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DESIGN NOTE

An automatic controller for filling and maintaining liquid nitrogen levels in Dewars

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Abstract
A controller for filling and maintaining the level of liquid nitrogen Dewars is described, which has been used in experiments where the boil-off rate is large due to the proximity of an atomic beam oven to a beam dump cooled by the liquid nitrogen. The control system uses either a pair of copper–constantan thermocouples, or a pair of green LEDs to monitor the upper and lower levels of the filled Dewar. The level of the Dewar is then maintained between these two detectors. The controller is simple to build and is inexpensive, thereby making it accessible to many undergraduate and research laboratories.

Keywords: liquid nitrogen Dewar, level controller, LED sensor, thermocouple, electron spectrometer

1. Introduction

Liquid nitrogen is used in many different fields of science. In many cases the liquid is contained in a Dewar which is connected to the experimental apparatus so as to maintain some part, such as a cold finger, at liquid nitrogen temperatures. As such, the Dewar connected to the apparatus needs to be filled, usually from a larger vessel, and the level must be maintained over the lifetime of the experiment. It is therefore convenient to adopt an automatic filler which controls the level of the Dewar throughout the time the experiment is operating.

A number of different techniques are possible for this application. The method that is presented here is inexpensive to build, and maintains the Dewar between two levels as set either by thermocouples, or by using green LEDs as sensors. Both types of detector have different advantages. The thermocouples are passive devices which are very sensitive to the level of the liquid. This type of detector can be used in Dewars where there is no turbulence in the liquid, and the boil-off rate is low. It is advantageous to thermally insulate the sensors while immersed in the liquid, as this reduces their sensitivity to small temperature fluctuations, and allows the detection electronics to switch more cleanly. By contrast, the LEDs are run in conductive mode, and so act as a small heat source inside the liquid. As such their response is slower than the thermocouple, but they have the advantage that if there is a high boil-off rate or turbulence inside the Dewar, they will not switch off inadvertently. The circuit presented here allows both types of detector to be used.

The liquid nitrogen controller detailed here has been used in both undergraduate and research laboratories at the Department of Physics and Astronomy at Manchester. In the undergraduate laboratory the controller is used for experiments using liquid helium, where the liquid nitrogen Dewar acts as a cold jacket outside the main liquid helium cryostat. In the research laboratory, the controller maintains the level of nitrogen in a Dewar connected to an electron spectrometer. This Dewar gravity feeds liquid nitrogen to a cold trap located opposite a hot calcium oven, and so the rate of use

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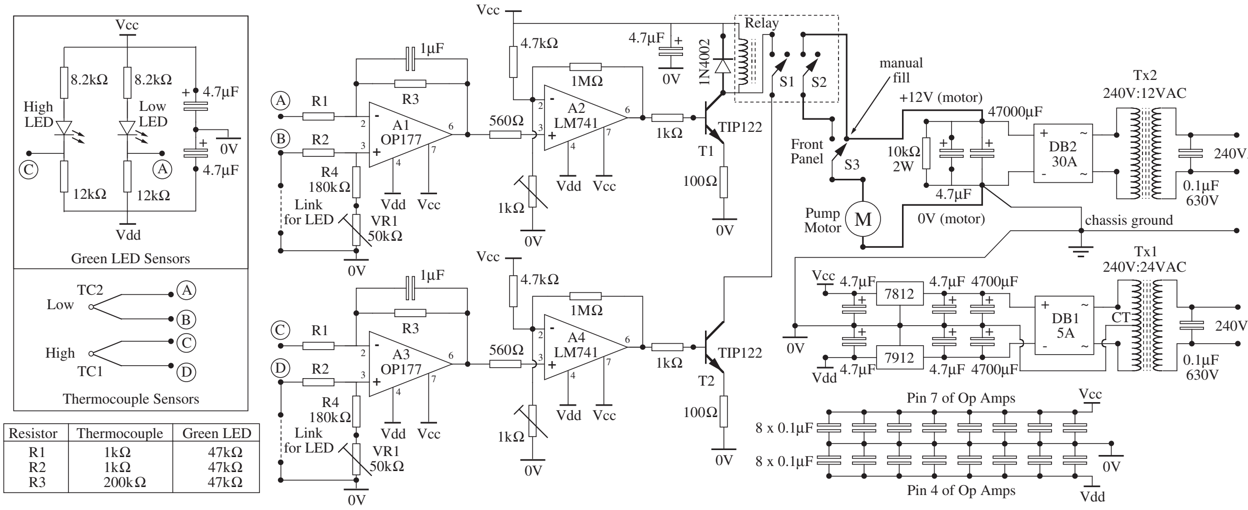

Resistor	Thermocouple	Green LED
R1	1kΩ	47kΩ
R2	1kΩ	47kΩ
R3	200kΩ	47kΩ

Figure 1. Circuit diagram of the liquid nitrogen controller, showing the power supplies and control electronics that have been adopted. Sensors can either be biased green LEDs or thermocouples. For details, see the text.

of liquid nitrogen is considerably higher in this application [1–3]. Further, since unused liquid nitrogen is recycled back to the top of the Dewar via an outlet pipe, there is considerable sputtering and turbulence within the Dewar when the oven is operating. In this case, the relative insensitivity of the green LEDs to this sputtering allows the controller to reliably maintain the level inside the Dewar while the experiment is running.

