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Author
Turner, James O.

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UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence Radiation Laboratory

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LAWRENCE RADIATION LABORATORY

University of California
Berkeley, California

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Reinforced Epoxy Resin Segment for Synchrotron Vacuum Tank Is Economical to Make and Simple to Modify

James O. Turner, Materials Engineer

Lawrence Radiation Laboratory
University of California
Berkeley, California
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An unusual laminating technique involving plastic foam was used to shape a fiberglas-reinforced epoxy resin segment of an annular vacuum tank for the Lawrence Radiation Laboratory's 340-Mev electron synchrotron. In more than a year of service so far the epoxy resin has demonstrated these advantages:

(a) The laminated segment is more economical to produce and is less subject to breakage than fused quartz, glass, or ceramic.

(b) It is a good dielectric material, has excellent vacuum properties, and low vapor pressure, and thus far exhibits no radiation deterioration.

(c) The laminate can be machined easily for the ports and windows required for various radiation experiments.

Experimenters' Requirements

This application of plastics was developed in the search for a substitute for quartz, which does not lend itself to modification of segments for different experiments. The electron synchrotron accelerates electrons to 340 million electron volts in a doughnut-shaped vacuum chamber. The chamber is made up of eight removable segments, all of which were originally made of quartz. Experimenters' requirements may call for windows or openings in one of these segments, which means that it ought to be possible to cut a tank segment without danger of breakage.

Several different nonconductive materials were tested for segment use.

Fused quartz, glass, and ceramics each had disadvantages. Quartz was the only material found usable until the epoxy resin laminate was developed, but quartz is expensive, subject to breakage, and difficult to cut. Segments made of glass imploded when vacuum was applied, probably because of residual strains. Ceramic segments proved unsuitable, because high shrinkage meant difficulty in holding required tolerances. Metals could not be considered, because the eddy currents set up in any conducting material by the changing magnetic field of the synchrotron would distort the magnetic field and cause ruinous heating.

Obviously a completely different type of material was needed—one that could be worked easily, that could be machined, and that would offer high strength and dimensional stability along with good dielectric properties. We felt that an epoxy construction should meet all these requirements. We had used these resins successfully in other casting and laminating applications. The remaining problem was how to shape it. We eventually developed a technique by which we made a highly satisfactory laminated epoxy resin segment. That segment, now in service, has replaced one of the original quartz segments in the doughnut chamber. More of the quartz segments may be replaced with similar laminates in the future.

Shaping a Core

The annular vacuum tank, situated between two broad pole tips, has a radius of 1 meter. Each quartz segment of the tank is about 31 in. long and represents 45 deg of arc. In cross section it approximates an oval 6 in. wide and 3 to 4 in. high, but is of complicated geometrical shape.

At first we attempted to duplicate the shape of a quartz segment by pouring epoxy casting resin between matched male and female laminated molds. But the shape of the segment (see Fig. 3) made a construction of a core too complicated. There seemed to be no way of removing the core from the segment after casting. We considered the idea of an aluminum core made up of several mating pieces, but abandoned it as too difficult and expensive.

Then we went to a system involving a low-melting-point alloy (below the softening point of the epoxy) that could be melted out afterward. The core was cast of this alloy in a laminated epoxy mold that had been built up on a wood pattern. Although this method was better, the core proved too heavy and awkward to handle.

The next approach was to try a foam-in-place material for the core. A rigid polyurethane was foamed in an inner mold. This foam provided a substantial core with good surface characteristics. The core was then positioned inside the outer mold so that an epoxy resin casting of the segment could be made.

This technique was fine--up to the point of removing the core, which was to be done by dissolving it. Here we struck a snag, because polyurethane foam is quite resistant to solvents. After about two-thirds of the foam material had been removed with various high-powered solvents (acetone, methyl ethyl ketone, etc.), the remainder was soaked in a container full of solvent. But the foam, instead of dissolving, took up the solvent and expanded so much that over a week end it broke the epoxy casting.

The next step was to try to prepare a core from foam material that could be readily dissolved. Polystyrene foam, which is easily dissolved by any one of several solvents, was the obvious choice. It was obtained in block form, then sawed out to roughly the size and shape of the segment. The foam was cut to exact core section by a thin stainless steel ribbon, that was ground down to a knife edge, formed into a loop of appropriate cross section, and heated electrically. The block of foam was placed on a rotatable table over which the cutting loop was fixed at the proper radius. As the table was turned and the foam was pushed through the heated loop, the core was cut to the exact cross section and curvature.

