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A SANDWICH STRUCTURE BEAM PIPE FOR STORAGE RINGS*

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ABSTRACT

A beam pipe fabricated from aluminum foil and plastic honeycomb has been used in the DELCO detector on the PEP storage ring at SLAC for one year. The pipe has a radiation thickness of $5.8 \times 10^{-3} X_0$, a failure pressure of 3.5 atm and was baked for high vacuum service.

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Detector performance at storage rings is often limited by multiple scattering of particle trajectories as they pass out through the wall of the vacuum pipe or by photon conversion into e^+e^- pairs in the pipe wall. To minimize this the pipe should have the smallest radiation thickness possible without collapsing. On the other hand the vacuum pipe wall should not be so transparent to synchrotron and x-ray radiation that the detector is flooded with low energy background radiation characteristic of storage ring operation.

MECHANICAL DESIGN

The failure mode for pressurized pipes depends on whether the pressure is external or internal. An internally pressurized pipe is elastically stable and fails when the circumferential wall stress reaches the yield strength of the wall material. For long thin-walled pipes of radius R and wall thickness t at differential pressure p the stress is

$$\sigma = p\left(\frac{R}{t}\right) \qquad (1)$$

Externally pressurized thin-walled pipes such as an evacuated beam pipe often become unstable and collapse at pressures far below the limit set by the yield strength of the wall material. Failure is then caused by elastic instability. For long thin-walled tubes without end reinforcement, the critical collapse pressure[1]

$$p_c = \frac{1}{4}\cdot\frac{E}{1-\nu^2}\left(\frac{t}{R}\right)^3 \qquad (2)$$

Here E is the material elastic modulus and ν is its Poisson's ratio. Yield strength of the wall material does not appear in this equation. In many cases the tube becomes unstable and collapse begins before the wall stresses reach the yield point of the material. Collapse pressure is often limited by the tube's elastic modulus E and its resistance to deformation rather than its ultimate yield strength. As an example a long thin-walled high strength aluminum tube of 50 mm radius and 2 mm wall collapses from external pressure at 1/8 the pressure it could withstand internally.

To resist unstable collapse under vacuum load and to minimize the pipe's radiation thickness, a high elastic modulus, low Z material such as beryllium is often used [2]. A tube fabricated from beryllium is both exceptionally stiff against collapse and transparent to radiation. The product of elastic modulus times radiation length for beryllium is 17 times that of aluminum. Another method of stiffening the pipe against collapse is to note the $(t/R)^3$ dependence in eq. (2) and increase the bending stiffness of the wall by a change in construction. Beam pipes for the ISR at CERN have been made of stainless steel tube with bellows convolutions to stiffen against collapse [3]. The DELCO design reported here employs sandwich construction to increase the wall stiffness. External pressure is supported by a tube wall made of two thin metal skins laminated to a core of low density honeycomb [fig. 1]. The bending stiffness of such a sandwich structure increases as the second power of the core thickness [4,5]. The stabilizing effect of the low density core can raise the elastic collapse pressure to the point where the tube's failure pressure is the same for external pressure as for internal pressure and is limited only by the yield strength of the load bearing skins. Instability is no longer a problem.

MATERIALS

For the skins of the sandwich, aluminum foil was chosen over beryllium because it is easily welded and bonded and is less expensive. Moreover it is less transparent to x-ray radiation. Calculations of the penetration of scattered synchrotron radiation through various materials showed that it was not necessary to add a higher Z liner to the DELCO pipe as it was in the case of the beryllium beam pipe for the MkII detector [2].

The function of the core material in a sandwich structure is to stabilize the metal skins so they can bear compressive loads without wrinkling or bending. The core material should be of low density and needs little strength or stiffness in the plane of the sandwich. Only transverse compressive strength and high shear modulus are important for supporting the load bearing skins. HRH 10 OX-3/16-1.8 honeycomb[1] was used for the sandwich core. This material is a

[1]Hexcel Corp., Dublin, CA 94566

flexible honeycomb structure made from 50 μm thick Nomex[2] , a nylon fiber base paperlike material. The material has 5 mm hexagonal cells and an average density of 0.029. Its transverse compressive strength is 9 kg/cm^2 and it retains 60% of this up to 200°C.

CONSTRUCTION

The beam pipe has dimensions inner dia. 143 mm, outer dia. 163 mm, length 560 mm, (fig. 1). The inner wall of the pipe must have good electrical conductivity and be free of sudden changes in diameter in order to minimize heating from beam induced image currents. High vacuum requires an all metal inner wall without seams or adhesive contamination. Unalloyed-hardened-aluminum foil 0.25 mm thick was used for the inner skin of the pipe. The foil was rolled onto a collapsible aluminum form and fused into a cylindrical tube by electron beam welding the longitudinal butt joint. After welding, the tube wall thickness was reduced to 0.15 mm by chemical etching. Weld zones are differentially attacked by acid and must be masked off during this process. Aluminum-to-stainless-steel transition rings were then electron beam welded to each end. An alternate method for fabricating the inner wall is to machine it from thick-walled extruded tubing while supported in suitable fixtures.

