FERMILAB CENTRAL HELIUM LIQUEFIER OPERATIONS

G.A. Hodge, R.K. Rihel, M.E. Stone, and R.J. Walker

Fermi National Accelerator Laboratory*
Batavia, Illinois

INTRODUCTION

The Central Helium Liquefier (CHL), in conjunction with 24 satellite refrigerators, supplies refrigeration for the Fermilab superconducting accelerator. Liquid from the CHL is transported in a six kilometer circular transfer line and each satellite withdraws the amount required to boost its refrigeration capacity to the necessary level. Unused liquid is presently returned to compressor suction through a 250 kW calorimeter-heater.

A helium gas flow of 1.1 kg/s is supplied to the cold box at 15 bars pressure. The gas flows through a demister and an oil adsorber before it enters the cold box.

In the cold box,[1-3] manufactured by Koch Process Systems and Sulzer Brothers, Ltd., the gas is first cooled by liquid nitrogen and then the flow is split. Three quarters of the flow is further cooled by a series/parallel combination of three oil bearing turbines and then returned to the low pressure side of the heat exchangers. The return gas is used to cool the remaining high pressure gas which is then expanded to 3.5 bars in a 900 L receiver. From there the fluid is transferred into a distribution box, and thence routed to either a collection dewar, directly to the ring, or to a heater. The liquid helium, which is utilized by the satellites to increase their cooling capacity, is warmed to near ambient temperature in the satellite heat exchangers. The satellite

*Operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

compressors return the excess inventory to the CHL via a 20 bar gas header. This gas is injected into the high pressure supply to the cold box. The system is shown in Fig. 1.

DESCRIPTION OF EQUIPMENT

Compressor

The main source of the high pressure helium supply to the cold box is two reciprocating, oil lubricated, Worthington compressors. The compressors,[2] which were originally used for air service, have had their six cylinders reconditioned, converted and repiped into three stages for helium service. Each compressor is driven by a 4000 hp Elliot synchronous motor running at 1700 hp in the present configuration. The Elliot motors are energized by Westinghouse motor starters which were unreliable for some time, generating numerous trips on startup. The switchgear has been reliable after significant redesign and rework. A third identical compressor, previously planned for a nitrogen reliquefier, is now being piped into the helium system as a back-up for improved system reliability and additional capacity as needed.

Heater

The 250 kW heater has a 12 m heating element which consists of 28 parallel 0.95 cm stainless steel tubes. Every 69 cm there is a mixing chamber which helps to equalize the flow through all tubes. Teflon baffles direct most of the flow through the inside of the tubes and at the same time position the heating elements. The heating element is U-shaped to permit penetrations for both power leads to be at the warm end

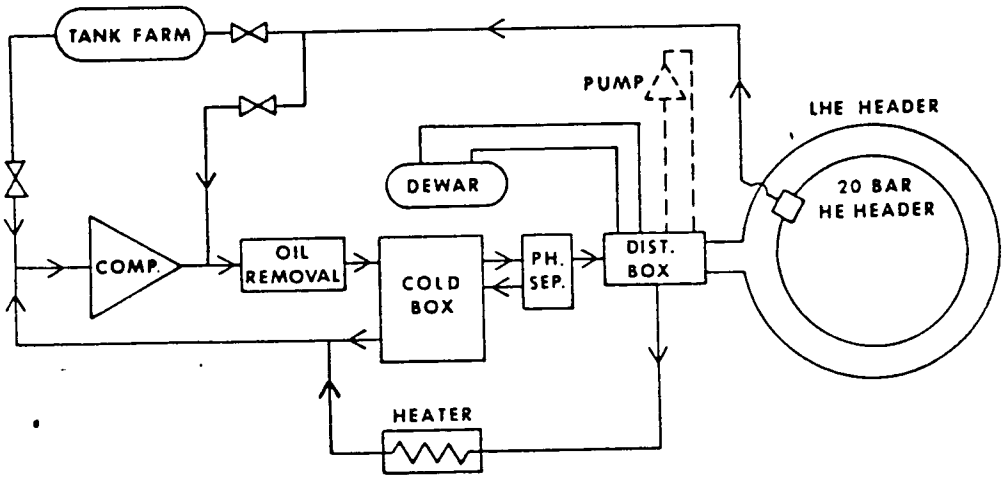

Fig. 1. Simplified Helium Flow Diagram for CHL.

