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Publication Date
1983-08-01

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Accelerator & Fusion Research Division

Presented at the 12th International Conference on High-Energy Accelerators, Fermilab, Batavia, IL, August 11-16, 1983

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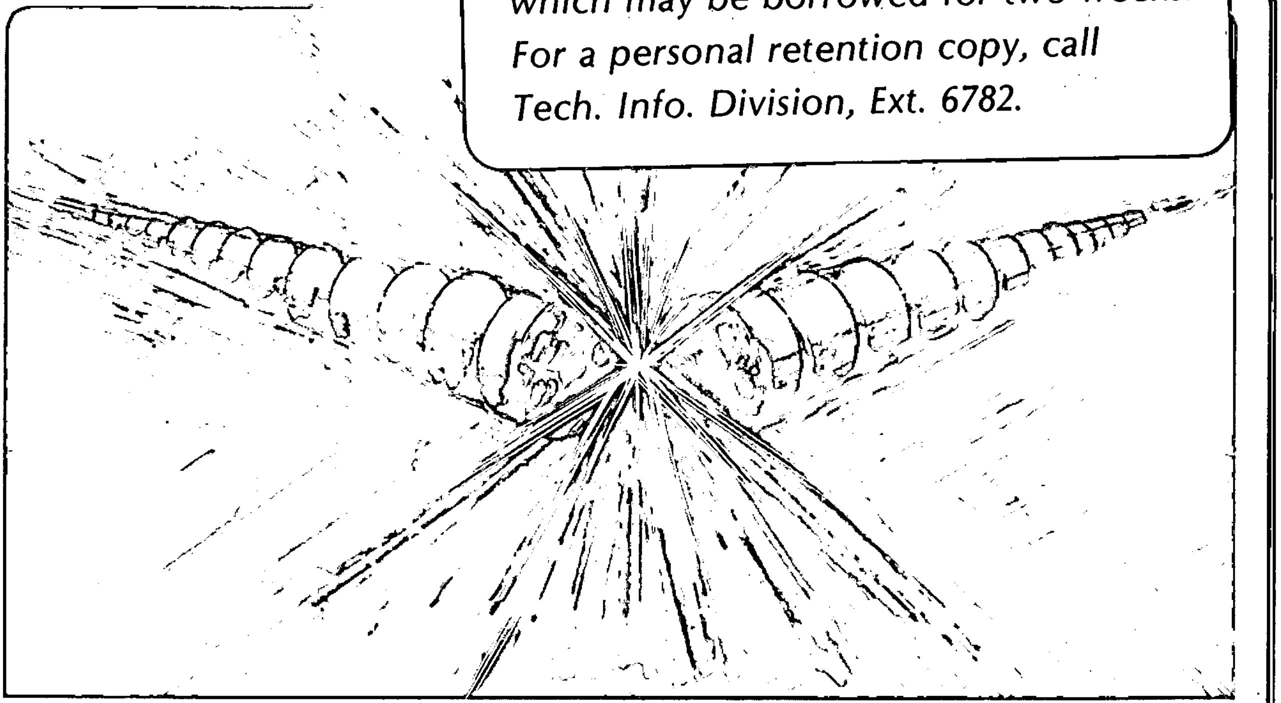
August 1983



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-15991

A 344 CM x 86 CM LOW MASS VACUUM WINDOW*

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Summary

The LBL Heavy Ion Spectrometer System[1] (HISS) superconducting magnet contains a 1 m x 3.45 m x 2 m vacuum tank in its gap. A full aperture thin window was needed to minimize background as the products of nuclear collisions move from upstream targets to downstream detectors. Six windows were built and tested in the development process. The final window's unsupported area is 3m^2 with a 25 cm inward deflection. The design consists of a .11 mm Nylon/aluminum/polypropylene laminate as a gas seal and .55 mm woven aramid fiber for strength. Total mass is 80 milligrams per cm^2. Development depended heavily on past experience and testing. Safety considerations are discussed.

