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A Cold Mass Support System Based on the Use of Oriented Fiberglass Epoxy Rods in Bending

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This report describes a cold mass support system that uses oriented fiberglass epoxy (other low heat leak oriented fiber material can also be used) rods. In the direction of the rods, where forces are carried in tension or compression, the support system is very stiff. In the other directions, the rods are subjected to bending stresses. When the support rods are put in bending the cold mass support is quite compliant. This type of support system can be used in situation where space for a cold mass support system is limited and where compliance can be tolerated in at least one direction. Break test data for 15.9-mm and 19.1-mm diameter oriented fiberglass rods is presented in this report. The cold mass supports for the DFBX distribution boxes are presented as an example of this type of cold mass support system.

INTRODUCTION

Oriented fiberglass epoxy compression rods and tension bands have been used as cold mass support members in cryostats for many years. Tension and compression rod support systems with oriented fiber support rods will often have very low heat leaks for the mass of the cold mass being supported.

For many applications, it is desirable to have a cryogenic support system that is self-centering. (The position of the cold mass does not change as the cold mass is cooled to cryogenic temperature.) In general, self-centering support system takes up space at the ends of the cryostat. Support systems that use oriented fiber rod in bending can have the supports near the center of the cold mass in a location that does not interfere with the function of the cold mass. This report describes a support system that carries the shipping forces and other forces on support rods, which are in bending. Oriented fiber rods are selected *because the breaking stress and elastic modulus can be very high in the direction of the fiber.

This report presents deflection and break test data for oriented glass fiber rods in bending for rods made by three different vendors in two diameters. This reports shows how a support system using rods in bending can be used to support the cold mass of the DFBX boxes for the LHC at CERN.

TESTS OF ORIENTED FIBER RODS IN BENDING

The tests were performed at LBNL used round oriented fiber rods that were about 55 percent oriented glass fiber bonded together using a resin. Samples of 15.9-mm diameter rods were tested from three vendors. For comparison, 19.1-mm diameter samples from one of the vendors were tested. In all cases the effective rod length L was about 19 times the rod radius R. The center of the rod was guided while the ends of the rods were clamped. The apparent rod end-state was about half way between fixed and simply supported. The stress and deflection formulas used to analyze the test data reflect this intermediate end point condition. The test configuration for the experiment is shown in figure 1.

The peak bending stress σ_p for a round rod in bending with a radius R, an effective length L, and an intermediate end-state can be estimated with the following expression [1,2];

$$\sigma_p = \frac{2W}{3\pi R^2}\frac{L}{R}. \tag{1}$$

The deflection of the rod center δ with an intermediate end-state can be estimated as follows [1,2];

$$\delta = \frac{W}{24\pi E R}\left[\frac{L}{R}\right]^3. \tag{2}$$

The maximum shear stress τ_M in the rod is given from the following beam formula [2];

