Fermi National Accelerator Laboratory

FERMILAB-Pub-93/367

Fermilab Central Helium Liquefier System Upgrade

J. Makara, T. Barnes, R. Bossert, M. Geynisman, G. Hodge, R. Kolar and R. Walker

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

December 1993

To be published in *Advances in Cryogenic Engineering*

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

FERMILAB CENTRAL HELIUM LIQUEFIER SYSTEM UPGRADE

J. Makara, T. Barnes, R. Bossert, M. Geynisman, G. Hodge, R. Kolar, and R. Walker

Fermi National Accelerator Laboratory*
Batavia, Illinois 60510

ABSTRACT

A significant upgrade to the Fermilab Central Helium Liquefier (CHL) facility's 4000 liters/hour helium system has been made to support the Laboratory's Tevatron superconducting accelerator. The upgrade includes a second helium liquefier with a rated capacity of 5400 liters/hour, a fourth reciprocating compressor rated at 750 grams/second, and an improved cryogenic distribution system including liquid helium dewars and pumps. The system design and operating experience to date are discussed.

INTRODUCTION

Supporting the world's largest proton/antiproton collider in high energy physics research, the Tevatron cryogenic system consists of a hybrid system of a Central Helium Liquefier (CHL) feeding twenty-four 1 kW satellite refrigerators supplying liquid helium for the superconducting magnets of the accelerator[1]. The original CHL system consisted of one 4000 liters/hour helium liquefier (Coldbox-I) and two 537 grams/second reciprocating compressors (Compressor A, B)[2]. The original design of the Tevatron cryogenic system envisioned redundancy of accelerator operations on either the CHL assisted satellite mode or stand-alone mode with twenty-four dry expanders and LN2 precooling of the satellite system in periods when the CHL was off-line due to failure or trip. However, the refrigeration loads of the accelerator magnet system have increased beyond the capacity of the stand-alone mode of the twenty-four independent satellite refrigerators, thus making the CHL system vital for normal accelerator operations.

Over the years of operations, general upgrades were made to improve the reliability of the system, including an addition of a third helium compressor (Compressor C) and 64,000 liters of liquid helium storage[3]. These upgrades, together with operations control and training, has greatly improved the reliability of the system to less than 12 hours per year of unscheduled accelerator downtime[4]. Nevertheless, a significant impact on the accelerator physics program due to a major CHL failure pointed out the need for the CHL redundancy.

Another reason for the system upgrade is the Tevatron accelerator upgrade to 1 TeV operations. This will be accomplished by lower temperature operation of the magnet system with twenty-four cold compressors. The net effect on the cryogenic system is the increase of the CHL load to 170 grams/second, which is beyond the capacity of the Coldbox-I system[5].

---

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

Therefore the CHL system has been recently upgraded to include the second cold box (Coldbox-II) and the fourth reciprocating compressor. Overall, the system has been configured to provide both redundancy and increased capacity. The Coldbox-II design is generally identical to Coldbox-I. It is tied to the common compressor suction and discharge headers in parallel with Coldbox-I (see Figure 1). The oil bearing turbo-expanders are designed for three compressors flow capacity (1800 grams/second) for an estimated liquid helium production of 190 grams/second. The fourth reciprocating compressor has an increased capacity to 750 grams/second. Additionally, new distribution valve boxes and liquid helium pumps were added in parallel configuration allowing independent operations of either system. The option to operate both systems concurrently exists, thus allowing cool downs and engineering runs with the available compressors.

5400 liters/hour Liquefier (Coldbox-II)

The Coldbox-II system consists of Trane plate fin heat exchangers (see Figure 2) identical to the units used for Coldbox-I. The main Coldbox-I and II vessels were assembled by Koch Process Systems, Inc. The Coldbox-II piping has not been modified with the exception of bringing the turbine inlet filters outside the main vacuum vessel for ease of maintenance. Each filter is housed in its own indium sealed pressure vessel and o-ring sealed vacuum vessel. The filters provide turbine protection from debris, but also trap various contaminants. The problem of aluminum oxide dust accumulation as experienced with Coldbox-I heat exchangers, due to the brazing process, has not been a factor to date since the Coldbox-II heat exchangers were vacuum brazed.