Design Criteria

The window withstands a differential pressure of one atmosphere at ambient temperature. The rectangular vacuum tank aperture is 344 cm x 86 cm. The materials used in the window should minimize background fragmentation and present minimal mass to particles. Radiation degradation of the material results both from tuning with a focused beam and fragmentation experiments using heavy ions. The finite lifetime of the window is thus dictated by operating history.

Hydrostatic pressure testing at twice normal operating was appropriate for this case of large stored energy and unproven design. It is also LBL policy[6] to stress thin window material to less than 45% of yield when in service.

Previous Large Thin Windows

Numerous[2, 3, 4, 5] vacuum windows have been built and analyzed since the first cyclotrons. Certain polyester films are popular as durable radiation resistant materials for thin beamline windows. 0.25 mm thick polyester films can span up to about 15 cm at 1 atm without preforming or use of additional structural support across the aperture. Stress considerations require that larger, higher pressure windows be preformed to approximate a hemisphere. Simple window stress is pr/2t where r is the radius of curvature of the window. Attainable consistent elongation of the material limits one in how far this approach can be taken. Experience with rectangular formed membranes has shown that the zone of highest stress can be far from the corners, thus allowing the hemispheric approximation for cross sections a sufficient distance from the corner.

Rectangular windows constructed at LBL in the past with spans of 30 and 45 cm (up to 360 cm long) used woven polyester fiber (Dacron)[a] as mechanical support for the familiar polyester film vacuum seal. The woven nature presents an inconsistent thickness to particles - this is not a problem at high energies, but some low energy threshold exists where this mass inconsistency becomes important.

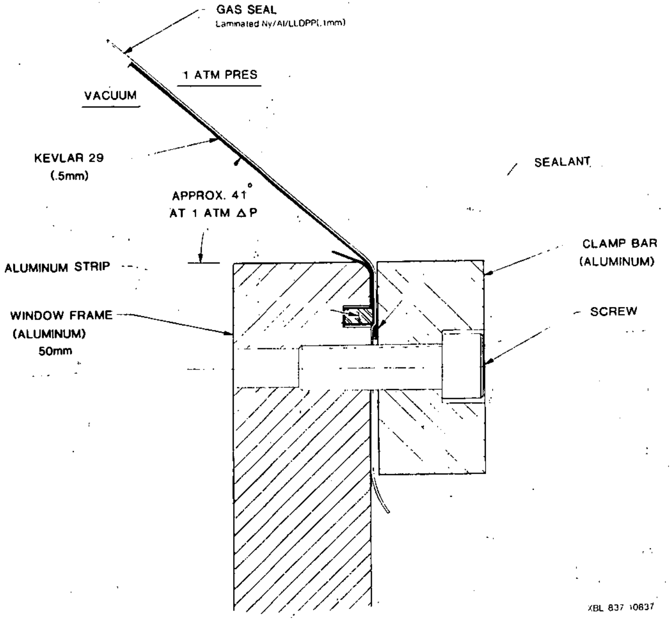

Fig. 1: Window Design

A much lower average density is possible by separating the load bearing function from the vacuum seal function. Fiber strengths of up to 2750 MPa (400,000 psi) are available in the new woven aramid materials, and up to 1120 MPa (160,000 psi) in traditional polyester fibers. Typical polyester films yield at 62 MPa (9000 psi). Forming around square corners is also facilitated by separating functions.

Because traditional sailcloth (polyester) has one of the highest bulk strength to mass ratios of the flexible materials and has been used successfully, it was a logical design basis for the 86 cm HISS span.

Window Development

Table 1 shows results of the techniques tried in this mostly empirical design evolution. Initial trials using 12 oz.[b] Dacron[a] (0.6 mm thick) and 0.25 mm Mylar[c] failed because the elongation limits of the Mylar were exceeded. Preforming the

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*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Science Division, US Department of Energy under contract no. DE-AC03-76SF00098.

[a] Dupont trade name (polyester fiber No. 68)

[b] 12 oz. refers to the weight of sailmakers yard which is 70 x 90 cm.

