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A. B. Berryhill; D. M. Coffey; R. W. McGhee; E. E. Burkhardt

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NOVEL INTEGRATION OF A 6T CRYOGEN-FREE MAGNETO-OPTICAL SYSTEM WITH A VARIABLE TEMPERATURE SAMPLE USING A SINGLE CRYOCOOLER

A. B. Berryhill, D. M. Coffey, R. W. McGhee, and E. E. Burkhardt

Cryomagnetics, Inc.
1006 Alvin Weinberg Dr., Oak Ridge, TN 37830, USA

ABSTRACT

Cryomagnetics' new “C-Mag Optical” Magneto-Optic Property Measurement System is a versatile materials and device characterization system that allows the researcher to simultaneously control the applied magnetic field and temperature of a sample while studying its electrical and optic properties. The system integrates a totally liquid cryogen-free 6T superconducting split-pair magnet with a variable temperature sample space, both cooled using a single 4.2K pulse tube refrigerator. To avoid warming the magnet when operating a sample at elevated temperatures, a novel heat switch was developed. The heat switch allows the sample temperature to be varied from 10K to 300K while maintaining the magnet at 4.2K or below. In this paper, the design and performance of the overall magnet system and the heat switch will be presented. New concepts for the next generation system will also be discussed.

KEYWORDS: Heat switch, Superconducting magnet, Magneto-Optical.

INTRODUCTION

A new magneto-optical property measurement system has been developed by Cryomagnetics that uses a single cryocooler for a sample in vacuum measurement system with optical access. The use of a single cryocooler reduces both the initial cost of the system as well as the additional complexity and maintenance of a second cryocooler.

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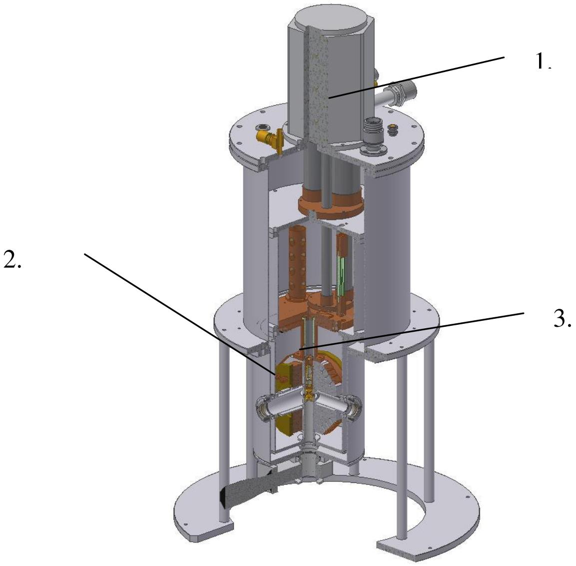

Figure 1 - Overall System Model, 1. Cryocooler, 2. Magnet, 3. Heat Switch

The system consisted of a 6 Tesla split pair magnet, a 0.7 watt Cryomech cryocooler, a Scientific Instruments model 9700 temperature controller, a TM-600 temperature monitor and a cryostat with integrated heat switch and KRS-5 optical windows. A three dimensional model of the system is shown in Figure 1.

The low-vibration 4K cryocooler provides the necessary refrigeration for both the superconducting split-pair magnet and the user's samples. The magnet must be maintained at low temperature at all times to insure its ability to operate at fields up to 6 Tesla. At the same time, the user's samples must be varied in temperature between 300K and 4K. This presents a challenge in that when the sample is operated at high temperature, the heat load on the cryocooler can be very high. The thermal link between the sample and the cryocooler must be broken to prevent overheating the magnet.

Heat switches have been used to provide variable thermal links, however, they are usually designed[1,2,3] to cover only a narrow temperature range. In this case the heat switch was designed to operate from room temperature to as low of a temperature as possible while still keeping the magnet to much less than 4.9 K which is the point at which Iop/Ic of the magnet wire equals 1.0 at full field. The heat switch presented here was a closed design which used helium 4 gas captured in a getter inside the system. A heater was attached to the getter to increase the temperature of the getter and release the gas. Once the heater was turned off the gas was allowed to adsorb back onto the activated charcoal in the getter by cooling straps attached to the 2nd stage of the cryocooler. The heat switch is shown schematically in Figure 2.

