OPERATION OF CRYOGENIC SYSTEM AT NSCL

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Summary

The superconducting cyclotron at Michigan State University depends extensively on cryogens. Over the past five years we have developed and refined techniques to make it possible to run the K500 cyclotron continuously. In particular, we have now successfully operated a parallel branch liquid helium distribution system that supplies liquid helium to the magnet coil cryostat and to cryopanels located in the magnet valley sections of the cyclotron beam chamber. Operation characteristics of the parallel branch system and operation parameters of the cryopanels are discussed. Two materials, INVAR 36 and explosively bonded copper to stainless steel,have simplified design and improved performance of cryogenic equipment. The latter is useful in situations where a transition is desired from the good heat conduction quality of copper to the low heat conduction and good welding properties of stainless steel. The INVAR, due to its low coefficient of thermal expansion, is used in long cryogenic transfer lines.

Introduction

The delivery system providing cryogens to support the needs of the K-500 cyclotron has evolved from simple transfer lines used during the early testing stage to a multi-branched system in use at this time. There are two separate networks. Fig. 1. is a line drawing of the open loop carrying liquid nitrogen to devices. The exhaust gas is vented to atmosphere. The liquid nitrogen is stored in two 3600 gallon tanks which are filled periodically by tanker truck. The liquid nitrogen consumption rate for operating the K-500 cyclotron is presently near 20 g/s. Fig. 2. shows how liquid helium and cold helium gas from a CTI-1400 refrigerator are supplied to the cyclotron magnet coil and to cryopanels. This network is operated in a closed loop with a 500 l storage dewar, 10,000 gal. gas tank, and three CTI-1400 compressors. The refrigeration load at 4.2 K is near 85 watts. The complete coupled cyclotron system requires more refrigeration capacity; a refrigerator has been bought from Cryogenic Consultants Inc. to operate this system as it evolves. This refrigerator has associated with it a 2500 l dewar, a 30,000 gal. gas storage tank, and a pair of Sullair compressors which deliver 55 g/s at 240 psig. At present this equipment is at times already used to provide redundancy for the K-500 system. The first step was to build a transfer line to feed the 500 l dewar from the 2500 l dewar. The compressor output can also be shared by both refrigerators as can the gas storage tank. A cold helium gas return branch from the K-500 system to the new refrigerator will shortly be build, and then it will be possible to do maintenance on the CTI-1400 liquefier or any one of the other redundant components without interfering with the experimental program.

Cryogen distribution system operation

To illustrate the operation of the system a typical cooldown cycle starting with the magnet coil at room temperature and finally filling the coil cryostat and starting the cryopumps is described below. Initially all valves in Fig. 1 are assumed to be closed. Operation of the liquid nitrogen cooled shield of the coil cryostat is initiated by opening NV7 and NCV1. The cooldown of the coil starts by cooling the helium stream with the nitrogen precooler heat exchanger of the CTI-1400 refrigerator. Valve NV6 must be open and the air supply to SV20 must be on. The liquid nitrogen supply to the refrigerator is then regulated automatically by SV20. Gas return valves HV5 and SV14 are opened as well as the supply valves HV10, GV17 and GV18. The cryostat pressure is monitored as SV19 is opened; the cryostat pressure is limited to about 10 psig. The supply gas temperature stabilizes at about 130 K. The magnet coil is cooled in this mode for 4 to 5 days. The return gas temperature is initially near 180 K and gradually drops to around 160 K. One compressor is sufficient to supply the required mass flow; however,in the early stages of cooldown, contaminants are released by the coil so usually 2 to 3 compressors are operated with part of the flow being diverted to a cryogenic absorber which traps out contaminants, such as water and nitrogen, from the helium stream. Once the coil temperature has reached 160 K, the expansion engines are used for additional cooling. They are operated in the parallel mode during this cooldown phase which lasts about 3 days. SV19 is closed and SV6 and SV9 are opened. The gas is returned via SV7 until the return gas temperature drops below 100 K when it is returned via SV5 and the engines from then on are operated in series. SV6 is closed and the coil is cooled to 5 K in an additional two days. Toward the end of the cooldown the full flow from the compressors is used to operate the refrigerator and no flow is diverted through the external absorber at this time.

Once the coil is at ≈5 K, the coil cryostat can be filled with liquid helium. Valves of the CTI-1400 are set for reliquefaction. SV9 is closed and valves 307 and 308 are opened. To start liquid transfer HV1 and HCV3 must be open. The heat pulse associated with cooling down the transfer lines must be coped with; this involves valving operations at the refrigerator. About 2 hrs. after the liquid feed valves are opened, the liquid helium level sensors indicate that the coil is filling. Usually it takes 6 hrs. from the time liquid is first detected in the coil until the magnet can be energized.

