CRYOGENIC DESIGN OF THE D-ZERO LIQUID ARGON COLLIDER CALORIMETER

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OVERVIEW

The superconducting Tevatron was added to Fermilab's 400 Gev Proton Accelerator, the main ring, in 1983. An antiproton source was added in 1985, and the system became a p-pbar, 1 Tev/1 Tev, collider in 1987. A Collider Detector surrounding one of the points of the accelerator p-pbar beam crossings can measure virtually all the energy of the colliding interaction (Fig. 1.) The measurement of all the energy is called hermetic calorimetry. Although there are other liquid argon calorimeters and other hermetic collider detectors, the D-Zero (named for the accelerator beam crossing location) liquid argon collider calorimeters will be the first of their kind (Fig. 2). The cryogenic aspects of the liquid argon calorimeter portion of the D-Zero detector are described here.

The liquid argon serves as the particle detector ionizing media in a repetitive cell structure (Fig. 3) of argon, signal board, argon, and Uranium or copper absorber plate, with a superimposed electric field. Local signal board pads indicate location and the electric charge collected is proportional to the ionization and the ratio of the argon to plate absorption lengths. This arrangement provides a dense, intrinsically calibrated, drift-free calorimeter.

Fig. 1. Calorimeter cross section showing the module layout, the central tracker, and two arbitrary trajectories from the collision point.

*Operated by the Universities Research Association, Inc. for the U.S. Department of Energy.

CRYOSTATS

The three cryostats serve to hold and insulate the liquid argon, transmit the large module assembly weights to room-temperature supports, and contain all the necessary electrical and cryogenic feedthroughs. The 5m diameter type 304 stainless steel inner vessels are ASME Code-stamped (Section VIII, Div. 1) and are designed for an internal pressure of 1 atmosphere plus insulating vacuum plus liquid head. The inner vessels are also designed to accommodate a full vacuum loading. The vacuum jackets are designed in accordance with CGA-341 with fabrication comparable to ASME Code rules (Div. 1), and are also fabricated of stainless steel to preclude fault brittle fracture.

The cryostat shapes reflect efforts to maximize the calorimeter hermeticity and absorption depth uniformity as a function of angle, and to minimize the energy absorption of the walls. All the vessel details not covered under the rules the ASME Code (Div. 1) were designed by analysis. Aggressive Code design minimized particle-entry wall thicknesses by use of finite-element (Fig. 4) and ASME Division 2 analysis methods, and independent third party review.

The 1.52m bore of the torus-shaped CC cryostat contains the warm Central Tracker surrounding the interaction point. In contrast each EC vessel contains a 7.5 cm center tube in order to bring the detector as close as possible to the Tevatron beam tube. The EC tubes include bellows assemblies to accommodate vessel movements and to minimize deflection-induced stresses. Each vessel also contains a rigid (no bellows) reentrant tube (27 cm dia.) near its outer shell to accommodate passage of the Main Ring through the detector.

The calorimeter modules are to be erected inside the fabricated, tested, and stamped vessels. Access requires that the EC heads at one end and the CC heads at both ends be removed. After module assembly, the heads are refitted, welded, and tested as before by an ASME Code stamp holder. The flangeless design enhances the compactness of the vessels and the efficient use of available space made possible by the passive nature of the liquid argon detector.

Fig. 2. Detector cutaway showing central and bypass beam tubes, shifted EC, and electronics racks below.

Fig. 3. Cell Structure. 1.5 kV is applied, ionization occurs in the Argon gaps, and charge is collected on the copper pads as signal.

SUPPORTS

The inner vessel and internal module structure of each cryostat are supported within the vacuum vessel on four custom-designed thermal contraction support stanchions, details of which are shown in Figure 5. Each stanchion is designed to accommodate a movement of 6cm while supporting weights to 90,900 kg. The needed flexibility is provided by an array of fifteen parallel vertical Inconel plates Micro-brazed to header plates. The intersection of the vertical planes passing through the centers of the stanchions and normal to the plates defines the stationary vertical "centerline" of each cryostat, warm and cold.

