DESIGN CONSIDERATIONS OF THE IUCF COOLER DIPOLE MAGNET VACUUM CAN*

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Summary

Various stainless steel alloys were investigated for use in constructing vacuum cans for the IUCF Cooler dipole magnets. The wall deflection due to vacuum forces was measured. The outgassing rate after the chosen surface treatment was determined. Interesting results on the measured magnetic properities of welds were obtained. A scheme for vacuum bakeout was developed and heat loss thru the thermal insulation was measured.

Design Considerations

The design pressure for the IUCF Cooler is $<1x10^{-10}$ Torr. To maximize the usefulness of the ring for experimental physics, three target stations have been incorporated directly into the ring vacuum system. Consequently, the inevitable contamination by hydrocarbons requires that the vacuum system be bakeable to 300^{0}C. This raises the problems of heaters, thermal insulation and strength of the vacuum can at elevated temperatures.

There are two types of dipole magnets in the ring; eight with a 30^{0} bend angle and four with a 27^{0} bend angle. Each has a bending radius of 2.38 m and a gap of 5.2 cm.

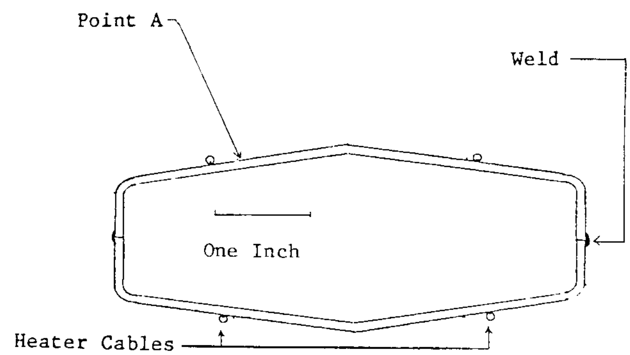
It is desirable to minimize the dipole magnet gap in order to reduce the cost of the magnet steel, coils and power supplies. This must be balanced against adequate room for heaters, insulation, beam clearance and wall thickness to resist deflection.

Prototype

In order to meet the requirements for minimum wall thickness and adequate strength at 300^{0}C, we selected stainless steel .075" thick for making the dipole vacuum can prototype. Ease of fabrication dictated that we use a segmented can made from straight sections welded together to approximate the curve of the dipole pole tips. Each straight section was made from two pieces of stainless steel sheet formed by bending, and then welding them along the sides as shown in figure 1. This cross section encloses the elliptically shaped beam as well as providing good resistance to deflection and space for heaters and insulation. The maximum deflection measured at point A in figure 1 was .015".

Bakeout Heating

We hoped to use the dipole power supplies for resistive heating of the vacuum can during the bakeout. Some initial tests using 3" O.D. by .065" wall 304 stainless steel tubing were made. Reaching 300^{0}C required passing about 500 amps thru the tubing, which was thermally insulated with ceramic wool. We successfully passed 500 amps thru a 4.625" knife edge copper gasket sealed vacuum flange. Eight temperature cycles were performed without causing vacuum leaks or discernable damage to either the knife edge or copper gasket. Increasing cross sectional area of the vacuum can, which leads to much higher required currents , forced us to abandon this scheme.



Dipole Vacuum Can Cross Section

Figure 1

Our initial bakeouts using heater elements were made using fiberglass insulated heat tapes. We suffered numerous shorts thru the insulation and burnouts of the conductors with these tapes. We then switched to an ARI Industries electric heating cable of 1.6 mm diameter. This cable has a Nickel-Chrome-Iron center wire insulated from a thin Inconel sheath by compacted Magnesia. The cable can be bent and soldered or welded directly to our vacuum can. The maximum operating temperature is 1500^{0}C. Although we sucessfully silver soldered this cable to our vacuum can, it was very easy to melt thru the thin outer sheath. As an alternative, we have been fastening the cable with brass clips silver soldered to the vacuum can. Since this greatly reduces the thermal contact to the vacuum can, we were concerned about overheating the cable in spots. A prototype vacuum can 1.6 m long with the cross section shown in figure 1 had two heater cables each 6.7 m long fastened to it as previously described. It was then insulated with Fiberfrax ceramic wool 6mm thick and wrapped in aluminum foil. This assembly was placed between two water cooled plates which simulate the heat loss to the dipole magnet. The power to the heater cables was controlled by commercial 1000 watt SCR dimmer switches. Approximately 600 watts was required to hold the vacuum can at 262^{0}C. The heater cable sheath stabilized at a temperature of only 279^{0}C.

Since many of these heaters cables will be extremely difficult to replace, reliability is very important. To date several heater cables have developed no problems after over twenty bakeout cycles.

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Magnetic Properties of Welds

We were warned by Fred Mills of Fermilab that incorrect welding rod used during the welding of some magnet vacuum cans had caused him problems with magnetic welds. We consequently made measurements on the perturbation to the magnetic field caused by the welds in our prototype vacuum can.