The cryopanels have to be operated to achieve the vacuum required for cyclotron operation. The cryopanels have experienced a number of modifications to improve their performance since their initial design. The latest design modifications are discussed below. The cryopanels are made up of a liquid

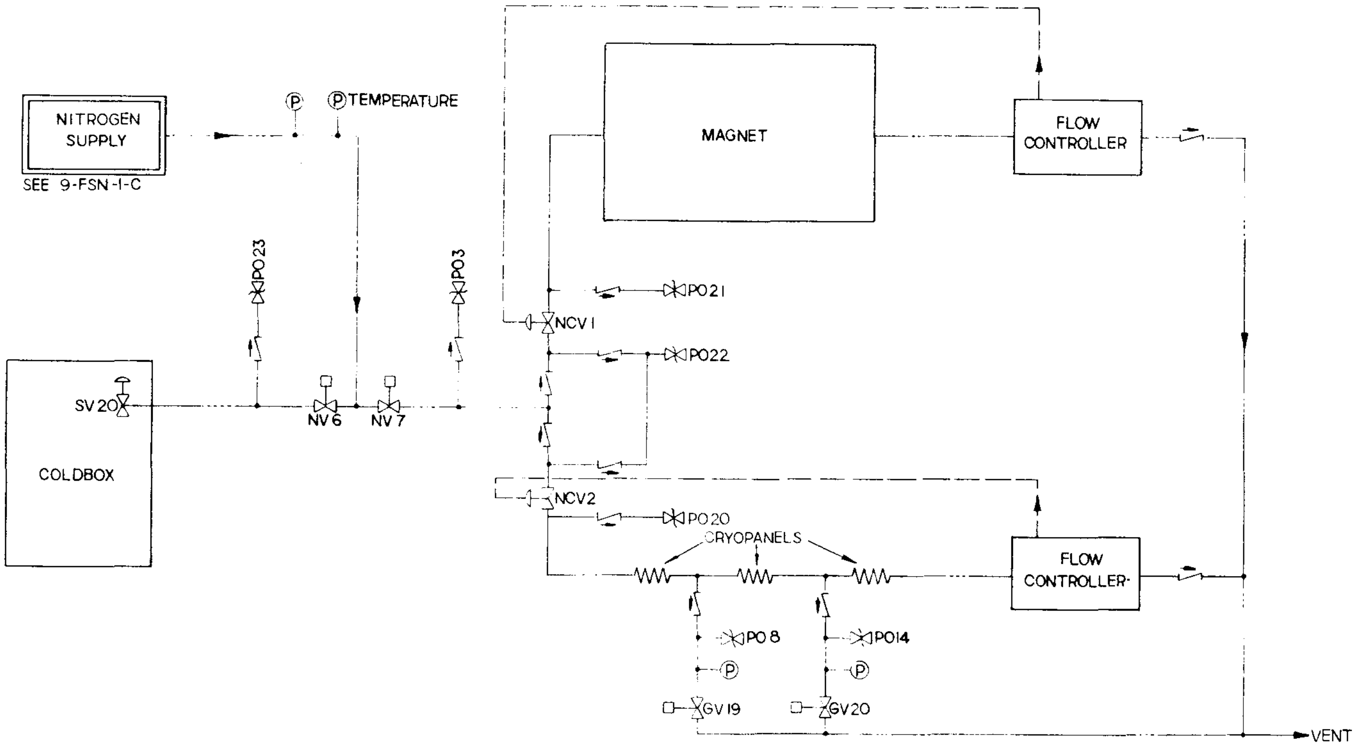

Fig. 1. Flowchart of the open loop liquid nitrogen supply system.