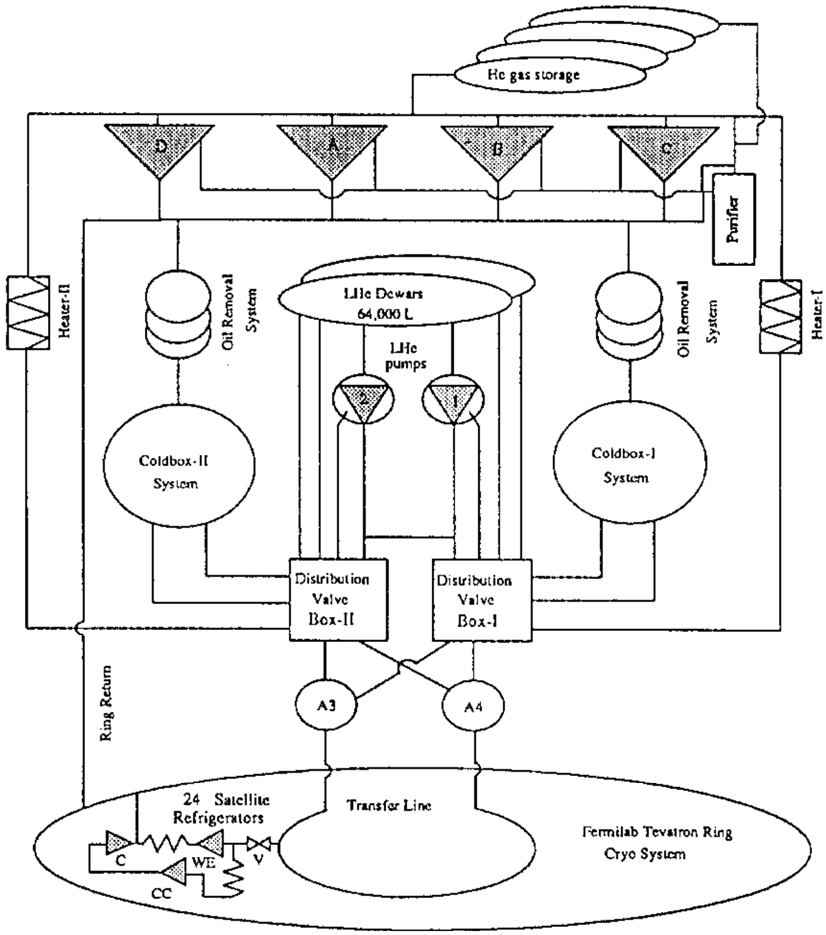

Figure 1. Central helium liquefier layout

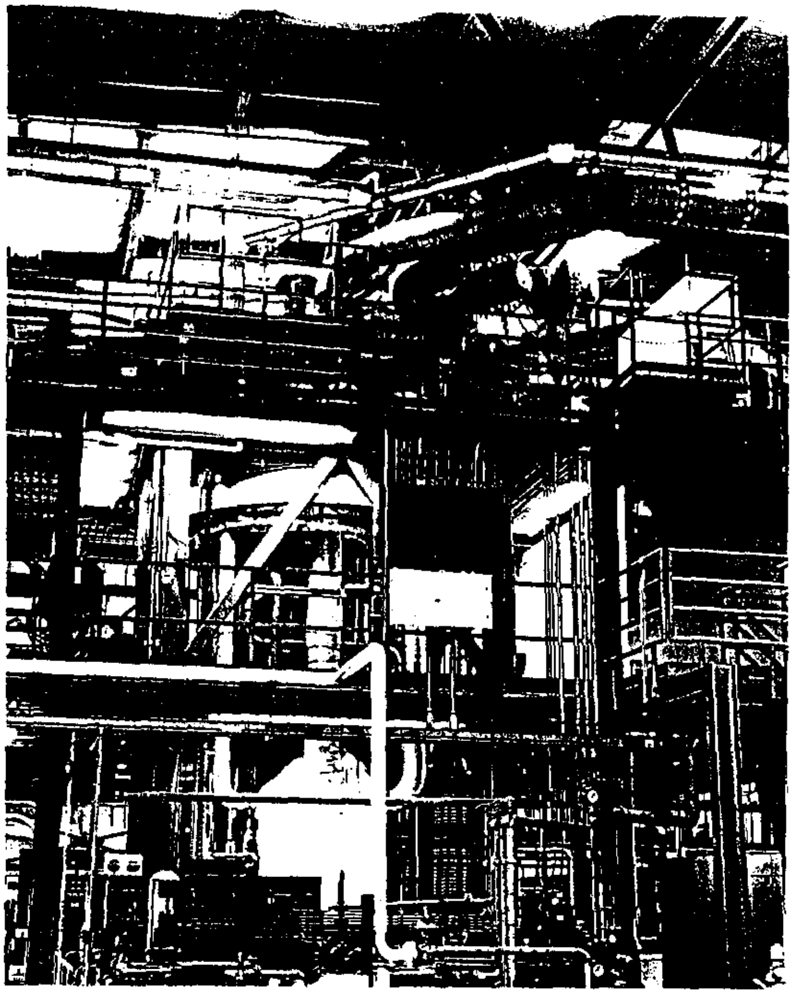

Figure 2. Central helium liquefier coldbox-II assembly

Rotoflow oil bearing turbo-expanders (see Table 1) with variable nozzle control are vertically mounted on the vacuum jacket to the cold box process piping. The variable nozzles provide process flow control with higher efficiency over a wide range of flow. Labyrinth seals provide control of process gas leakage into the oil system with additional protection provided by seal gas flow from warm compressor discharge pressure. The oil skid, located on the main floor, provides a supply of 4.4 liters/seconds of oil at 11 atm and 38°C to expander bearings and dynamometers. The oil is cooled by industrial water. Though a local control panel exists on the oil skid, all parameters are transmitted to the computer process control system and alarm/trips are duplicated with ladder logic in addition to relays.

Several engineering runs were performed on the system during 1992, limited by the availability of compressors. Initial problems of Coldbox-II inadequate thermometry response was fixed with modification to the installation procedure of thermodiodes in their wells. Two compressor tests at 1400 grams/second flow provided proof of producing 157 g/s liquefaction as measured during March 1992. Two electrical heaters, which are normally used for cool down, warm up and capacity balance operations for each cold box, were used as a measure of Coldbox-II output capacity. Several contamination upsets and a loose turbine exit valve plug hampered additional testing before the start of normal accelerator operations. During the initial week of accelerator cool down with Coldbox-II, turbo-expander unit 1 failed catastrophically, requiring a switch to Coldbox-I operations. Investigation of the expander failure indicated

Table 1. Coldbox-II expansion turbines characteristics.