Apparently most austenitic stainless steels such as 304 and 316 are designed to form 2-4% ferrite in the weld to resist hot cracking. Our welder attempted to fusion weld the pieces together with a minimum heat affected zone. This should minimize the volume of metal forming the ferrite. We also fabricated a prototype from 310 stainless which forms ferrite free austenitic welds. Our welder, John Ragle, was able to make vacuum tight welds with this alloy almost as easily as with 304 or 316.

Figure 2 shows the change in the magnetic field caused by the weld in the side of the vacuum can. These measurements were made on three vacuum cans, one each of 304, 316L, and 310 stainless steel. The field was measured with a Hall probe having a sensitivity of ≈ ±.1 gauss. The measurements were made in the median plane of the vacuum can as a function of distance away from the weld. The field was set at 1420 gauss in order to maximize the sensitivity of the Hall probe. We next measured the change in the magnetic field at a fixed location as a function of field to see when the weld metal saturated. These results are shown in figure 3.

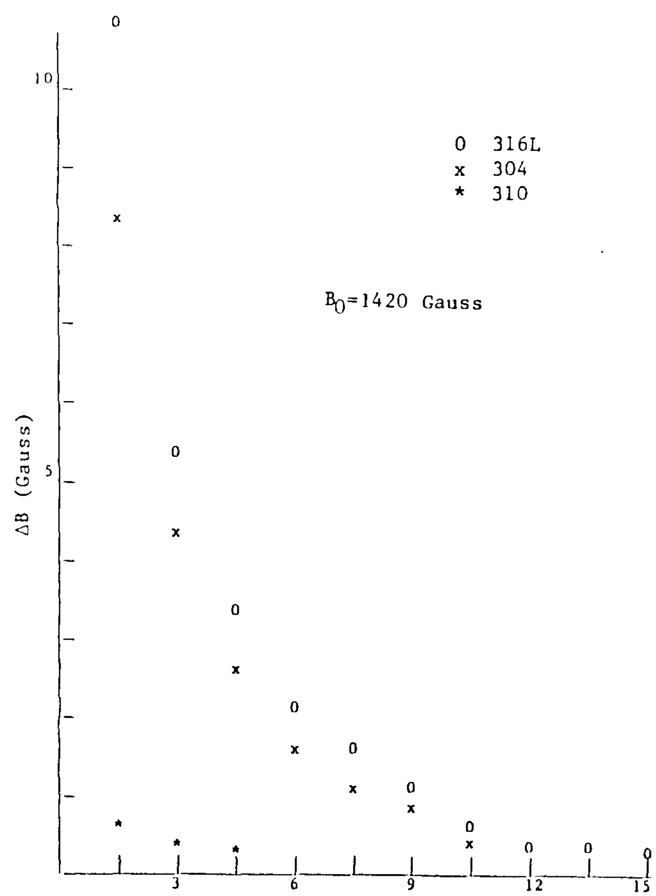

Figure 2

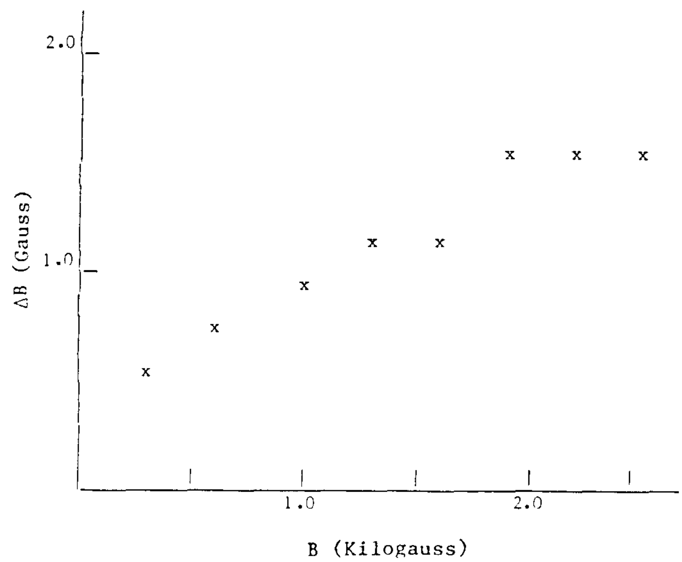

Figure 3

In order to reduce the specific outgassing rate of the stainless steel these vacuum cans were next heated in a vacuum furnace. They were held at a temperature of 800°C for 2 hrs. with the pressure below 2×10^{-6} Torr. When the above measurements were repeated on a 316L vacuum chamber the magnetic field difference was reduced to values of the same level as those measured earlier for the 310 stainless steel can.

Conclusions

We have decided that heater cables are the logical choice for bakeout heating. 310 stainless steel can be sucessfully welded for very high vacuum use, and these welds are much less magnetic than those in 304 or 316L. However, if the welds are subjected to a standard vacuum heat treatment, we found no measureable differences in the magnetic properties of the welds in 304, 316L and 310 stainless steel.

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