Return End Can Deflection of DS0310 and DS0311 at Room Temperature

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Introduction. The return end can of DS0311 was recently installed using G10 collet pieces with the fiber planes running perpendicular to the magnet axis ("radial fibers.") We may expect some differences in the behavior of this end relative to the corresponding end on DS0310, due both to the shape of the new G10 pieces (they don't have the "warping"[1] that characterizes the G10 pieces with "azimuthal fibers") and their potentially different mechanical properties. Of course, the main reason to try them is their much smaller thermal contraction in the radial direction.[2]

In this report I compare end can deflection data from DS0310 and DS0311. For each magnet, strain gage data and strains inferred from caliper measurements are compared.

Strain Gage Measurements. The return end cans of DS0310 and DS0311 were both instrumented with six active and four compensating strain gages. These gages were attached to the end cans before installation ("free" state) at azimuthal angles given in the second column of Table 1. (The azimuthal angle is measured from the vertical position, counter-clockwise looking toward the coil from the return end.) The DS0310 end can was installed correctly, so that strain gage A1 was at Phi = 0 degrees. The DS0311 can was unintentionally installed in a rotated position, so that the angular positions of the gages were as given in the third column of Table 1.[3]

Table 1. Azimuthal Positions of Return End Can Strain Gages

Gage Name	Phi DS0310 (degrees)	Phi DS0311 (degrees)
AC1	0	113.9
AC2	30	143.5
AC3	60	175.4
AC4	90	202.8
AC5	180	293.9
AC6	270	23.9
CC1	~240	350.9
CC2	~180	309.9
CC3	~240	353.2
CC4	~180	309.9

Room temperature resistance values for all strain gages were recorded before end can installation (their "free" values), at two points during end can installation, and after the end can was in its final installed position (their "loaded" values.)

Figure 1a shows the strain recorded by the DS0311 active gages as a function of azimuthal angle. To obtain strain from the resistance measurements, the following formula[4] was used:

$$\text{strain} = (R_{loaded} - R_{free}) / (2.08 * R_{free})$$

The y -axis scale in Figure 1a is chosen so that the DS0311 strains may be easily compared with the values from DS0310, which are plotted in Figure 1b. The strain values for DS0310 are taken directly from Wayne Koska's analysis.

The strains for the DS0311 end can show fairly good azimuthal symmetry, and are all between 1 and 2 mils per inch. The DS0310 end can had negative strains of about .5 mils per inch at 90 degrees and 270 degrees, angles unfortunately not covered by the rotated strain gages on the DS0311 end can.

The positive strains of about .5 mils per inch at angles near the vertical for DS0310 are four times smaller than the value for DS0311 close to the same position. Likewise, the value for DS0310 at 180 degrees is nearly 0 mils per inch, wheareas DS0311 shows abourt 2 mils per inch in the same angular region.

The relatively small value for strain close to 120 degrees shown by DS0311 may indicate a return from negative strain values at angles close to 90 degrees.

Figures 2a and 2b show the radial pressures[5] inferred from the strain gage readings, assuming a simple pressure vessel with walls of uniform thickness. (The thickness used is the value at the strain gage position.) In the case of DS0311, the pressure has values between 7 and 16 kpsi. (See Note 5, however.)

Caliper Measurements. For both DS0310 and DS0311, the diameter of each end can was measured in free and installed positions (and at several intermediate positions during installation) using a caliper. Diameter measurements were made at 0 degrees, 45 degrees, 90 degrees, and 135 degrees from the vertical at longitudinal positions .5", 1.5", 2.5", 3.5", 4.5", 5.5" and 6.5" from the coil end of the end can.

For comparison with the strain gages, the ideal set of caliper measurements would be the set taken 1.5" from the coil end of the end can, since the strain gages are mounted about 1.13" from the coil end of the end can. However, the physical positions of the strain gages make some of the caliper measurements at 1.5" impossible. We therefore take the caliper measurements at .5" and 3.5" (DS0310) and 2.5" (DS0311) for comparison.