$$\tau_M = \frac{2W}{3\pi R^2} \tag{3}$$

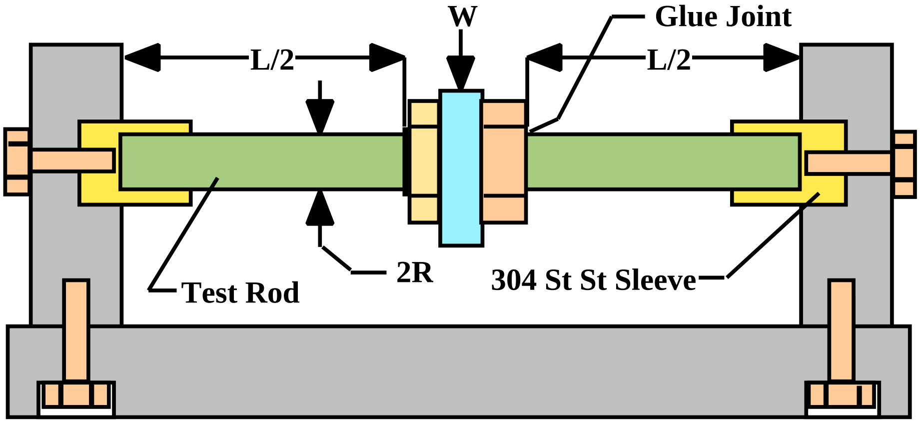

Figure 1. The Test Setup for a Test of Oriented Fiber Rods in Bending

Three 15.9-mm diameter samples (samples A, B, and C) from three vendors (vendors 1, 2, and 3) were break tested as shown in Figure 1. Three 19.1-mm diameter samples (samples 4A, 4B, and 4C) were break tested. All of these samples came from vendor 1. All samples exhibited a green stick type break. When the sample broke, the force on the sample was reduced to the fallback force. The sample continued to deflect at the fallback force. Table 1 compares the break force, the fallback force, and the sample bend deflection when the break occurred. Table 1 also compares the calculated breaking stress, the shear stress, and the apparent elastic modulus for the twelve samples, as calculated using equations 1 through 3. All of the vendors rated the breaking stress (in tension) for their product to be about 820 MPa. The rated shear stress for vendors 2 and 3 was 60 MPa. The rated shear stress for vendors 1 was over 40 MPa. The elastic modulus for the product from all of the vendors was rated at 41 GPa.

All of the rods from vendors 2 and 3 broke above the rated bending stress. The samples showed a definite breaking of the glass fibers in the rods. The resin used by vendors 2 and 3 was an epoxy resin. The rods from vendors 1 and 4 (the same vendor) broke at a stress below their rated stress. In these cases, the bond between the glass fiber and the resin broke. The manufacturer of these rods used a polyester resin. Figure 2 compares deflection versus force for samples 1B, 2B, and 3B. The two samples with epoxy resin show similar deflection versus force curves. Sample 1B, with the polyester resin, exhibits a lower spring constant than the samples with epoxy resin. The samples from vendors 2 and 3 also showed a smaller variation in deflection from sample to sample. Figure 3 compares the deflection versus force for a 15.9-mm diameter rod (sample 1B) and a 19.1-mm diameter rod (sample 4B). As expected, the larger diameter rods had a higher spring constant and required more force to break. All of the rods exhibited elastic behavior to over 60 percent of the rod breaking force in bending.

Table 1. Results of the Oriented Glass Fiber Rod Break Test for Various Samples

Sample	Break F (N)	Fallback F (N)	Break δ (mm)	Break Bend σ (MPa)	Break Shear σ (MPa)	Apparent E (GPa)
			Rod Samples with 2R =15.9 mm and L = 146 mm			
1A	11917	8359	8.51	737	40.0	20.6
1B	10849	8893	9.43	671	36.4	21.4
1C	12984	9449	9.35	802	43.6	21.5
2A	13428	9782	8.92	830	45.1	28.9
2B	13339	10227	8.80	824	44.7	27.7
2C	13784	10227	7.70	852	46.3	28.3
3A	14229	11472	9.00	879	47.8	28.5
3B	15563	13339	9.90	962	52.2	26.4
3C	14940	13028	8.91	923	50.2	26.5
			Rod Samples with 2R =19.1 mm and L = 178 mm			
4A	18119	14784	9.46	789	42.4	24.6
4B	17875	13828	9.18	778	41.6	22.7
4C	14940	12339	9.03	709	38.0	20.9