[c] Dupont trade name

Table 1: Test Data

Window Number	Window Tested	Window Materials	Max Test Press. ATM. (PSI)	Failure Mode	Deflection cm (inches)
1	5/24/82	.25 mm (.010 in) Mylar + "12 oz" .6 mm Dacron (.025 in)	1.56 (23)	Mylar	19.6 (7.75)
2	6/22	.6 mm Dacron Impregnated with silicone	.3 (4.5)	Edge	13.3 (5.25)
3	6/24	.25 mm Mylar preformed to 8 inch bulge, epoxied to frame, + .6 mm Dacron, improved edge clamping	1.76 (26)	At Bolt Holes in Mylar	20.3 (8)
4	6/28-29	.25 mm Mylar + .67 mm Kevlar 49 woven roving	1.36 (20)	Kevlar at Edge	9.2 (3.62)
5	7/9	.25 mm Mylar + .55 mm (13.6 oz) Kevlar[c] 29 tight roving (Clark-Schwebel No. 735)	No failure at 2 atm. Hydrotest	No Material Failure, Not Vacuum Tight	24.1 (9.5)
6	No Hydro Test, Vacuum Test 7/82	.002 inch Nylon/.00035 inch alumi/.002 inch LL propylene Laminate Plus .55 mm (13.6 oz) tight roving Kevlar 29	No Hydro Test vacuum tight	None	25.4 (10)

Mylar with hot water helps to control the consistency of elongation and did indeed provide a gas seal eventually, but never one which was high vacuum tight. It is possible to open up pin holes in the film during radical elongation.

Edge clamping of the structural material is difficult because of the 5000 kg/meter perimeter load. By trial 3 edge clamping as shown in figure 1 evolved as a solution. Bolt placement on the attachment flanges in this working area should be avoided - in our case the 3 cm bolt circle to tank I.D. distance made construction awkward.

Trial 3 also indicated that elongation of the structural Dacron was always going to be a problem - the search for a higher modulus, stronger material led to woven aramid fabric (Kevlar)[c] - it has the highest specific tensile strength known (tensile/density = 7.7 x 10^6 inch); the specific strength of Dacron is 3.2 x 10^6 inch. The modulus of the Kevlar 49 fiber is 117,000 MPa (17 x 10^6 psi) - 8.5 times higher than polyester.

The loosely woven fabric of trial 4 (Kevlar 49) was difficult to assemble in such a manner that the fibers were evenly loaded - the shallow preformed bulge also stressed the material excessively. Trial 5 used tighter weave (Kevlar 29 ballistics grade), a deeper preform and prebulged Mylar to withstand the 2.0 atm hydrostatic test. The Mylar was being excessively elongated in the vicinity of the bolt holes, and was not vacuum tight. Note that the modulus of this aramid fiber is about 50% of the Kevlar 49.

The search for a strong, stretchy gas seal led to a laminate of .05 mm Nylon/.01 aluminum/.05 mm linear low density polyproylene as a solution. Unfortunately, the radiation resistance of this laminate is not as good as Mylar, but it is vacuum tight.

Safety Considerations

The stored energy of the vacuum tank is 7 x 10^5 joules. The tank geometry is such that a considerable shock wave ($1/2\ \rho V^2 = .5$ atm.) would be generated in the event of a total window failure. Fortunately, this is highly unlikely - a more probable failure would result in tearing only a portion of the window. The magnitude of the shock wave is a function of the velocity of rupture propagation and the initial pressure differential. The dynamics of this event are currently being studied.

Identified failure modes include radiation degradation and abrasion at the edges during pressure cycling. Abrasion can be reduced by design, and the degradation situation can be improved by a material change. Concern exists that an unsecured magnetic object could be drawn through the window by the 3 tesla magnetic field in the vicinity of the window. Stray field as high as .1 tesla exists 2 meters from the window. The philosophy chosen to minimize risk is to limit personal access to the area, and to pump the tank down only when it is in use.