Figure 3a shows the strains inferred from the caliper measurments on the DS0311 return end can.[6] Two sets of caliper measurments appear on the graph, taken at .5" and 2.5" from the coil end of the can. Each caliper measurement gives two points; for example, the measurement at 0 degrees is also a measurement at 180 degrees, and so on. The open squares show the strain gage readings on the same plot.

The strain gage readings are seen to lie reasonably close to the strains inferred from the caliper readings at 2.5" from the coil end[7]. The caliper measurements indicate the highest strains at the coil end, which is where the steel can is the thinnest and suffers the highest stress during installation.

Figure 3b shows the analagous readings for DS0310. As in Figure 3a, the strain gage readings and caliper measurements seem to track each other qualitatively. In this case, there are also strain gages mounted at 90 and 180 degrees, which show the negative strains indicated by the caliper readings. As in the case of DS0311, the .5" caliper measurements indicate the greatest strains.

Conclusions. Measurements of room temperature return end can strain in two SSC 40mm short dipole magnets, DS0310 and DS0311, have been examined both with strain gage and hand measurement techniques.

The strain gages of DS0311 show in general higher strain values than DS0310. The pressure on the DS0311 end can inferred from the strain values are close to 12 kpsi, and are fairly azimuthally symmetric over the angular regions sampled.

The caliper readings for both magnets show negative strain at the parting plane of the magnet. This negative strain is confirmed by the strain gage data of DS0310, but cannot be checked for DS0311 due to improper azimuthal positioning of the DS0311 end can.

The strain gage readings track qualitatively the strains inferred from caliper readings for both DS0310 and DS0311. However, the detailed agreement between magnitudes is less clear. The uncertainty in the strains inferred from the caliper readings is the controlling source of systematic error.

References and Notes

1. The standard G10 collet pieces, with fiber layers in the azimuthal direction, are machined as a tapered cylinder and then cut into four quadrant pieces. When the pieces are cut out of a cylinder in this manner, they have a tendency to warp inward, so that the original inner cylinder diameter of 3.198" becomes about 3.168".

2. Simple "dunk" tests in liquid nitrogen (TS-SSC 90-053) have shown that G10 shrinks almost 5 times less in directions within the planes of the glass fibers than in directions perpendicular to the fiber planes (1.4 mils per inch as opposed to 9.7 mils per inch.) This result is well known and intuitive, of course.

3. As Table 1 indicates, the DS0311 end can was rotated counter-clockwise by about 114 degrees from its correct position prior to installation. This was due to a mistake in the felt pen marks layed out on the end can to indicate vertical, horizontal, 45 degree and 135 degree diameters.

4. The gage factor 2.08 is used for these gages (Micro-Measurements Division of Measurements Group, Inc., gage type WK-15-250BG-350 option W.) The manufacturer's quoted uncertainty on the gage factor is 1% at room temperature. The compensating gage readings are ignored in this report since their inclusion only changes the strains by several parts in 10^3.

5. I use the formula **pressure = (strain * (2.83e4 kpsi) * t) / r_{inner}** where t is the average thickness of the stainless steel end can, and r_{inner} is its average inner radius. After making the figures, I discovered that using the thickness and inner radius of the can at the position of the strain gages, the pressures can increase by as much as 1 kpsi.

6. I just assume a "local" strain of **(change in diameter / free diameter)** at each position.

7. If we assume a measurement uncertainty in the caliper readings of 1mil, then the caliper readings should have uncertainty bars of about 300 in the y direction.