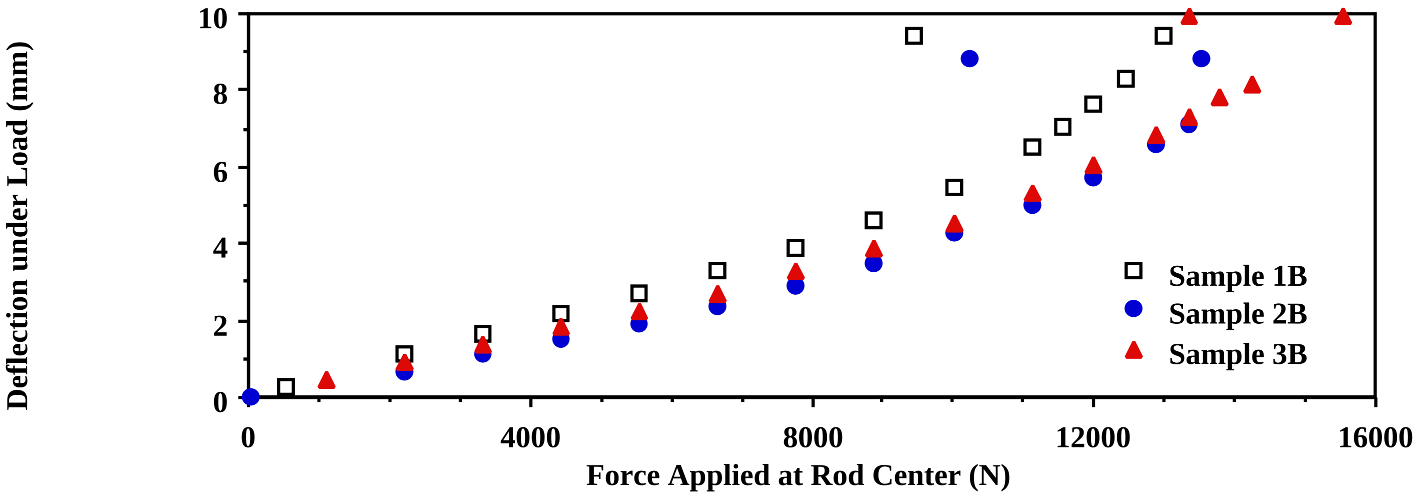

Figure 2. Deflection versus Force for 15.9 mm Rods from Three Vendors

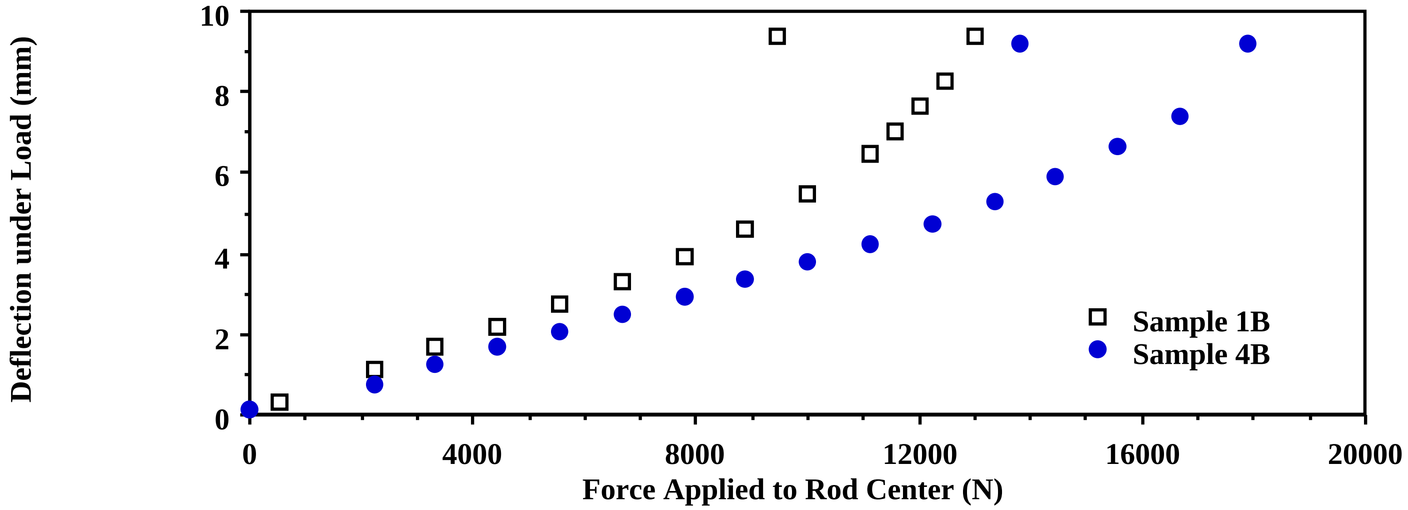

Figure 3. Deflection versus Force for a 15.9-mm Diameter Rod (Sample 1B) and a 19.1-mm Diameter Rod (Sample 4B) from the Same Manufacturer

THE DFBX COLD MASS SUPPORT SYSTEM

The cold mass support system for the DFBX box [3] for the LHC straight sections is a mixed support system consisting of four vertical stainless steel tension rods and a pair of 24.5 mm diameter oriented glass fiber rods that are subjected to bending loads. The overall length of the oriented glass fiber rods in the supports is 300 mm. Because the center section of the rod assembly is guided, the effective length L of the DFBX oriented support rods is 237 mm. Figure 4 shows one of the DFBX oriented rod supports.

The four stainless steel tension rods are designed carry only the downward forces caused by the pressure difference between the helium tank and the vacuum vessel. These forces can be as high as 80 kN when the helium tank is pressurized to its maximum test pressure of 4.4 bar. The stainless steel tension rods also limit the downward motion of the helium tank to less than 1 mm.

A primary role of the oriented fiber rods is to keep the helium tank and all of the piping that is attached to the helium tank in the correct position during all phases of the DFBX operation. The oriented fiber rods carry the shipping vibration loads (up to 15 kN) in all directions. They also carry the transverse forces created by thermal contraction of the helium tank compared to the vacuum vessel (about 5 kN per rod), and vertical forces while the tank is under vacuum and the vacuum vessel is at 1 bar (about 10 kN).