The 40W thermal conduction in each stanchion is removed by a thermal siphon heat intercept mounted at the top. Liquid from the bottom of the vessel, driven by the liquid head, is boiled in the intercept and piped to the gas space at the top. The resulting heat load penetrating the inner vessel at the supports is reduced to less than 4 watts.

Each of the three cryostats is supported by a welded carriage structure which transfers the weight of the calorimeters to the relatively narrow (1.5m) central beam of the platform. The narrow beam is required to allow opening of the toroid (see Fig. 6). The heavily loaded carriages are fabricated of 304SS because of the finite

Fig. 4. Fully loaded FEM half model of the EC. Note the exaggerated flange rotations.

Fig. 5a. Cryostat/module support stanchion assembly.

Fig. 5b. Plan view showing orientation of stanchions.

possibility of a cryogenic spill. A spherical interface is located between the bottom of the stanchion and the top of the carriage in order to accommodate the distortions of the carriage as the calorimeter is assembled, (i.e., loaded). The radius of the spherical interface is sized to maintain alignment of the stanchions and the spherical surfaces as the carriage arms rotate and translate under load.

A system of hydraulic jacks and drivers and heavy-duty rollers are used to move the 5000 ton detector system on its platform from the assembly hall into the collision hall (a distance of 25 meters) and into position in the accelerator ring for physics experimentation. Positioning of the calorimeters on the central beam of the platform is accomplished by initial placement. All four toroidal iron pieces and both EC's are roller mounted to provide access to the Central Tracker in the bore of the CC. High-capacity, low-profile, carriage-mounted rollers allow each EC to be moved a distance of 1.3m on hardened steel ways imbedded in the central beam. Jacks are provided on the EC's to unload the rollers and, as required, to trim the vertical position. Each 228 tonne EC is moved while operational and full of liquid argon in order to avoid the time penalty required to empty and refill the liquid (CC=19.9kL, EC=8.8kL). Six specially-designed (Cryolab, Inc.) rotary bayonet triplets are required to maintain the cryogenic and vacuum connections during the excursion.

Fig. 6. EC end section.

COOLING SYSTEM

The operating cooling requirement of three cryostats is provided by an inventory-maintained, 76.6kL, 0.3% per day boiloff, LN2 storage dewar. The ground level dewar location, 8m above the loops, provides 0.64 atmosphere subcooled liquid at the cryostats. Each cryostat is equipped with two sets of cooling loops (cooldown and operating, see Fig. 7). The 10kW max (condensing) operating loop is in the gas space. The two 20kW (condensing) cooldown loops straddle the apex of the calorimeter, operate only during cooldown, and occupy a space beneath the operating liquid level. Loop temperatures from 77.4K to 91.4K are controlled by a common back pressure control valve (Fig. 8).

The steady state system refrigeration loads are listed in Table 1. The weights and cooldown loads (by module) are given in table 2.

	CC	EC	Totals
Cables	1120	1120	3360
Radiation	150	130	410
Nozzles	83	83	249
Piping	24	24	72
Supports	16	16	48
	<u>1393</u>	<u>1373</u>	<u>4139</u>
Dewars(.3%)			1200
Wet Lines			<u>315</u>
			5654 W

Table 1. System Heat Loads

	CC	EC	System
Copper	7.82	8.41	24.64
G-10	0.50	0.27	1.04
Uranium	3.17	1.20	5.57
304SS	1.00	1.58	4.16
Cryostat	<u>0.90</u>	<u>0.90</u>	<u>2.70</u>
	13.4	12.4	38.11

Table 2. Cooldown Loads (10^9 joules)

Cooldown is provided by (a) natural convection, (b) direct condensation and forced convection, and (c) direct pool boiling, in that order. The cooling loops are set to a temperature above T_c , the two-atmosphere liquid argon equilibrium temperature (a), then just below T_c and heaters boil the condensed liquid (b), condensing is maximized, heaters are off, and liquid level rises (c). The assembly stresses due to the temperature gradients and differential thermal contraction as indicated by a set of module RTD's will limit the rate of cooldown of all calorimeters. Finite Element Models (FEM) of the module assemblies have been developed which provide stress profiles for given temperature gradients on both the inter- and intra-module levels.