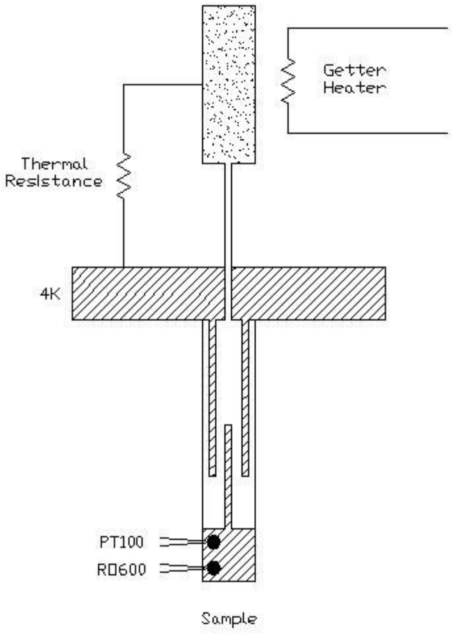

Figure 2 - Heat Switch Schematic

The results shown here will show the operation of the heat switch with the magnet at six (6) Tesla over the temperature range of 4K to 300K with cold windows on the 40K shield and from approximately 10K to 300K without the cold windows in place.

HEAT SWITCH DESIGN AND OPERATION

The heat switch design was determined by the allowable space in the bore of the magnet as well as the distance from the 4.2K cold plate of the cryocooler to the magnet centerline. The sample space was approximately 0.013 meters (0.5 inch) and the overall length of the switch from sample end to 4.2K cold plate was slightly more than 0.127 meters (5 inches). Internal heat exchange surfaces were gold plated OFHC copper and the outer shell was stainless steel. A 0.003 meter (1/8 inch) diameter stainless steel tube extended through the rear of the switch and connected to a getter containing activated charcoal. The getter was non-inductively wrapped with a 25 ohm heater and small copper wires were epoxied onto the getter back to the 4.2K cold plate for cooling. The sample tip was non-inductively wound with a 10 ohm resistor for control of the sample tip. Two temperature sensors were used to monitor the sample tip temperature, a 1kohm ruthenium oxide sensor (RO600) and a 100 ohm platinum (PT100) temperature sensor.

The heat switch was tested by mounting it on the second stage of a two-stage cryocooler in a test cryostat. A radiation shield was mounted to the first stage. Thermometry monitored the second stage as well as the getter end temperature. The getter was initially pumped on for 16 hours with the 25 ohm getter heater turned on through a 0.0016 meter (1/16 inch) diameter stainless steel capillary tube coming from the getter to remove any residual gas. A valve on the outside of the cryostat allowed for the getter to be either evacuated or backfilled with helium gas. Helium gas was admitted and removed from the getter by trial and error until a suitable temperature range could be obtained with the getter turned on, corresponding to 100 milliwatts of heat input, and with the getter off.

With 100 milliwatts into the getter, the temperature of the sample end of the heat switch was approximately 6K. By increasing the getter power to 250 mW the sample end temperature was reduced to 4.5K. The upper temperature limit with the getter heater on corresponded to approximately 60K with the 2nd stage temperature at 4.2K.

Once the getter was turned off and the temperatures allowed to stabilize the sample end temperature was approximately 35K and the upper temperature limit of the sample end was 300K with the sample heater powered. The overlapping of the temperature ranges provided sufficient room for control of the getter power for a continuous ramp from lowest to highest obtainable temperature.

Too much gas in the getter (typically more than 13790 Pa (2 psig) with the entire system at room temperature) would not allow the upper temperature of the heat switch to reach greater than 300K without the second stage of the cryocooler going above 4.2K. Higher pressures exceeded the strength of the getter joints and cracked the heat switch.

SYSTEM OPERATION

The heat switch was removed and re-installed in the final cryostat and unfortunately had to be disassembled. This meant that the pressure setting in the switch had to be repeated in the final cryostat. Additionally the customer requirement for the system was that no cold radiation windows could be installed. It was understood that this would increase the lowest temperature attainable but had to be tested to be determined what that temperature actually was. For our initial testing however we covered the 40K shield openings with aluminum tape.

The power for the getter heater as well as the control for it came from the auxiliary output of the SI9700 temperature controller. By configuring its output to apply a 2.5 Volt output and thus approximately 200 milliwatts of heat when the system was less than 5.0 Kelvin and 0 volts output at 60 Kelvin we were able to have a continuously adjustable getter pressure between those temperatures. Above 60 Kelvin the getter was kept in the off position to minimize the heat load from the warm end of the heat switch to the 2nd stage of the cryocooler and thus the magnet.