The heater is powered by a 0.5 MW power supply capable of providing up to 2500 A at 200 V. A process controller monitors the temperature of the gas exiting the heater and adjusts the output of the power supply to maintain the set point temperature.

Control System

The controls[1] for the present system consits of two Texas Instruments 5TI-1023 Programmable Sequencers, thirty eight Fisher Process control loops, and digital panel meters for display of process variables. Each sequencer scans a set of inputs and gives a set of outputs based on a ladder logic program with burned-in PROM memory. The inputs are logic signals from conditioned process variables and equipment status switches. The outputs are logic signals used for alarm display and equipment permissive functions. The control loops utilize Fisher process controllers with electrical to pneumatic interfaces at pneumatically operated valves. Each control loop is independant of all others in function. The various loops interact only by the process system. A more advanced control system is being installed for the third helium compressor. This system incorporates a Texas Instruments PM 550-112 programmable process controller. This unit has an enlarged EPROM memory and the ability to input and output analog, as well as digital, information. Texas Instruments has provided for PID control loop action through a loop access module. This enables the sequencer to perform the control loop functions while maintaining the protective interlock logic. Digital panel meters will be incorporated into a schematic display panel for process variables.

Gas Storage

Medium pressure gas storage is provided by thirteen propane tanks. At 15 bars the tanks can store a total of 22,100 m^3. This is closely matched to the gas equivalent of the liquid volume in the transfer line and superconducting magnet system, making it possible to store the helium if warm-up becomes necessary. Three gas lines between the CHL and this tank farm and numerous valves at both ends permit multiple operations involving the tanks to take place at once. This makes it possible to purify dirty gas from one tank and pump the clean gas into a different tank while simultaneously using a third tank as a ballast on the high pressure return line. Since our supply of helium gas is somewhat sporatic, the tank farm has made possible an adequate supply of helium in quantities necessary for commissionning the system.

It is essential to the reliable operation of the system of satellites and the CHL to closely monitor the gas inventory and purity. An elaborate system of monitoring and tank farm controls is part of the CHL control room euqipment. A data logging and processing system has been developed to provide a history of inventory shifts and monitor the overall helium losses. The CHL purifier is used to decon-

taminate the gas in storage whenever it has been necessary to divert contaminated gas to storage, as sometimes happens during unexpected satellite warmups.

Liquid Storage

There will be two liquid helium dewars at the CHL. The 19,000 L dewar has transfer lines into the CHL and is itself ready to be used. However, a liquid helium pump, which is presently being reconstructed and tested, is necessary before the dewar can be fully utilized. The 43,700 L dewar will be delivered in October, 1983.

A 53,000 L liquid nitrogen dewar is being used as a reservoir for both the CHL and the satellite refrigerators. All liquid nitrogen is presently being supplied by an outside vendor.

Nitrogen Reliquefier

Construction will begin on a lqiuid nitrogen plant in late fall of 1983. All components have been ordered and many are now in hand. Where possible, existing equipment has been utilized. The plant operating expenses plus makeup nitrogen should cost approximately half what is now being spent on commercially purchased liquid.

The plant capacity will be a maximum of 100 tons per day or 4675 L/h. Variable nozzles permit the turbine expanders to operate near 70% efficiency over a range of flows. The output from the plant will go into the existing 53,000 L liquid nitrogen dewar and from there will be used by the ring and the CHL cold box as needed. Boil off nitrogen will be returned to the suction of the nitrogen compressor.

Gas Purification

The gas purification system[2] consists of two separate systems: one purifies the process flow whose main contaminent is oil, and the second purifies the compressor packing blow-by, or seal gas, which is contaminated by air and oil. The oil removal system consists of a full flow Monsanto Demister and a charcoal adsorber, followed by a 2 micron particle filter.