Unit	1	2	3
Inlet pressure, atm	11.50	5.92	5.80
Inlet temperature, K	45.7	25.7	12.9
Exit pressure, atm	5.99	1.32	1.37
Exit temperature, K	37.10	16.10	8.06
Flow, grams/second	1282	660	622
Power, kW	58.31	32.21	13.20
Speed, rpm	55000	55000	43000
Efficiency, %	82	81	80

overheating of the thrust bearing resulting in vibrations sufficient to break the stem between the dynamometer and expander wheels. The oil cooling system was modified to provide more positive cooling of the oil entering the bearing. Recent full capacity operations at 1600 grams/second flow indicated 179 grams/second of liquefaction (see Figure 3 for process conditions). Pressures and flows were 10% below design conditions as limited by compressor capacity. Problems with expander inlet filter contamination and turbine mounting flange leaks were experienced at the time, but can be resolved before the next accelerator operation period.

750 grams/second Compressor (Compressor D)

Compressor D is a Worthington six cylinder reciprocating compressor with, balanced and opposed pistons using carbon-filled Teflon piston rings. The cylinders are water jacketed, oil lubricated, and double acting. This unit is similar to the existing compressor units A, B, and C with air cooled heat exchangers. This unit is a converted BDC-5 Worthington air compressor with a 2980 kW synchronous motor.

Modifications were made which incorporate a 4-stage design for increased throughput of 750 grams/second of helium while also providing cooler operations. Units A, B and C are of three stage design. Table 2 provides the design specifications for Compressor D. Addition of oil injector block-and-bleeds to all compressor water jacket penetrations has prevented any further water contamination problems since 1986. In an attempt to improve on the helium leakage through the compressor crankcase, compressor D has additional seals between the crankcase and the piston rod packing seal gas recovery system.