Originally we had planned on using a Cernox temperature sensor to monitor the sample temperature, however, because of the poor resolution of the SI9700 temperature controller near room temperature we decided to use two temperature sensors, a 1K ruthenium oxide for 4K to 35K and a 100 ohm platinum sensor from 35K to room temperature. Data was taken on the magnet temperature, sample temperature for the two sensors, and heater power on the getter versus time. Note the entire temperature ramp can be done in less than six hours. This data is shown in Figure 3 below.

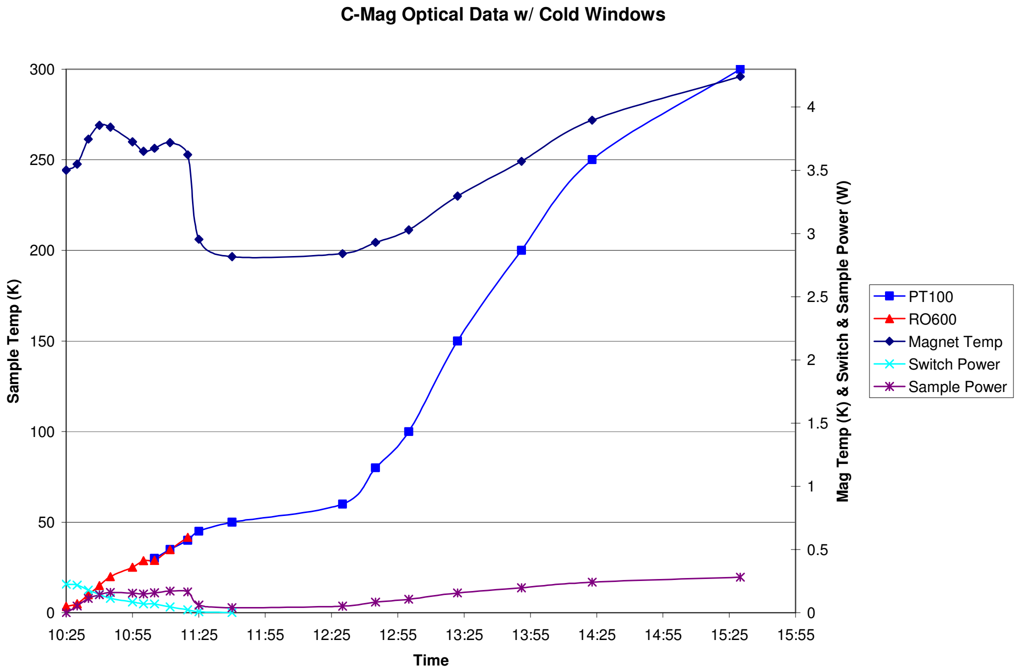

Figure 3 - System Data

Once the cold 40K radiation shield windows were removed the additional heat load on the system raised the lowest attainable temperature of the system to 10.5K. An upper limit of 325K was verified at the customer's facility.

RESULTS AND DISCUSSIONS

The most difficult aspect of this particular system was the small amount of space in which to place the heat switch and wiring for it. Future system will probably utilize a one inch sample space and allow for additional space for wiring. There is also a danger of over-pressurizing the heat switch during fill and thus damaging the heat switch as the system warms. A couple of ways to overcome this obstacle could be to either control the pressure via external means or to install a check valve and expansion volume in parallel with the fill valve so that if the pressure in the heat switch exceeded a set limit it could vent back into the expansion volume. Once the system needed to be cooled the bypass valve would be opened and the gas could condense back down into the getter. Before operating the system the bypass valve would be closed. The advantage of the external gas control would be a lower sample temperature while the advantage of the closed loop system would be simplicity and cost.

A cryogen free magneto-optical cryostat has been designed and built that allows for operation of a sample in vacuum with a temperature range of approximately 10K to 300K with a single cryocooler. The advantages of the system lie in its reduced cost and complexity as well as the ease of operation.

REFERENCES

[1] Kittle, P., “Heat Switch Limitations on Multi-Stage Magnetic Refrigeration,” in *Advances in Cryogenic Engineering* 47B, edited by Susan Breon et al., Plenum, New York, 2001, pp. 1167-1174.

[2] Shirron, P.J., et al., “Passive Gas-Gap Heat Switches for use in Adiabatic Demagnetization Refrigerators,” in *Advances in Cryogenic Engineering* 47B, edited by Susan Breon et al., Plenum, New York, 2001, pp. 1175-1182.

[3] Roach, Pat R. and Helvensteijn, Ben P. M., “A 3He-Gap Heat Switch for use below 2K in Zero G,” in *Advances in Cryogenic Engineering* 37B, edited by Ronald W. Fast et al., Plenum, New York, 1991, pp. 923-930.