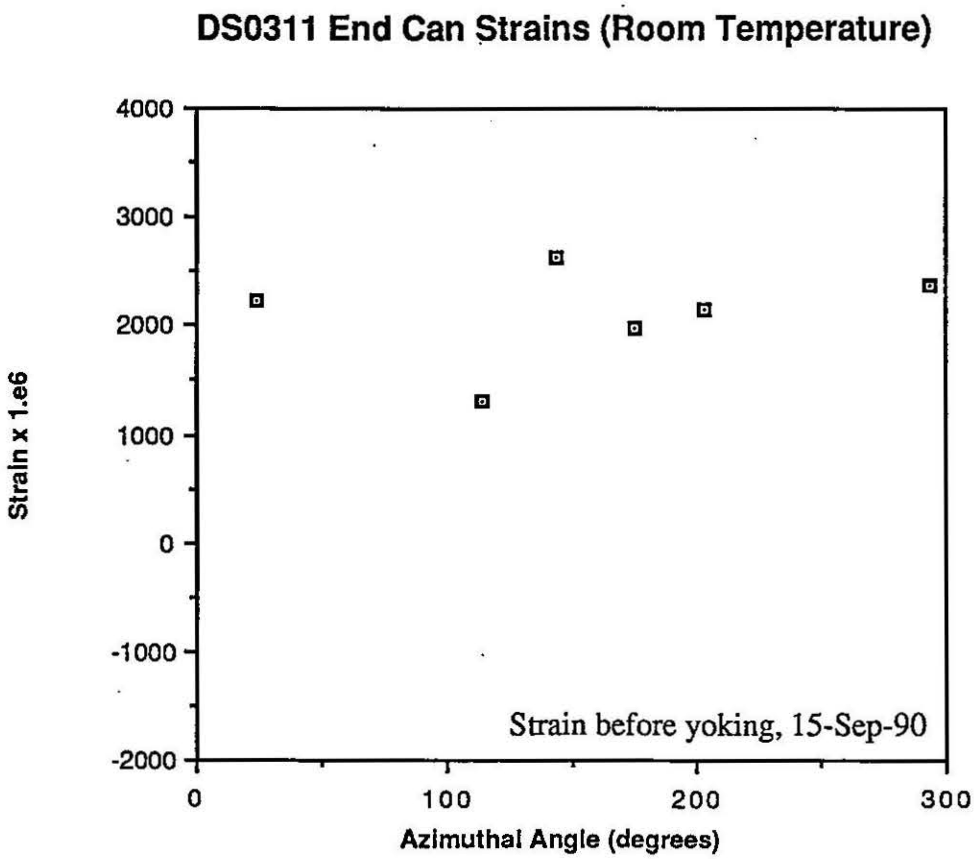

Figure 1a

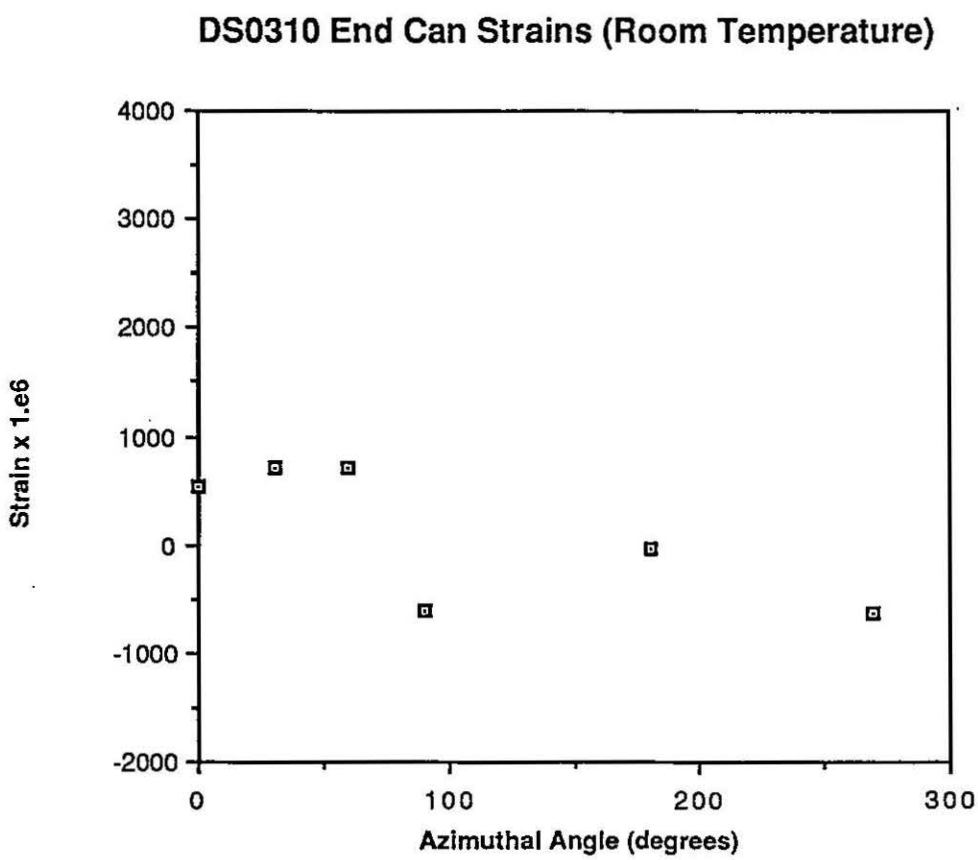