Other steps include the following:

a. Ferromagnetic objects in the stray field zone have been secured.
b. Non-ferromagnetic tools are used.
c. The entire cave is searched for nuts, bolts, steel, etc. prior to each magnetization producing significant stray field.
d. Warning lights and signs are in use.
e. Non-essential personnel have been excluded.
f. Tours have been restricted.
g. Protective window cover is used.
h. The tank containing the window is let up to nitrogen most of the time.
i. Operational Safety Procedures (OSP) have been developed and are being promulgated.
j. Plans for future window tests are under development.
k. A metal detector has been tested and rejected as technically unsuitable. Further work is needed.

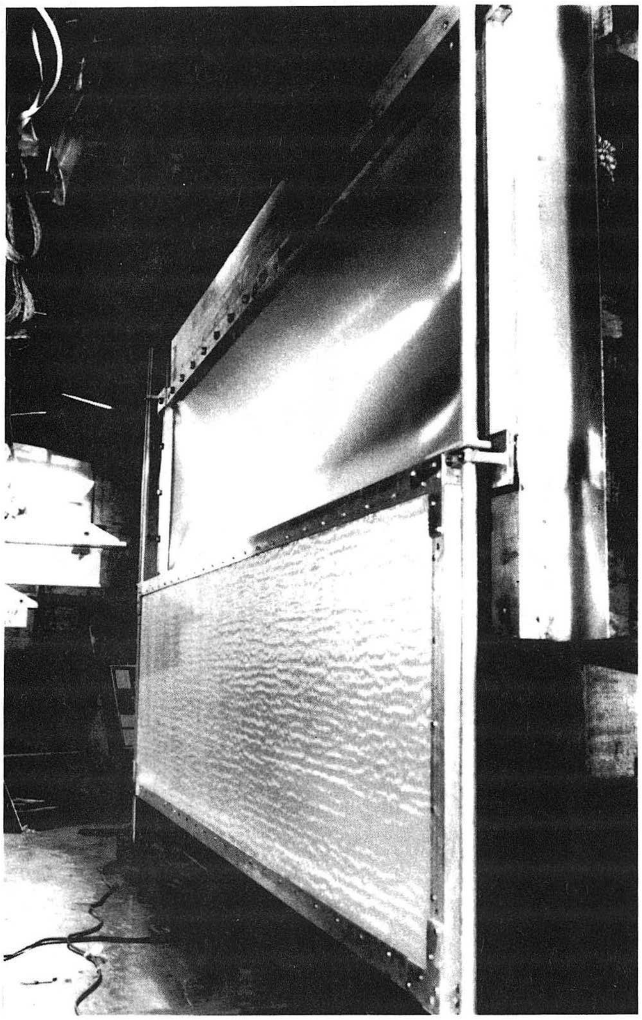

Fig. 2: Window Assembly

Note that it is possible for the accelerator to share common vacuum with this tank. A fast valve is installed for accelerator protection.

A log is kept on beam exposure to the window so conservative operational decisions can be made regarding degradation. The existing window has been in use for one year without problems. Several heavy ion experiments have been run without visual window degradation. The radiation resistance of aramid fiber is not well documented, although bulk aramid compounds are not considered outstanding. Beam intensities at 10^9 protons/pulse (12 pulses per second 20 hours total) have been used for tuning, and heavy ions (carbon, argon, oxygen, in descending order of duration) have been run in the 10^5 to 10^7 range (300 hours total). We will choose to change the complete window should visual discoloration occur.

Conclusion

Calculated stress in easily analyzed portions of the window indicate that further mass reduction is possible using lighter material. Because Kevlar 29 is a "controlled" long lead material and development was on a crash basis, optimization is not complete; the 80 milligram/cm^2 average window mass has been adequate for experiments to date.

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Acknowledgment

We wish to thank Craig Riley of Orcon Corporation, Union City, CA for assistance in the procurement and use of high strength fabrics. Stu Ryce and Bruce MacDonell were instrumental to success by means of their persistent efforts in this development.

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