This will turn the heater off completely and can be used when the system appears to malfunction. However, exercise some caution if the oven is at an elevated temperature since it will quickly cool down if heater power is disabled and you will lose time bringing it back up to operating temperature.

13. In an emergency, simply turn the power to the chassis off completely. This will open the interlock loops, thereby cutting power to the heater and placing the laser in standby mode.

Menu	Submenu	Setting
Output Redirection		S1.o1
Input Type		RTD
	RTD Type	385.3
	RTD Value	100_
RDG Configuration	Decimal Point	FFF.F
	Temperature Units	°C
	Filter Constant	0004
Alarm 1		Enabled
	Type	Absolute
	Latched	Latched
	Contact	n.c.
	Setup	Above
	Power On	Enabled
	Low Value	(anything)
	Hi Value	210.0
Alarm 2		Not Installed
Loop Break		Disabled
Output 1	Self	Disabled
	% Low	0000
	% High	0095
	Control Type	PID
	Action Type	Reverse
	Auto PID	Disabled
	Adaptive Control	Disabled
	Anti Integral	Enabled
	Start PID	Disabled
	Proportional Band	0038
	Reset Setup	0050
	Rate Setup	0000
	Cycle Time	0001
	Damping Factor	0001
Output 2	(any)	(anything)

Table 1: Suggested default parameters for the temperature controller.

Menu	Submenu	Setting
Ramp & Soak	Ramp	Disabled
	Soak	Disabled
Analog Output		Not installed
Communication Option	Baud	9600
	Parity	Odd
	Data Bits	7bit
	Stop Bits	1bit
Bus Format	Checksum	no
	Line Feed	no
	Echo	no
	Standard	232C
	Mode	Command
	Separator	Space
Data Format	Status	yes
	Reading	yes
	Peak	no
	Valley	no
	Unit	yes
	ID	no
Address Setup	(any)	(anything)
Transmit Time	(any)	(anything)
Remote Setpoint		Not installed

Table 2: Suggested default parameters for the temperature controller (continued).