The oriented rod supports are tucked under the helium tank and attach it to the bottom plate of the DFBX vacuum vessel. The oriented fiber rods do not interfere with the DFBX piping or the chimneys that contain the leads for the magnets in the straight section near the DFBX. Other types self-centering cold mass support system would interfere with piping and chimneys off of the top of the DFBX helium tank.

The DFBX cold mass support system heat leak is estimated to be 6.0 W without a 60 K heat intercepts. Adding a 60 K heat intercepts, will reduce the heat leak to about 0.8 W. About forty percent of the heat leak to the helium tank is from the stainless steel tension rods used to support the tank pressure.

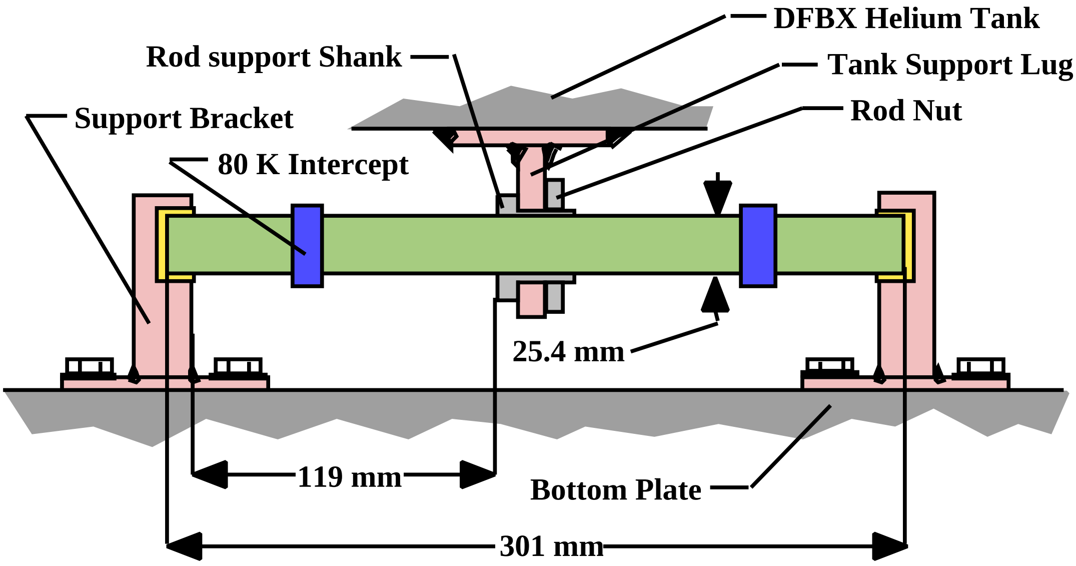

Figure 4. A schematic Representation of a DFBX Oriented Fiber Cold Mass support

CONCLUDING COMMENTS

The use of oriented fiber rods in bending as a cryogenic cold mass support is often justified, particularly if space is limited. Oriented glass fiber rods are much stronger than comparable rods made from made from NEMA G-10 or G-11. Oriented fiber rods used in bending will have a factor of five higher heat leak per unit force supported than one would get with the same rods in tension. Oriented fiber rods in bending can be part of a self-centering support system provided the rods are correctly located geometrically. Oriented fiber rods are well suited for protecting a cryostat from the accelerations that occur during shipment.

Oriented fiber rods are quite compliant in a direction perpendicular to the rod axis. This compliance can be used to allow for thermal contraction of the cold mass. The connection from the rod shank to the rod can be a glue joint provided the contact area between the rod and the shank fitting is large enough. The support shank can also be attached to the rod with pin provided the pin does not pass through a high bending stress region in the rod. Oriented fiber rods are quite stiff along the axis of the rod.

The LBNL tests show that oriented fiber rods break at stresses close to the rated breaking stress for the material in the rod (in the direction of the fiber). The bond between the fiber and the resin holding the rod together can be very important. When the bond between the fiber and the resin is poor, the rod will fail due to shear failure. Rods that broke at stresses lower than the rated failure stress broke because the bond between the fiber and the resin failed. Virtually all of the rods tested exhibited elastic behavior at a stress below 60 percent of the breaking stress. Creep at high stress was evident during the tests. All of the oriented fiber rods tested exhibited green stick breakage. The rods tested stayed together after they had failed. Most of the rods could still carry two thirds of the breaking force after they have failed.

ACKNOWLEDGEMNT

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