Cryogenic Distribution System

Two large distribution valve boxes, each with a subcooler, provide alternate modes of operations with two cold boxes. One unit has been operating since 1986 with no problems of contamination plugs or operations difficulties beyond normal control hardware failures. The liquid helium storage dewar system, together with pumps[3], has improved overall cryogenic system stability by allowing short durations of increased liquid helium flow to the satellite system for quench recovery or system upsets, including CHL Coldbox-I or -II trips. Typically, the pump can keep the cryogenic system fully operational up to four hours (with the CHL off line), limited by the gas storage system rather than the liquid helium inventory. Normal operations has both the liquid helium Pump-I or -II and its mating Coldbox-I or -II outputs in parallel to each other feeding the Tevatron cryogenic system transfer line.

The Liquid helium pumps are in-house built single cylinder positive displacement reciprocating units similar in concept to CVI Inc.'s high pressure cryogenic pumps. The warm end drive mechanism is a CVI unit with Teflon bellows for piston rod seal. Liquid helium pump performance has been improved with the addition of an inlet subcooler, improved inlet and outlet valves, and improved piston. The inlet subcooler consists of copper finned tubing inside a 100 liters pot, the vent returning to the Coldbox-I and -II heat exchangers return side, or to the heaters in case of Coldbox-I or -II trips. Typically, the subcooler provides about 0.6 K of subcooling. Both valve seats and plugs are stainless steel 316L and are semi-spherically shaped for improved sealing. The piston seal consists of a set of three carbon-filled Teflon

