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ENGINEERING NOTE

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Project: LHC I.R. Feedboxes

Title: Pressure Test of Pre-Prototype High-Current Feedthrough

I. Description

We describe the thermal cycling and subsequent pressure and leak test of a pre-prototype High-current feedthrough called a lambda plug that will be used in the LBNL-designed cryogenic feedboxes (DFBX) for the LHC at CERN. This feedthrough allows the superconducting inner triplet magnets and associated corrector magnets to be supplied with current while providing a leak-tight barrier between the 1.8K, 1 bar superfluid helium magnet bath and the 4.3K, 1.3 bar liquid helium bath in the DFBX. The item to be tested is called a "pre-prototype" because it has short conductors, whereas the actual fedthrough will have about 2 m of conductor sticking out of each end.

A cross-sectional sketch of the part to be tested is shown in Figure 1.

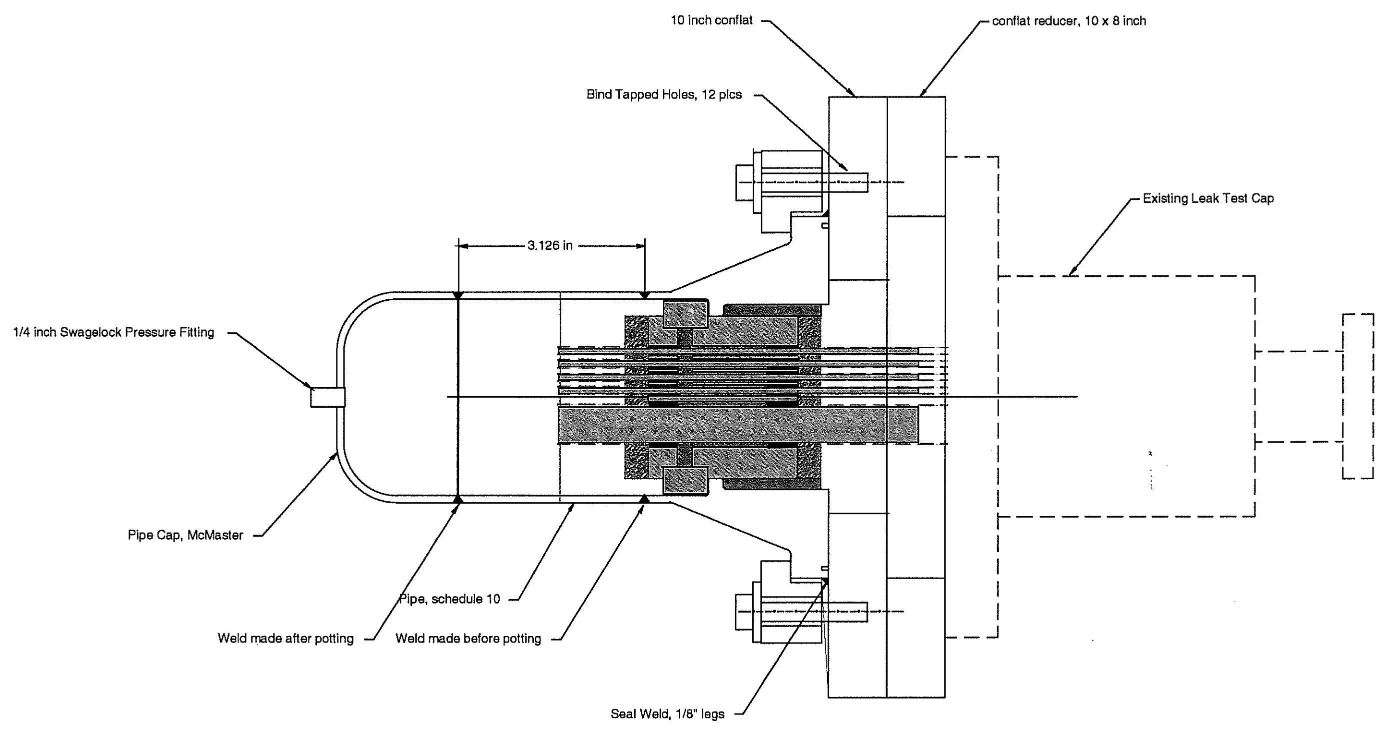

Figure 1. Test Configuration

In operation the feedthrough will have up to 20 bar applied to the magnet side while the DFBX side is at 1.3 bar. The feedthrough would be rendered useless with hydrostatic testing using water since the electrical insulation would be damaged, so it will be tested pneumatically with dry nitrogen or helium, in accordance with Pub3000. The production models will be tested to 25 bar, but the Pre-production units will be subjected to 420 psig (30 bar absolute) of pressure.