2. The controller circuit

Figure 1 shows the circuit diagram for the controller. The status of the sensors is measured by two OP-177 high stability operational amplifiers configured in differential mode to allow the small voltages derived from the thermocouples to be measured while reducing common mode noise. At room temperature, the copper–constantan thermocouple sensors produce an output of around +0.8 mV, whereas at liquid nitrogen temperatures the output is around −5.2 mV. The gain of the OP177 operational amplifiers for each input is set to be $G = -200$ by R1, R2, R3, R4 and VR1, and so the amplifiers produce an output of around +1 V when the thermocouples are immersed in liquid nitrogen, and −0.2 V when held at room temperature. For thermocouple sensors, the values of the resistors are selected to be $\mathrm{R1} = \mathrm{R2} = 1$ kΩ, $\mathrm{R3} = 200$ kΩ, $\mathrm{R4} = 180$ kΩ and $\mathrm{VR1} = 50$ kΩ. R1 to R4 are all high stability resistors to allow the gain to be accurately controlled. The trim potentiometer is used to balance the differential pair so as to reduce common mode noise.

When green LEDs are used as sensors the values of the resistors are less critical, and normal metal film or carbon resistors can be used. The LEDs are biased as shown from the Vcc (+12 V) and Vdd (−12 V) supplies which are decoupled using 4.7 μF tantalum capacitors. The LEDs have a forward bias voltage of ~2.5 V when at room temperature, and this increases to ~8 V when immersed in liquid nitrogen. Hence at room temperature the current from the power supply that passes through the LED is around 1 mA, and the input to the operational amplifiers is $V = +0.9$ V with respect to the ground. By contrast, when the LED is immersed in liquid nitrogen, the current passing through the LED is 0.8 mA and the input to the operational amplifier is then −2.4 V.

When using LEDs as sensors, the resistors that control the OP177 amplifiers are chosen so as to yield a gain $G \sim -1$. It is unnecessary to use a differential amplifier and so the resistor values are chosen to be $\mathrm{R1} = \mathrm{R2} = \mathrm{R3} = 47$ kΩ, and a 0 Ω link is made to the ground between inputs (B) and (D) for each operational amplifier. Using these values, the output from the OP177 is –0.9 V at room temperature, which increases to +2.4 V when the LED is immersed in liquid nitrogen.

The output from the OP177 amplifiers passes to LM741 operational amplifiers which are configured as high gain non-inverting amplifiers. An LM741 operational amplifier is used as it is inexpensive, and has a low slew rate which reduces the sensitivity to any high-frequency noise that may be present. The LM741 amplifier uses a 1 MΩ feedback resistor to provide high gain, and uses a 4.7 kΩ/1 kΩ resistor divider network at the negative input to set the switching point for the circuit. This divider network allows both types of sensor to be used by setting the appropriate voltage on the negative input to the LM741. For thermocouple sensors, the negative input is biased at around +0.8 V whereas for LED sensors this point is biased at around +2V.

At room temperature the output from the OP177 amplifier is negative, and so the high gain of the LM741 drives the output close to the negative rail (Vdd) at around −12 V. When the sensor is immersed in liquid nitrogen, the output of the OP177 amplifier becomes positive and rises above that of the bias point, so that the output of the 741 amplifier is driven to the positive rail (Vcc) at around +12 V. The LM741 therefore acts as a switch between ±12 V due to the high gain of this stage.

Current from the LM741 amplifiers passes to the base of TIP122 Darlington power transistors via a 1 kΩ resistor. The TIP122 transistors have a current gain $\beta > 1000$, and so can be used to directly drive the double pole double throw (DPDT) relay from the operational amplifier output. The emitters of each TIP122 are connected to 0 V via a 100 Ω 1/2 W carbon resistor, whereas the collector of T1 is connected to the relay coil which operates the liquid nitrogen pump from the +12 V supply rail.

The TIP122 transistor associated with the low sensor (T1) is directly connected to the relay coil as shown, whereas the TIP122 associated with the high sensor (T2) connects to the relay coil via one of the contacts (S1) of the DPDT relay. The second pole of the DPDT relay (S2) connects the +12 VDC motor supply to the liquid nitrogen pump via a 10 A DPDT switch (S3) mounted on the front panel. This front panel mounted switch (S3) can be used to directly engage the pump motor from the +12 VDC motor supply rail (manual fill), or can be switched to allow the pump to be controlled by the monitoring circuit.

The operation of the relay is as follows. With the Dewar empty both the high and low sensors produce a positive output, and the OP177 amplifiers drive each LM741 output HIGH (∼Vcc). Transistor T1 conducts current, thus engaging the relay ON. The switch (S1) to the collector of transistor T2 engages, and since the base of transistor T2 is high, current also flows through T2 via the relay coil. The relay simultaneously switches +12 V to the motor of the liquid nitrogen pump by engaging (S2), and the Dewar starts to fill.