Fig. 7. Cooling loops. Note small gas space.

In tests, isolated and typical ECMH modules have cooled down in 24 hours when limiting the maximum temperature difference to 65K, and warmed-up in 24 hours when limiting the maximum gas temperature to 400K. The communication of the EC vertical absorber plate gaps in the assembly can be easily arranged to support the target two-week cooldown. CC module cooldown testing is not as far advanced, and the cooling suffers from an assembly which aligns the absorber plate gaps in 82 closed polygons concentric about the horizontal axis. Layer to layer communication is by equally spaced, azimuthal, 0.120 inter-module and 0.60" end plate nominal clearances.

Warm-up is driven by 40 kW of redundantly-connected, finned heaters located at the bottom of the cryostat, and may be improved by the pump and purge of the cryostats to He to increase the convection. It is anticipated that a cold pump and purge to He on cooldown can be avoided. The 100C maximum allowable temperature (signal boards permanently degrade at 150C) will control the warm-up heaters. Since warm-ups indicate major repair, it is hoped that very few to no warm-ups will be required.

The cryogenic system has provisions to purify the argon by passing the liquid through molecular sieves. The purifier is used when the electro-negative impurities, predominately oxygen, become greater than one part per million in order to avoid signal loss.

OXYGEN DEFICIENCY HAZARD PREVENTION SYSTEM

Special liquid argon/nitrogen spill provisions have been designed to minimize the possibility of an Oxygen Deficiency Hazard (ODH) to the personnel working in enclosed spaces of the accelerator tunnel or on electronics located below the cryostat elevation in the detector platform. A sheet metal trough on each cryostat is arranged so that all active line connections are above and within it. The trough drains to a flexible duct (to accommodate motion) and then off the platform through a 61 cm diameter pipe to a specially insulated 57 kL sump capable of holding all the cryostat capacity. An 85 m³/min vent fan continuously draws air in at the top of each cryostat through the trough duct pipe and sump, and exhausts out-of-doors. The vent rate is increased to 280 m³/min when temperature changes of the duct are (failsafe) sensed. The system is shown in Figure 9.

These arrangements provide ODH protection against pneumatic depressurization, flashing, and spillage of any single cryostat nozzle from any feedthrough opening less than 5cm in diameter. Note there are nozzles below the liquid level. Active cooling loop and fill lines with greater continuous flow capability will be flow monitored and latched closed at each end on overflow. ODH detectors will sense manned and connector concentration locations, and close all source valves on a fail-safe alarm voting scheme.

Fig. 8. General Cooling Configuration. Provisions allow setting the cooldown rate, loop temperature, and cryostat pressure independently.

Fig. 9. Spill Containment System

CONTROLS

The cryogenic controls are provided by a programmable controller of 300 I/O and 20 PID loops. Temperature (multiplexed), pressure, flow, and vacuum monitoring, control, alarm, interlock, shutdown, and logging support unmanned steady-state operation. Remote communication with the detector VAX computer is by way of an IBM Token Ring and is password-protected.

CURRENT STATUS

The fabricated CC vessel is due to be delivered in September, 1987. It will be cold tested, outfitted and prepared for module loading by the end of the year. The first EC is due to be ordered October 1, 1987 for delivery in eight months.

ACKNOWLEDGEMENTS

The authors would like to note the contributions of Co-op students Leo Engstrom, Iowa State University, Caroline Kurita and Dave Rudland, University of Illinois, and Steve Wintercorn, Marquette University, to this work.