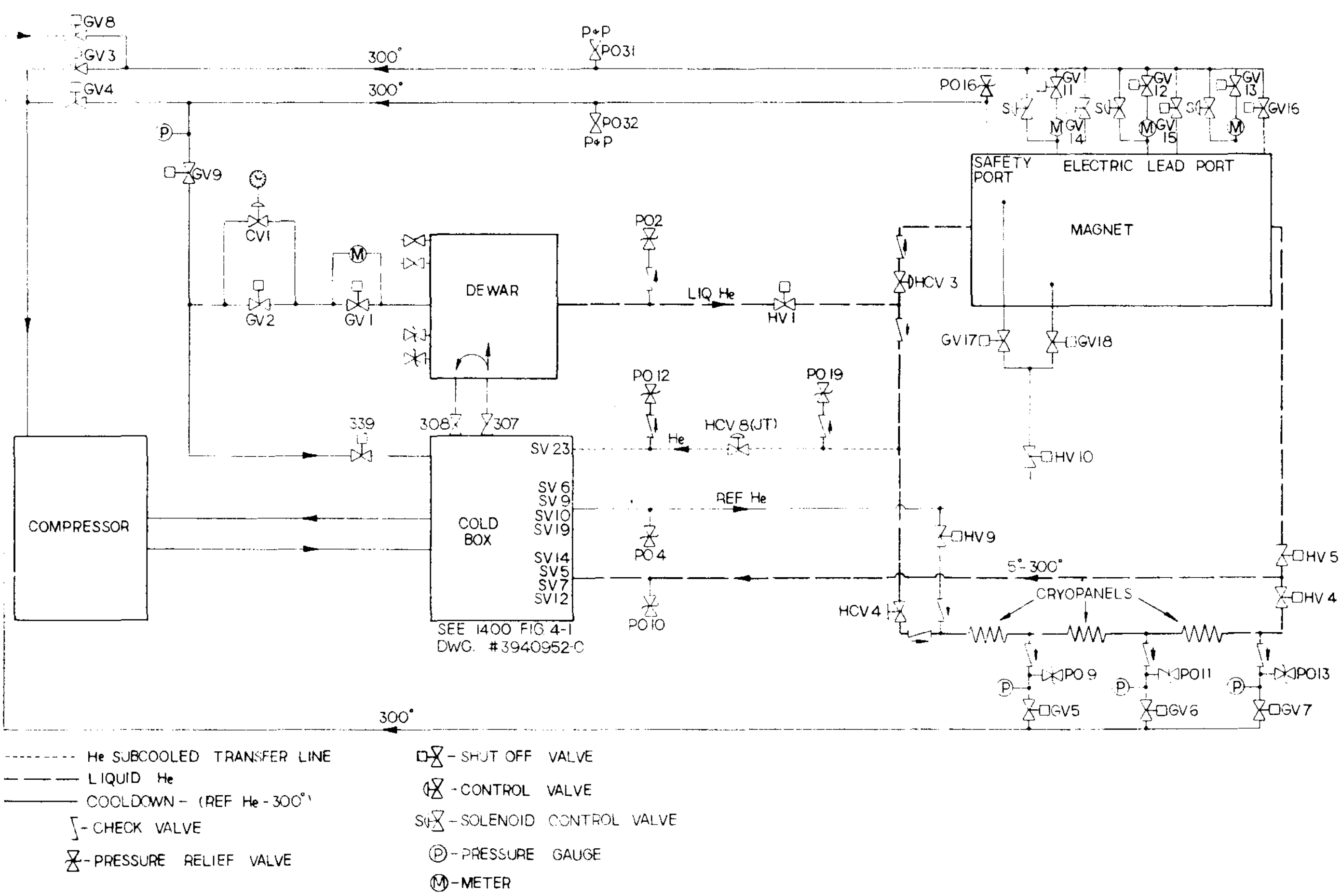

Fig. 2. Flowchart of the closed loop cryogenic helium distribution system.

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nitrogen cooled shield surrounding a charcoal covered liquid helium cooled copper plate. The shields are operated in series. It takes about 1.5 hrs. per shield to reach 100 K. They are usually maintained between 100 K and 110 K. Temperatures near 90 K can be attained at the cost of increased nitrogen consumption. Shield temperatures above 120 K lead to elevated temperatures on the liquid helium cooled panels. As the nitrogen shield temperature drops below 150 K, gas cooling of the cryopanels is initiated by opening GV7 and HV9. SV9 is opened half a turn so that part of the output of the low temperature expansion engine is delivered to the cryopanels. It takes about 40 minutes per panel to cool below 45 K. Once all panels are below 45 K,SV9 is closed and HCV4 is opened. The panels then cool to below 10 K within 10 minutes as liquid helium flow is established in the cryopanel circuit. To switch the cold helium return gas to the refrigerator the following operation of 10 minute duration is performed. Valves 308 and 307 are closed. HV4 is opened and GV7 is closed. The heat pulse associated with cooling down the return line is monitored at the refrigerator. As the return gas temperature drops below 10 K valves 308 and 307 are restored to their operating values. The return gas at this time enters the refrigerator- liquefier at SV12. When the CTI-1400 performs at its optimum level it can keep up with the combined heat load of coil and cryopanels and registers an in dewar liquid rate of rise near 5 l/hr. As contaminants build up, its performance deteriorates. It is at that time that the equipment installed for operating the future coupled cyclotrons is used to avoid having to shut down the K500.