Once the Dewar has filled to the level of the low sensor, the output of the LM741 (A2) swings to the negative rail, and transistor T1 switches OFF. The relay remains engaged however, since the high sensor is not immersed in liquid nitrogen, the base of transistor T2 remains high and current continues to flow through the relay coil and switch (S1) via T2. Once the high sensor is immersed, the output of the LM741 operational amplifier (A4) switches to the negative rail, and transistor T2 switches OFF. Current ceases in the relay coil, switches (S1) and (S2) disengage, and the pump switches OFF leaving the Dewar full to the level of the high sensor.

As liquid nitrogen boils off, the Dewar level drops below the high sensor, and the output of the LM741 (A4) reverts back to the +12 V rail. Transistor T2 does not turn on at this time however, as the coil is disconnected from the collector of T2 via the open connection (S1). It is not until the level of the liquid nitrogen drops below the low sensor that the relay once more engages, (S1) and (S2) re-connect and the cycle described above is repeated. Thus the level of the liquid nitrogen is maintained between that set by the upper and lower sensors.

The power supply used for this circuit consists of a 20 VA 240 V:24 VAC E-core transformer (Tx1) which provides the ±12 V rails for the operational amplifiers, together with a separate 100 VA 240 V:12 VAC toroidal transformer (Tx2), diode bridge and smoothing capacitor that provides a separate +12 V for the motor supply. By using individual supplies, inductive noise from the pump motor is effectively eliminated from the control circuit, thereby increasing the stability of the system.

±12 V supplies (Vcc) and (Vdd) are derived from a standard regulated power circuit as shown. The output from the centre tapped (CT) transformer is rectified by the 5 A diode bridge DB1 and passes to 2 × 4700 μF smoothing capacitors prior to being regulated by an LM7812 positive regulator and an LM7912 negative regulator. The regulators are decoupled using 4.7 μF tantalum capacitors at both input and output, and the operational amplifiers are further decoupled at their respective supply pins by 0.1 μF disc ceramic capacitors.

The +12 V supply for the pump motor uses a 30 A bridge rectifier (DB2) and a 47 000 μF smoothing capacitor which is bled by a 10 kΩ 2 W resistor placed across the output pins of the capacitor. A 4.7 μF tantalum capacitor is also connected across the smoothing capacitor to reduce high-frequency noise. The 10 kΩ resistor is used to discharge the capacitor if the pump is disconnected and the power supply is turned off. When operating, the pump can draw up to 6 A current, and so it is important to ensure that the low voltage side of the pump motor is directly connected to the negative pin of the smoothing capacitor as shown, so as to avoid earth loops. The negative side of the 47 000 μF smoothing capacitor is connected directly to the chassis ground to prevent noise pickup when the motor is engaged, and the 0 V point on the ±12 V power supply of the regulated supply is also connected to this point.

3. Operation of the controller

The liquid nitrogen controllers have been operating reliably for approximately six months in both undergraduate and research laboratories. The LED sensors used for the controller in the research laboratory are separated by 200 mm, and are secured onto a 4 mm diameter ceramic rod using heat-shrink tubing prior to being lowered into the Dewar. By placing the sensors along the ceramic rod, they can be positioned at a set height above the bottom of the Dewar, ensuring that the minimum level of liquid nitrogen is always above the base level. The resistors which feed bias current to the LEDs can be altered to decrease or increase the bias current through the LEDs; however, the values shown in figure 1 were found to be optimal for reliable operation of the controller while minimizing heat load due to resistive heating of the LEDs.

Operation with thermocouple sensors was tried in the research Dewar; however, this was not successful as sputtering from the outlet pipe tended to splash the sensors, causing them to switch off inadvertently. If thermocouple sensors are used, then they need to be thermally insulated from the liquid nitrogen to reduce their sensitivity until immersed. It was found that the relay would ‘chatter’ if the sensors were not insulated, whereas effective insulation around the sensor minimized this. The problem can also be reduced by placing a small heater around the sensors, which is constructed from a few loops of thin constantan wire fed by the 12 V power supply. The heater keeps the sensor warm until immersed in liquid nitrogen, however an additional heat loss is introduced to the system using this method.

The controller has been used to operate a BOC CSMTB 12 VDC liquid nitrogen pump which is installed into a 50 l Dewar located close to the experiment. This pump has been found to be very reliable; however, other methods can be used since the relay switch may be operated in a number of different ways, depending on the filling technique that is adopted. The Dewar on the spectrometer in the research lab is filled every 4 h by the controller, which has reliably maintained the level in the Dewar over many weeks, proving the success and reliability of this design. The controller has also been used in the undergraduate laboratory where the level of a liquid nitrogen Dewar surrounding a liquid helium cryostat is maintained over a period of days. The simple nature of the controller means that it can be used in many different environments where the level of the liquid nitrogen must be maintained over long periods.

4. Conclusion

A controller which maintains the level of liquid nitrogen between a high and a low set point in a Dewar has been described. The circuit can use either thermocouples or green LEDs as sensors by a simple interchange of resistors. The circuit is inexpensive to build, and has proven to be reliable in both research and teaching environments.

Acknowledgment

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