The sandwich core of 9.5 mm thick honeycomb was bonded to the outside of the etched aluminum tube with a layer of MA4518 film adhesive[3] This material is a 0.3 mm thick film of precatalyzed high-temperature epoxy which must be stored under refrigeration and protected by plastic foil until use. Bonding was done in a hot air oven at 175°C. Before heating, the longitudinal honeycomb seam and gaps between the honeycomb and end transition rings were filled with Hysol Thermofoam 3050 core splice adhesive foam.[4] Compression of the sandwich onto the form during bonding was provided by wrapping the structure with 2 layers of heat shrinking plastic film. Compression was uniformly distributed by

[2]Dupont Corp, Wilmington, DE 19898
[3]McCann Manufacturing, Oneco, CT 06373
[4]Hysol Div., The Dexter Corp., Olean, NY 14760

a 0.4 mm thick protective aluminum caul sheet wrapped around the assembly before heat shrinking film was applied. To avoid wrinkling of the outer skin of the sandwich tube wall as the honeycomb core slides into melting adhesive, bonding was done in 2 steps. The honeycomb core was first partially cured to the inner beam welded foil. The sandwich was then completed by bonding a 0.15 mm foil of high strength aluminum foil to the outside using a simple overlapping seam. Before final welding of vacuum flanges and expansion bellows to the pipe ends the inner supporting form was removed and the inner wall of the pipe was cleaned for vacuum service by painting on a gelled form of chromic acid[5] and rinsing with distilled water. The finished pipe was evacuated and baked at 80°C for 3 days after which its base pressure at 20°C was 1×10^{-9} Torr.

PERFORMANCE

Since pipes were relatively inexpensive to fabricate once tooling and procedures had been developed, three prototype pipes were tested to destruction. Loaded axially as a column one pipe failed at a load of 24500 N. Under external pressurization a crease or wrinkle developed in the outer aluminum skin at 3.5 atm differential pressure. At this point any further increase in pressure resulted in deformation of the wall but the pipe did not collapse catastrophically. Calculated stress levels in the outer aluminum skin of the sandwich were 6.9 MPa at failure. Small dents in the pipe wall did not reduce its strength. In general sandwich construction appears less sensitive to this type of damage than a thin solid wall of beryllium because of the much greater geometrical thickness. One pipe was subjected to 10^6 rads of radiation from a 3 MeV electron beam. Another pipe was heated for 1 hour to 175°C while under vacuum load. Neither of these tests caused any reduction in proof pressure.

The finished pipe contains 0.097 gm/cm^2 of plastic core and adhesive and 0.082 gm/cm^2 of aluminum in the skins. The total radiation thickness of 0.58% X_0 is a significant reduction compared to 2.22% X_0 of the 2 mm thick solid walled aluminum pipe it replaces and is comparable to the 0.56% X_0 of a 1.5 mm thick

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[5]PASA JEL 105, Semco, Glendale, CA 91206

beryllium-titanium pipe. The sandwich structure beam pipe was installed into the DELCO detector at PEP and has been in storage ring service at 5×10^{-9} Torr vacuum for over a year.

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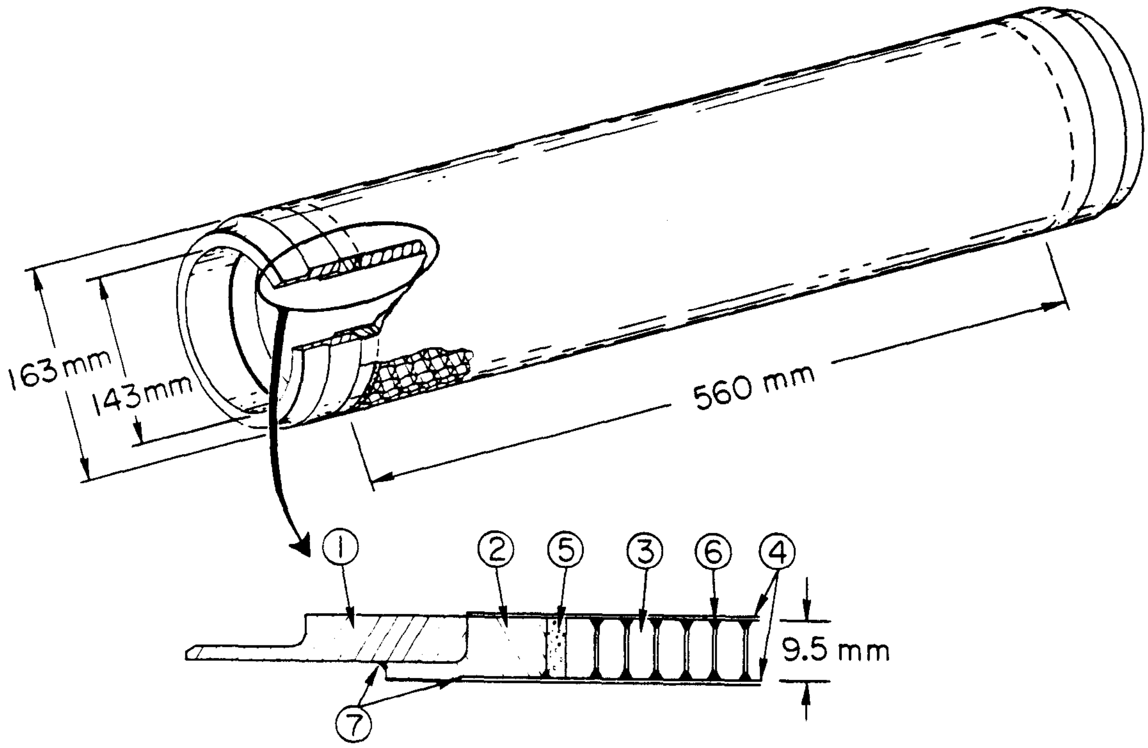

Figure 1: Sandwich structure beam pipe cross section.

1. Stainless steel ring
2. Aluminum ring
3. Nylon honeycomb HRH 10/0X-3/16-1.8
4. Aluminum foil 0.15 mm thick
5. Foam core splice adhesive
6. Adhesive film
7. Electron beam weld