On the left side of Figure 1, the piping accurately represents the lead-in to the high pressure ducting that contains the magnet-powering conductors in the DFBX, but here it is empty. As shown in Figure 1, 3" pipe and fittings, schedule 10, type 304L stainless steel are welded to a housing machined from 304 stainless steel. All welding was performed by LBNL welders using the GTAW process with ER308L filler wire. The housing has the general configuration of a weldneck pipe fitting. The assembly of NEMA G-10CR and conductors potted into the housing completes the actual pressure boundary.

To accurately simulate the actual conditions, and allow for detailed leak checking, the housing with potted assembly is seal-welded to a 10 inch conflat flange using a 0.13 inch fillet weld as shown. After the seal welding is completed, the housing is clamped to the 10 inch conflat flange with the 304 stainless steel retaining ring and secured with 12 bolts to prevent the seal weld from being stressed by thrust forces on the magnet piping or a pressure rise in the DFBX helium vessel. For the Production models, the bolts will be tack welded to ensure that they do not loosen.

On the right side of Figure 1 we show test flanges that allow for connection to a helium mass spectrometer leak detector.

II. Hazards

The chief hazard in this test is the stored energy in the pressurized gas providing a driving force that could eject the potted plug out of the housing.

The stored energy is given by:

$$U = \frac{P_h V_h}{\gamma - 1}\left[1 - \left(\frac{P_l}{P_h}\right)^{\frac{\gamma-1}{\gamma}}\right],$$

where U = stored energy in N-m (J)
P_h = Initial Vessel Pressure (absolute) in N/m^2 (Pa) = 30 bar = 3.0 MPa
P_l = Final Vessel Pressure (absolute) in N/m^2 (Pa) = 0.1 MPa
V_h = Vessel Volume in m^3 = 102 in^3 = 1.67 x 10^{-3} m^3
γ = specific heat ratio, C_P/C_V, = 1.67 for helium and 1.4 for nitrogen.

If we test with dry nitrogen,

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$$U = \frac{3.0x10^6 * 1.67x10^{-3}}{1.4-1}\left[1-\left(\frac{.1}{3.0}\right)^{\frac{1.4-1}{1.4}}\right]$$

$$U = 1.25x10^4\left[1-(.033)^{.286}\right]$$

$$U = 7.77 \text{ x } 10^3 \text{ N-m or } 7.7 \text{ kJ}$$

The stored energy is quite low, and is equivalent to about 1.9 g of TNT.

If we test with helium,

$$U = \frac{3.0x10^6 * 1.67x10^{-3}}{1.67-1}\left[1-\left(\frac{.1}{3.0}\right)^{\frac{1.67-1}{1.67}}\right]$$

$$U = 7.48x10^3\left[1-(.033)^{.401}\right]$$

$$U = 5.6 \text{ x } 10^3 \text{ N-m or } 5.6 \text{ kJ}$$

The stored energy is quite low, and is equivalent to about 1.4 g of TNT.

In spite of the rather low stored energy, the part should be tested behind a protective barricade such as inside a 1-inch-thick plywood box. The box should have inside dimensions 24 inch x 24 inch x 36 inch high to accommodate the dewar for cold pressure testing. The corners should be reinforced with 2 inch Al angle. The top should be easily removable to allow the part to be placed inside. The high pressure line and LN fill tube can also penetrate through the top.

III. Calculations

Allowable pressure in 3 inch pipe, fittings, and welds.