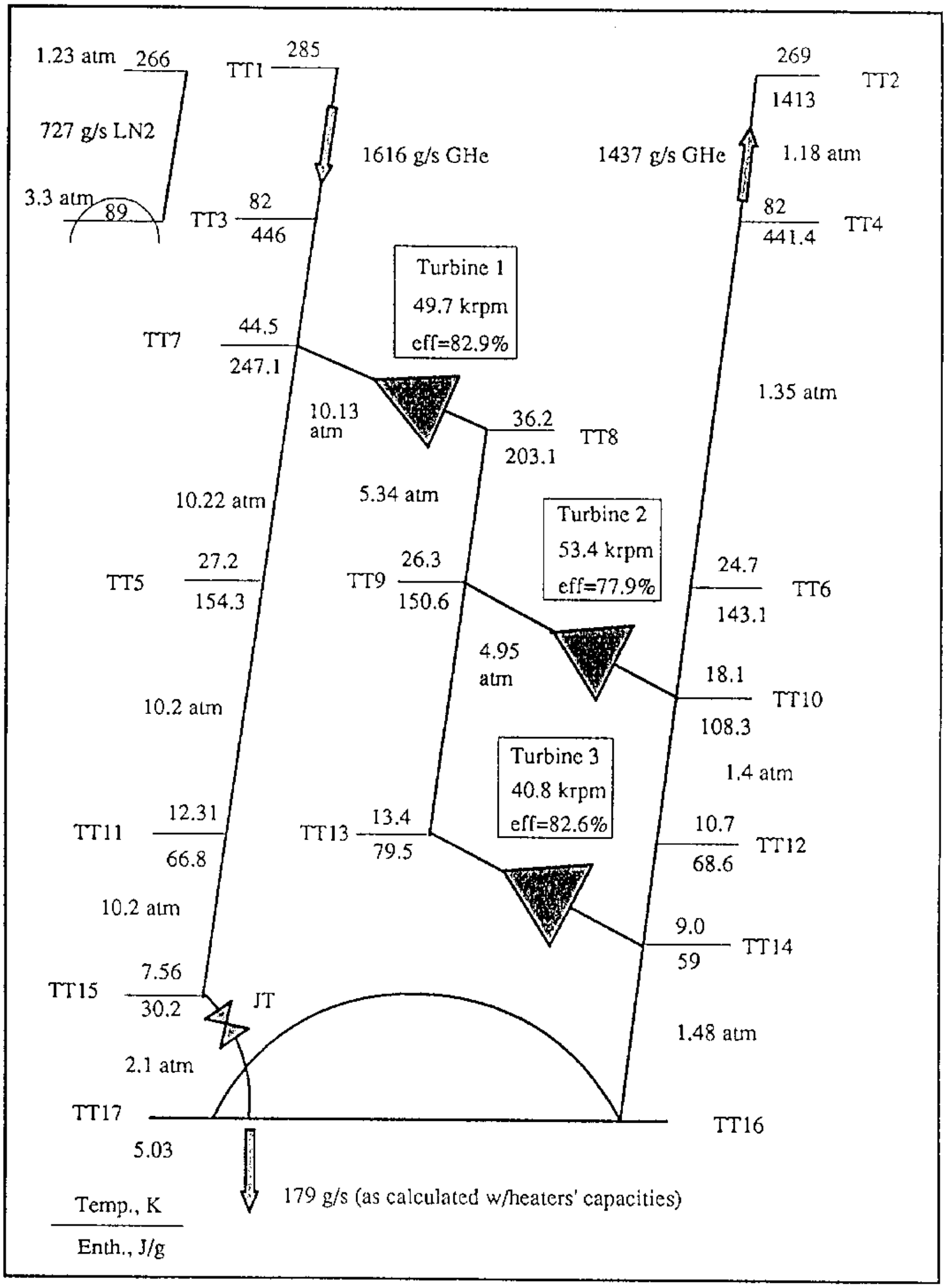

Figure 3. Coldbox-II T-S diagram (3 compressor flow, June 4, 1993)

Table 2. 4-stage 6-cylinder Compressor D design parameters.

Stage	1 (2 cylinders)	2	3	4 (2 cylinders)
Diameter, m	.87/.87	.900	.687	.267/.400
Piston Displacement., m3/min	285.7	156.75	87.68	43.16
Speed, rpm	277			
Stroke, cm	45.72			
Clearance, %	12.3/12.3	12.4	12.55	14.4/8.75
Suction pressures, atm	1.07	2.02	3.65	7.38
Discharge pressures, atm	2.13	3.78	7.63	11.88
Pressure drops, atm	.113	.129	.252	.354
Suction temperature, C	26.7	37.8	37.8	37.8
Discharge temperature, C	122.2	126.1	144.4	102.8
Compression ratio	2.00	1.87	2.09	1.61
Volumetric efficiency, %	93	93	92	93
Capacity, actual m3/min	266.7	146.2	80.9	40.0
Power per stage, kW	388.5	360.2	436.2	267.0
Total power, kW	1452.6			
Throughput, grams/second	757.5			
Piston load, kN	64.11/64.11	115.45	148.92	25.48/57.34

rings arranged such that breaks are at 120 degrees to each other. Additional thermal insulation was added above the piston to reduce the transport of thermal oscillation from the cold piston end to the warm crank end. The differential pressure across the Teflon bellows is kept low by pressurizing the crankcase to extend the bellows life. The current liquid helium Pump-I has operated 20,000 hours without any indication of performance degradation.

The CHL control system has been upgraded to the Texas Instruments PM550 process controllers and has been fully operational since 1986. The improved operator interfaces, together with Accelerator Control Network's plotting and datalogging capabilities[6], has reduced operator errors and increased operator effectiveness in problem diagnosis and resolution. Each major subsystem (i.e. Compressor A, B, C, D, Coldbox-I and -II, Distribution-I and -II, and Nitrogen Reliquefier) has an independent process controller thus single component failures do not always shut down the whole facility.

Future Upgrades

Upgrading the Coldbox-I system is planned to provide full redundancy at higher capacity operations required for the Tevatron low temperature operations. Options include an installation of larger capacity turbo-expanders, adding a fourth turbo-expander and replacing the JT valve at the cold box output with an expander. Additionally, compressor capacity limitations need to be addressed which may include upgrading one or more existing compressors for four stage operations with resultant increased capacity. Modifications would include the piping system, air cooled heat exchangers, and process control system.

ACKNOWLEDGMENTS

The years of successful and safe operations of the Central Helium Liquefier facility is due in large part to all CHL personnel, past and present, whose dedication and spirit must be applauded.

REFERENCES

1. C.H. Rode, Tevatron cryogenic system, "The Proceedings of the 12th International Conference on High Energy Accelerators" (1983).
2. G.A. Hodge, et al, Fermilab central helium liquefier operations, "Advances in Cryogenic Engineering," Vol. 29, (1984).
3. R.J. Walker, et al, Recent operating experience with the Fermilab Central Helium Liquefier, "Advances in Cryogenic Engineering" Vol. 31, (1986).
4. J.C. Theilacker, Current operating experience and upgrade plans of the Tevatron cryogenic system, *Advances in Cryogenic Engineering*, Vol. 35 (1990).
5. W.M. Soyars and S.G. Johnson, Simulating the Tevatron liquid helium satellite refrigerators, to be presented this conference.
6. D. Bogert, The Fermilab accelerator control system, "The Proceedings of the 2nd International Workshop on Accelerator Control Systems" (1986).