The seal gas purifier system has been expanded beyond the original concept by the addition of a commercial gas drier, upstream of a cryogenic purifier, and piping which allows purification of multiple systems. The drier and purifier have been sized to be compatible with each other in both pressure and flow, thus allowing them to be used in tandem on a wet system. The extensive piping matrix permits both independant and simultaneous use of the drier and purifier.

Five different contamination monitors are in use in the CHL flow system: continuous aerosol monitor, spectrographic nitrogen detector, thermal conductivity gas analyzer, hygrometer, and gas chromatograph. Oil entrained in the gas stream is monitored by a Model C20A aerosol monitor which has a sensitivity of 5 $\mu g/m^3$. Detectors are placed before the demister, between the demister and charcoal adsorber and after the charcoal adsorber. The spectrographic nitrogen detector[1] is used as a continuous contamination detector that can be plugged into any of the flow systems. It has a sensitivity in the range of 0.1 ppm. Total contamination is monitored by a Gow Mac Model 50-150 thermal conductivity gas analyzer, specifically calibrated for nitrogen in helium in two ranges, 0-500 ppm and 0-10 percent. The probe sensitivity of the Panametrics Model 2100 hygrometer is 0.01 ppm by volume. Probes are placed in the main helium stream as well as at each compressor and the seal gas system. The gas chromatograph is a Model 150G manufactured by Tracor, Inc. It is a mass sensitive instrument and has access to most systems. It has a dual detector system; one side separates the light hydrocarbons and the other separates fixed gases. The detectors exhibit a usable sensitivity of 0.5 ppm by volume.

OPERATIONAL EXPERIENCE

Initial and Early Operation

During the initial turn on in 1980 and for further testing in 1981, the CHL was totally decoupled from both the accelerator magnets and other components of the Fermilab refrigeration system. Liquid was produced into the 250 kw heater where it was warmed to ambient and then returned to compressor suction. Power input to the heater supplied an accurate measure of liquid production and flowmeters gave a cross check on this. The highest capacity measured during these periods was 3560 L/h; however, the flow was only 80% of design and the plant was not well tuned. Operation at higher capacity requires return flow from the satellites, which was not available during the test.

During the first half of 1982 the CHL ran for approximately four months supplying liquid to a portion of the liquid transfer line and to ~1/8 of the superconducting magnets. Three of the satellite refrigerators were operating at that time. All liquid, used by the satellites, was returned to the central as warm compressed gas. This return flow was generally small enough (15 to 25 g/s) so that it could be put through a LN_2 temperature charcoal purifier before it was returned to the CHL's gas inventory.

The CHL was strongly coupled to the ring at that time and any upset in the transfer line or the satellite refrigerators affected the plant. In this operating period the major problem encountered was surges, or oscillations, in the transfer line generated by having

a long warm section of line connected to the section being cooled. In times of heavy flow into the line, the plant operated moderately well. However, surges back toward the CHL affected temperatures at the cold end of the plant and turbine speeds, as well as causing compressor discharge pressure to drop close to the trip point of 100 psia. This problem was greatly reduced by taking some cold flow through the warm section of transfer line.

Once during this time, the filter on the inlet to the first turbine developed a high pressure drop and it was necessary to partially warm the plant in order to clear the filter. In addition, the inlet filter on the charcoal beds of the cyrogenic purifier plugged frequently. The substance or substances plugging the filter were not identified at this time, but when back flushed, a dirty white, foul smelling, oily snow was blown out.

The only problem we had in this operating period, which was strictly at the CHL, was with the compressors. The reeds in the 2nd stage cylinder valves frequently broke, often with the effect of shutting down the compressor. This problem was solved by removing all valves from the 2nd stage - both suction and discharge, milling a shallow hole under each end of the reeds and then putting teflon buttons in these holes. Since then, in four thousand hours of operation, the problem has not reoccurred.

Recent Operation

The CHL has operated most of 1983. The transfer line is now complete and all of the superconducitng magnets have been cooled. Operation with the completed transfer line has, on the whole, been considerably more stable than operating with only part of the line. When the demand of the satellites is not steady, such as immediately after a quench, there are fluctuations in the phase separator level but these generally present no major problem.