Assume full penetration welds, without Radiographic Testing. The allowable pressure in psi is given by:

$$P = \frac{SEt}{R+.6t},$$

where S = allowable stress (psi) = 16,500 psi
E = Joint Efficiency =.65 because of the welds
R = inner radius = 1.63
t = wall thickness (inch) = .12 inch

$$P_{allowable} = 756 \text{ psig}$$

The test pressure of 420 psig is considerably below the allowable pressure of 756 psig.

Shear Stress in Stycast 2850MT bond between 304 Stainless Steel and the G-10CR Insulator block.
We take the limiting case that the entire pressure load is carried by the Stycast epoxy bond between the stainless housing and the G-10CR insulator block,

$$\tau_{shear} = \frac{PA_{pipe}}{A_{shear}}$$

$$\tau_{epoxy} = P\frac{\pi r_i^2}{2\pi r_{G-10} l_{epoxy}},$$

where P = test pressure = 420 psig
r_i = inner radius of piping = 1.63 inch
$r_{G\text{-}10}$ = outer radius of G-10CR insulator = 1.35 inch
l_{epoxy} = length of epoxy bond = 1.75 inch

$$\tau_{epoxy} = 420x\frac{1.63^2}{2*1.35*1.75}$$

$$\tau_{epoxy} = 237\,psi$$

Shear Stress in NEMA G-10CR Plug
In this case we have the limiting case in which the pressure load is carried by a shear load in the end of the G-10 insulator block.

$$\tau_{G-10} = P\frac{\pi r_i^2}{2\pi r_{G-10*} l_{G-10}}$$

where P = test pressure = 420 psig
r_i = inner radius of piping = 1.63 inch
$r_{G\text{-}10*}$ = outer radius of G-10CR insulator joint = 1.1 inch
$l_{G\text{-}10}$ = shear length of G-10CR = .25 inch

$$\tau_{G-10} = 420\frac{1.63^2}{2*1.1*.25}$$

$$\tau_{G-10} = 2030\,psi$$

These shears are very low and are well within the materials' capability.

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IV. Pressure & Leak Testing

Pretest Conditioning: 50 thermal cycles to Liquid Nitrogen temperature and back.

To simulate operating conditions, the assembly shown in Figure 1 shall be pressurized to 20 psig with pure helium gas and submerged in a bath of Liquid Nitrogen for at least 1 hour to allow the part temperature to reach equilibrium. Remove part from Liquid Nitrogen bath, bleed the helium pressure to about 2 psig and allow the part to reach room temperature. Set up a fan to circulate a flow of air over the part and speed the warmup. Allow sufficient time for the part to defrost and become dry. Repeat until 50 cycles are achieved or until the part develops a leak from the thermal cycling. Keep track of the time and pressure of each operation to document the number of thermal cycles that were attained.

Pre-Test Helium Leak Checking

Attach the leak check manifold shown on the right side of Figure 1 and connect to a helium mass spectrometer leak detector using stainless steel flexible hose, conflat flanges and copper gaskets. Pressurize with helium gas using the swagelock fitting.

Measure and record the leak rate at room temperature with 0 psig and 20 psig helium pressure applied to the Swagelock fitting. (Tests will also be done with the part submerged in liquid nitrogen.)
Repeat at Liquid Nitrogen temperature using the following data sheet.

Date: ________________ 0 psig Helium Leak Rate: ________________ Signed: ______________

Date: ________________ 20 psig Helium Leak Rate: ________________ Signed: ______________

With 20 psig helium applied to the Swagelock fitting, submerge the part in liquid nitrogen and measure the leak rate. Take readings every 10 minutes for 1 hour.

Date: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ______________ Leak Rate: ______________

Signed: ________________________

Room Temperature Pressure Test
The pressure test is to be performed using dry nitrogen gas after the pre-test leak check has been successfully completed.

Measure the position of the insulator block from the 10 inch conflat flange at 3 locations.

Position 1 ____________ Position 2 ________________ Position 3 ________________

Date ________________________ Signed ________________________

Hook up dry nitrogen gas source to the Swagelock fitting as indicated in Figure 2. Use a pressure safety manifold with a relief valve set to 500 psig.