Since the foam was too porous for a mold, its surface was filled with plaster of Paris and smoothed carefully. After the plaster had dried it was sanded lightly. A silicone-base release agent was rubbed into the plaster and then wiped off until only a thin layer remained.

Building Up the Laminate

Now a laminating resin was prepared by mixing Shell Chemical Co.'s Epon 820 resin with 9% DTA curing agent and adding 4% by weight of Cab-O-Sil. This produced a thixotropic compound—that is, one that was thick enough to prevent run-offs and yet fluid enough to assure that the segment would have a smooth interior surface without voids. This resin formulation was applied to the core and allowed to set for 3 hours. After that time the coated cores could be handled.

We had salvaged an uncracked piece of the original cast epoxy segment and tested it for strength against vacuum. It collapsed. This finding convinced us that an evacuated epoxy segment could not withstand atmospheric pressure unless it had a fibrous reinforcement against flexural stresses. The obvious choice was fiberglas.

A layer of glass cloth was cut to fit closely, with a small overlap, over the coated cores. The layer was saturated with the same resin mixture and applied. Successive layers were saturated and applied (with the overlaps on alternate sides to assure equal wall thickness), until the laminate was 3/16in. thick. Each coat of resin was allowed to set for several hours before a fresh layer of cloth and resin was applied.

Heat lamps in the general area raised the ambient temperature and speeded up setting time. When the lay-ups were complete, the laminate was cured for 24 hours at room temperature.

The polystyrene foam core was removed easily enough—a cup of acetone poured on the core completely dissolved it. The thin layer of plaster of Paris remaining inside the laminate was shaved off and the release agent was washed out. Then the inside surface of the laminate was coated with a low-conductivity silver point to bleed off electrical charges that might accumulate on a nonconducting surface.

Fitting to the Vacuum Tank

As the cross section of the laminated segment did not exactly match the oval of the adjacent quartz segments, cast epoxy adapters (or transition pieces) were used to fit them together. An adapter was bonded to each end of the laminated segment with a layer of glass cloth embedded in the resin to provide the necessary strength. The joint between the epoxy and the quartz was made with ozone-resistant neoprene rubber boots.

Modifications When Needed

Ports, windows, and other openings are easily provided in a reinforced epoxy resin segment. The segment can be milled, sawed, filed, drilled, or sanded. For example, a circular port can be made in the laminate to match the standard port system on the quartz vacuum tank segments. Such ports permit insertion of equipment into the vacuum system. Equipment is mounted on flanges that are bolted up to the ports against vacuum-seal gaskets.

An example of a window is shown in Fig. 4. The long slender opening was first milled, then covered with 5-mil aluminum foil overlapping the milled areas by 1/4 in. A 50-50 mixture of Epon 820 and Versamid 125 was used to bond the foil to the segment. This resin combination produces an adhesive with some degree of flexibility, which meets the need for the aluminum window to flex slightly when the tank is evacuated.

Looking Ahead

We can expect to find other ways in which reinforced epoxy resin laminates will supplant glass, ceramics, and metals, so that research methods can be still further improved.