When the CTI-1400 refrigerator falls behind demand, periodic liquid transfers from the 2500 l dewar are carried out. The transfer line incorporates two valves close to the 500 l dewar. One valve facilitates transfer line cooldown by returning boil off gas to compressor suction. When air condenses on this return line, the valve is closed and the valve to the 500 l dewar is opened. A small pressure pulse is observed in the 500 l dewar as the remaining portion of the transfer line is cooled down. The pressure in the 2500 l dewar is limited by its protection popoff valve to 14.7 psig. During the transfer the pressure in the 500 l dewar is maintained at 8 psig. As a result the liquid rate of rise in the 500 l dewar is limited to about 50 l/hr during a transfer.

Liquid helium flow to the coil and cryopanels can be controlled by metering valves HCV3 and HCV4 respectively. At present they are only used as on-off valves and all liquid flow control is accomplished by adjusting the 500 l supply dewar pressure by opening or closing valve 308. A dewar pressure between 5 and 6.5 psig is usually appropriate to maintain the liquid level in the coil and sustain cryopanel temperatures below 10 K. The system runs for days in this mode without needing adjustment. As contaminants build up in the system the dewar pressure at times is increased to 8 psig to satisfy liquid demands. Eventually the drop in performance of the CTI-1400 or excessive pressure drops due to plugging of transfer lines would lead to cyclotron downtime because the liquid helium supply can't be maintained. Usually a complete decontamination cycle of refrigerator and transfer lines returned to full operation can be performed in less than 24 hrs. Since contamination buildup is usually gradual, this can be scheduled to occasion little interference with cyclotron operation.

Equipment reliability

Most of the CTI-1400 operating time has been accumulated in the last two years. Little or no cyclotron time was lost due to mechanical failures of the CTI-1400 refrigerator. In the years before the cyclotron was operational, periodic bearing and o-ring failures were experienced. The bearing in question has been replaced by a more rugged one and the O-ring problem was solved by using a polyurathane rod seal. For the last 2 years unscheduled refrigerator down time was mostly due to contaminant buildup. The CTI-1400 refrigerator has associated three 55 scfm compressors. Two of the sudden contaminant episodes could be traced directly to failures of compressor heat exchangers. The cooling water lines had corroded through so that water could enter the helium stream. It was found that this type of failure can at times be detected before any appreciable contamination occurs by monitoring for helium gas bubbles in the cooling water exhaust stream. Other compressor failures within the past year were due to pistons disintegrating and one motor winding burning out. The most recent failure resulted in a destroyed crank case. The cyclotron operation has suffered only indirectly from the compressor failures because at the time of the first failure in 1983, the connection to the Sullair compressors was completed. Besides the water contaminant cases noted, we are lately having difficulty with an oil like substance causing the refrigerator to plug up. We have not identified the mechanism of transport. We can find no evidence of entrained oil in the helium stream with a "Balston Oil Check" unit. We are inclined to suspect a low vapor pressure component not entirely removed in the processing of the oil but, nor can we rule out an oil breakdown product. A limit of operating at most 3 weeks between refrigerator warmups is becoming the rule.

Cryogenic design options

During the first cooldown of the K-800 coil we will be testing a for us new material, Invar 36. Its desirable characteristic for carrying cryogens is its low coefficient of thermal expansion. The design of long transfer lines is much simpler since the dimensional changes and hence the induced stresses are reduced by about a factor of 6. A liquid helium feed line, 65 feet long, will be build using Invar as the liquid carrying tube inside a stainless steel vacuum jacket. If this line and the somewhat shorter cold gas feed and return lines, which will be build, perform well, then we plan to incorporate Invar 36 extensively in the cryogen distribution system designed for the coupled cyclotrons.

As mentioned above the liquid nitrogen cooled shield of the cryopanels has been modified to improve cryopanel performance. The liquid nitrogen is carried inside stainless steel pipes and the thermal link between the shield and the liquid was not sufficiently direct to get adequate cooling at a reasonable liquid nitrogen flow. The modification which corrected this deficiency employed a bimetallic product, copper bonded explosively to stainless steel. The advantage of this product for this application was that the stainless steel is well suited for welding to the stainless piping and the transition to copper insured good heat conduction to the radiation shield of the liquid helium cooled cryopanels. The copper to stainless bond has performed well for over 3 months.

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It has remained leak tight through a number of thermal cycles between ambient temperature and 77 K. Two of the three cryopanels have been fitted with the improved "cold head" for the radiation shield. Liquid nitrogen consumption is 2.5 g/s per panel for a shield temperature near 110 K. The third panel will be modified as the cyclotron schedule permits.

Summary

The operation of the cryogen distribution system for the K-500 cyclotron has become rather routine. Redundancy in refrigeration equipment including compressors has been found very helpful. The cyclotron down time is rarely due to operational failure of the refrigeration equipment, and this is mainly due to equipment redundancy.

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