Place the part in a protective barrier as described above.
Raise the pressure to 420 psig in steps of about 50 psi. Pause at each step for 60 sec. When 420 psig is attained, close the shutoff valve and record the test gauge reading for 10 minutes at 1 minute intervals.

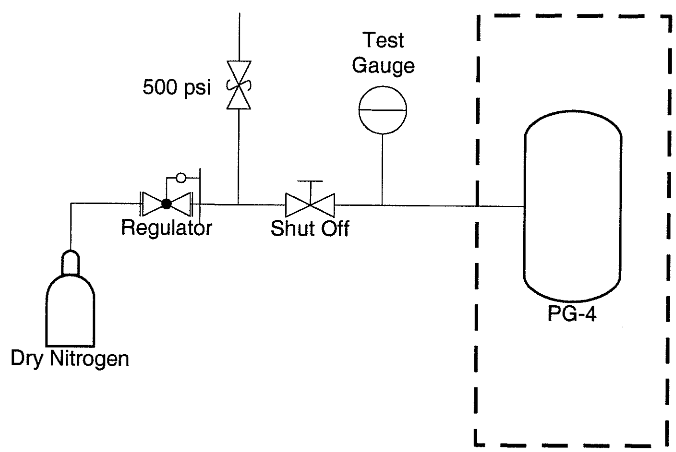

Figure 2. Pressure Test Setup.

Release the pressure and remeasure the location of the insulator block to determine if there has been any deformation.

Position 1 ____________ Position 2 ________________ Position 3 ________________

Date ______________________ Signed ______________________

Post-Test Helium Leak Checking

Attach the leak check manifold shown on the right side of Figure 1 and connect to a helium mass spectrometer leak detector using stainless steel flexible hose, conflat flanges and copper gaskets. Pressurize with helium gas using the swagelock fitting.

Measure and record the room temperature leak rate with 0 psig and 20 psig helium pressure applied to the Swagelock fitting.

Date: ______________ 0 psig Helium Leak Rate: ______________ Signed: ______________

Date: ______________ 20 psig Helium Leak Rate: ______________ Signed: ______________

With 20 psig helium applied to the Swagelock fitting, submerge the part in liquid nitrogen and measure the leak rate. Take readings every 10 minutes for 1 hour.

Date: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Time: ______________ Leak Rate: ______________

Signed: ______________________

Cold Pressure Test

This pressure test is to be performed using dry helium gas after the post-test leak check has been successfully completed.

Measure the end of the insulator block from the 10 inch conflat flange at 3 locations.

Position 1 ____________ Position 2 _________________ Position 3 ________________

Date _________________________ Signed _________________________

Hook up dry nitrogen gas source to the Swagelock fitting as indicated in Figure 2. Use a pressure safety manifold with a relief valve set to 500 psig.

Place the unit in a styrofoam box or dewar that will hold liquid nitrogen.

Place the styrofoam box or dewar inside a protective enclosure made of at least 1 inch thick plywood.

Raise the pressure to 420 psig in steps of about 50 psi. Pause at each step for 60 sec. Hold at 420 psig for 10 minutes.

Release the pressure and allow the plug to warm to room temperature.

Remeasure the location of the insulator block.

Position 1 ____________ Position 2 _________________ Position 3 ________________

Date _________________________ Signed _________________________

Final Helium Leak Check

Attach the leak check manifold shown on the right side of Figure 1 and connect to a helium mass spectrometer leak detector using stainless steel flexible hose, conflat flanges and copper gaskets. Pressurize with helium gas using the swagelock fitting.

Measure and record the room temperature leak rate with 0 psig and 20 psig helium pressure applied to the Swagelock fitting.

Date: _______________ 0 psig Helium Leak Rate: ________________ Signed: ______________

Date: _______________ 20 psig Helium Leak Rate: ________________ Signed: ______________

With 20 psig helium applied to the Swagelock fitting, submerge the part in liquid nitrogen and measure the leak rate. Take readings every 10 minutes for 1 hour.

Date: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Time: ________________ Leak Rate: ________________

Signed: ______________________________

V. Labeling

The plug is for R&D only, and will never be used as a part of a pressure system. Therefore it will not be labeled with an LBL Pressure-Test Label.