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Fig. 1

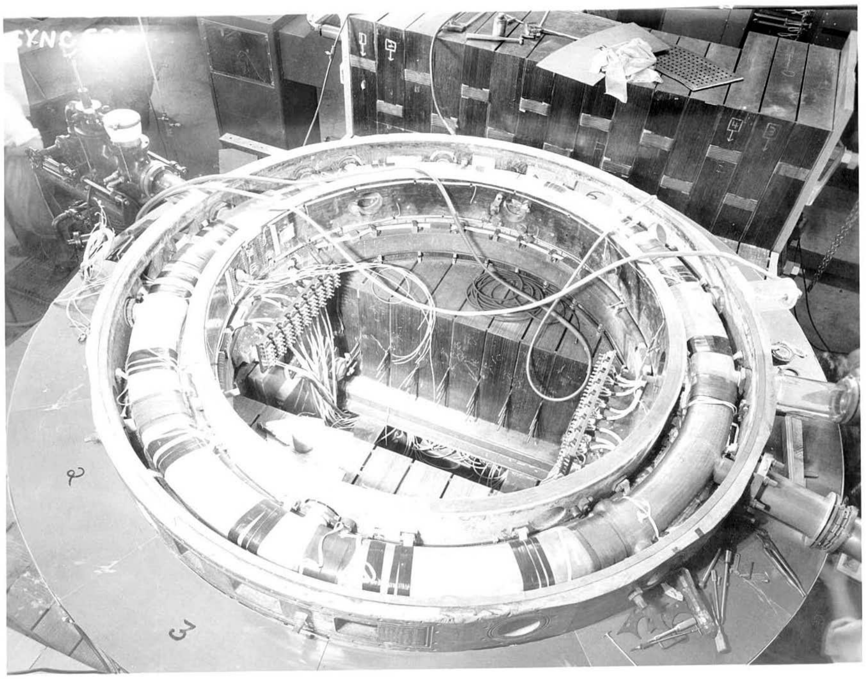

Fig. 2

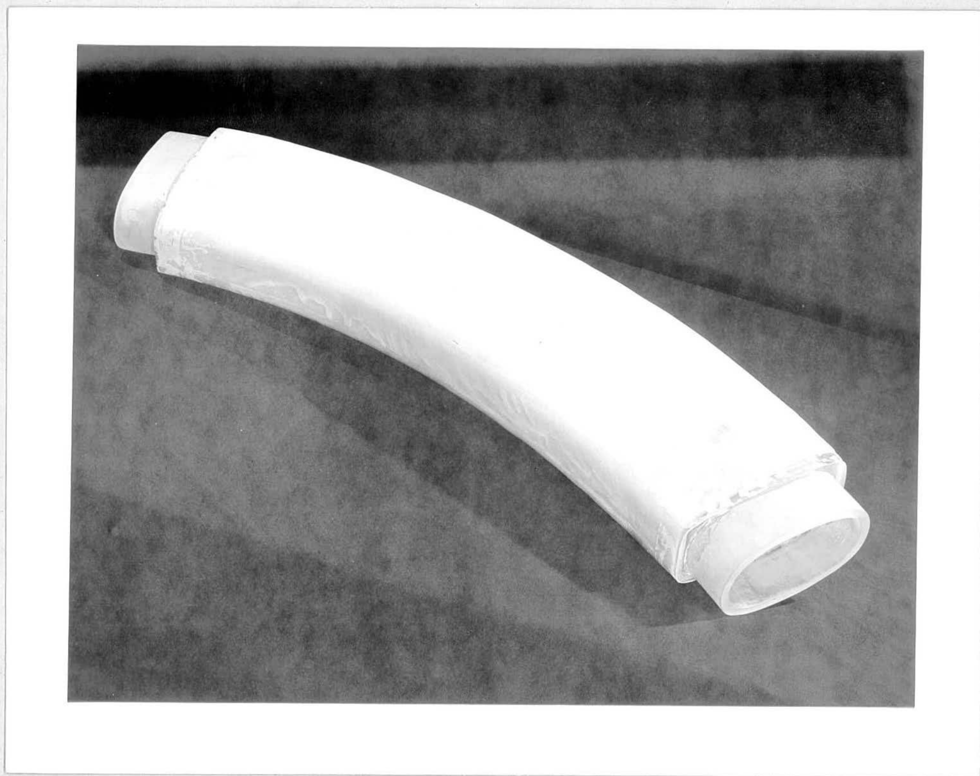

Fig. 3

Fig. 4

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Legends:

Fig. 1 - Rudy Johnson, electrical engineer who heads the synchrotron operating crew, inspects a setup for a nuclear research experiment with the 340-Mev unit. (SYNC-678)

Fig. 2 - Exposed view of the annular vacuum tank, showing the doughnut made up of the eight individual segments. Laminated segment is the white one at lower left. (SYNC-536)

Fig. 3 - Completed reinforced epoxy resin segment with end adapters bonded in place. (SYNC-687)

Fig. 4 - Ports and windows can be cut into the laminated segment without danger of cracking or breaking. Segments are joined by ozone-resistant neoprene boots for a flexible as well as vacuum-tight joint. (SYNC-689)