When using the design flow path, the smoothness of the CHL compressor and turbine operations is now directly related to the control of the ambient, high pressure return flow from the satellite compressors. On the average, this return flow is 136 g/s but instantaneous flow variations have been too great for smooth operation. Returning this gas directly to storage has permitted more stable operations. Then the CHL compressors can draw from storage as needed. This flow path is shown in Fig. 1. This is not the designed mode of operation and, because it decreases the flow through the cold box, the liquid production goes down.

Some turbine instabilities have been experienced beginning with the destruction of a turbine during the initial start-up. The instabilities seem to be a result of the particular series/parallel con-

figuration of the turbine piping. Most of the instabilities occur in the two smaller, parallel turbines downstream of the larger main turbine. A successful cure for the unstable turbine has been to restrict the flow through the parallel turbine, thereby increasing the flow through the unstable turbine.

On several occasions the first turbine inlet filter has developed a pressure differential near the collapse rating. One of these occurrences was in late May of 1983 when the turbine inlet filter had developed enough pressure differential that, once again, the plant had to be shut down long enough to warm the filter and purge it out. On this occasion the Tracor was used to analyze the gas being vented from the filter area. A trace amount of neon, some oxygen and nitrogen, a considerable amount of methane, and a small amount of ethane were detected.

In June of 1983 a pressure differential developed across the seal gas purifier that was determined as a plugged inlet filter. A sample of this plugging material was collected when the filter contents were blown out. The Tracor indicated a considerable number of hydrocarbons, some of them beyond the range of the column.

Subsequent turbine filter warm-ups did not permit time for sampling and were increasingly less successful. In July of 1983, it became necessary to warm the entire plant and replace the inlet filter. During the first part of the warm-up, the purge gas was sent to the seal gas compressor for recovery. The Tracor was again used to analyze this gas. The major components were oxygen, nitrogen, ethylene and propylene; some ethane and methane were also seen. As the plant neared ambient temperature, the Panametrics analyzer detected a maximum of 15 ppm water in the warm-up flow.

Upon removing the turbine inlet filter, no damage due to the high differential pressure could be detected. However, the filter was approximately 90% plugged with a gray dust. A previous analysis of a small amount of this dust had determined it to be aluminum oxide and other products of the manufacturing process.

Once the liquid helium pump is operational, the cold end of the CHL will be essentially decoupled from the remainder of the cryogenic system. Liquid from the phase separator will pass through the distribution box and into the dewar, which will be kept at low (~1.4 bar) pressure. The pump can feed the transfer line with 3.5 bar liquid at a greater rate than the satellites will need to withdraw it. The unused liquid will be returned to the storage dewar. This permits the ring to change its demand without affecting the CHL. Also, short term shut-downs at the CHL will not interfere with ring operation.

At the time of this writing (August, 1983) the CHL has logged approximately 7000 hours of operating time. The plant has yet to be brought up to design operating conditions and the output capacity measured. Most of the operating time has been spent running in a mode somewhat less than optimum as the average demand from the satellite refrigerators is less than the CHL capacity.

REFERENCES

1. R.A. Ahlman, H.R. Barton, Jr., J.E. Harder, G.A. Hodge, J.A. Hoover, M.E. Price, R.K. Rihel, V.T. Sauter, R.J. Walker, and D.M. Wilslef, Process control system for the Tevatron liquefier, IEEE Trans. Nuc. Sci. NS-26:4099 (1979).

2. R.S. Ahlman, H.R. Barton, Jr., J.E. Harder, G.A. Hodge, J.A. Hoover, M.E. Price, R.K. Rihel, V.T. Sauter, R.J. Walker, and D.M. Wilslef, Central liquefier for the Fermilab Tevatron, IEEE Trans. Nuc. Sci. NS-26:4105 (1979).

3. W.M. Toscano and F.J. Kudirka, Thermodynamic and mechanical design of the FNAL central helium liquefier. "Advances in Cryogenic Engineering, Vol. 23", Plenum Press, New York (1978), p. 456.