Figure 1b

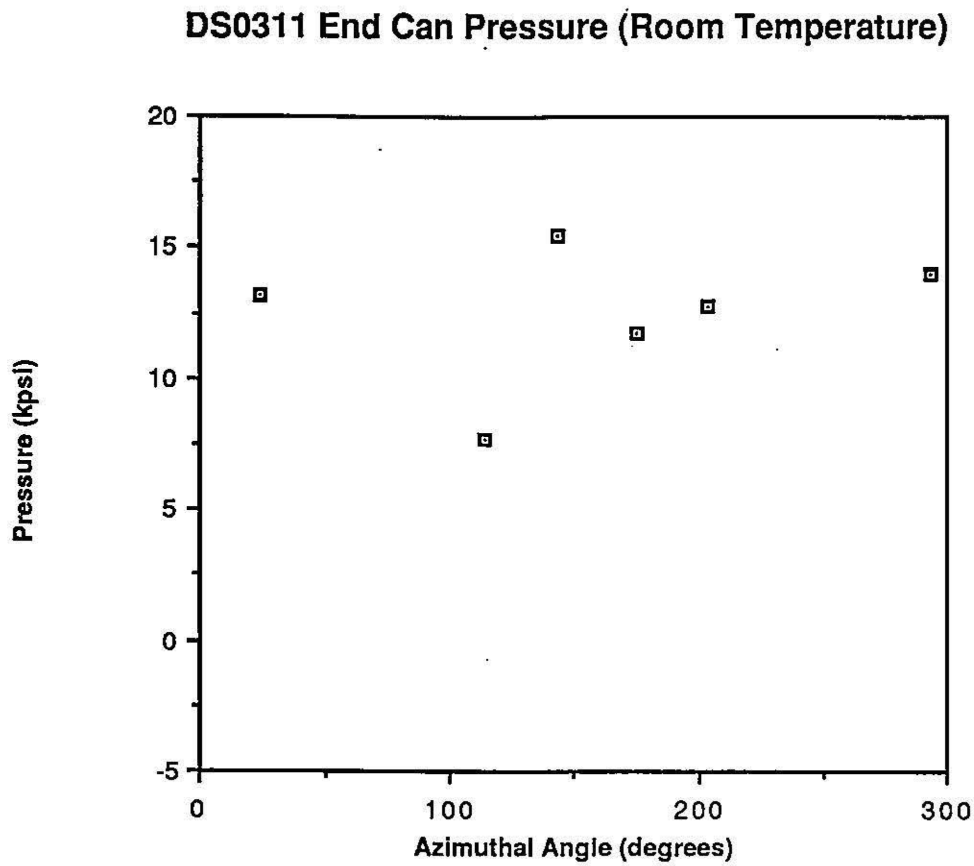

Figure 2a

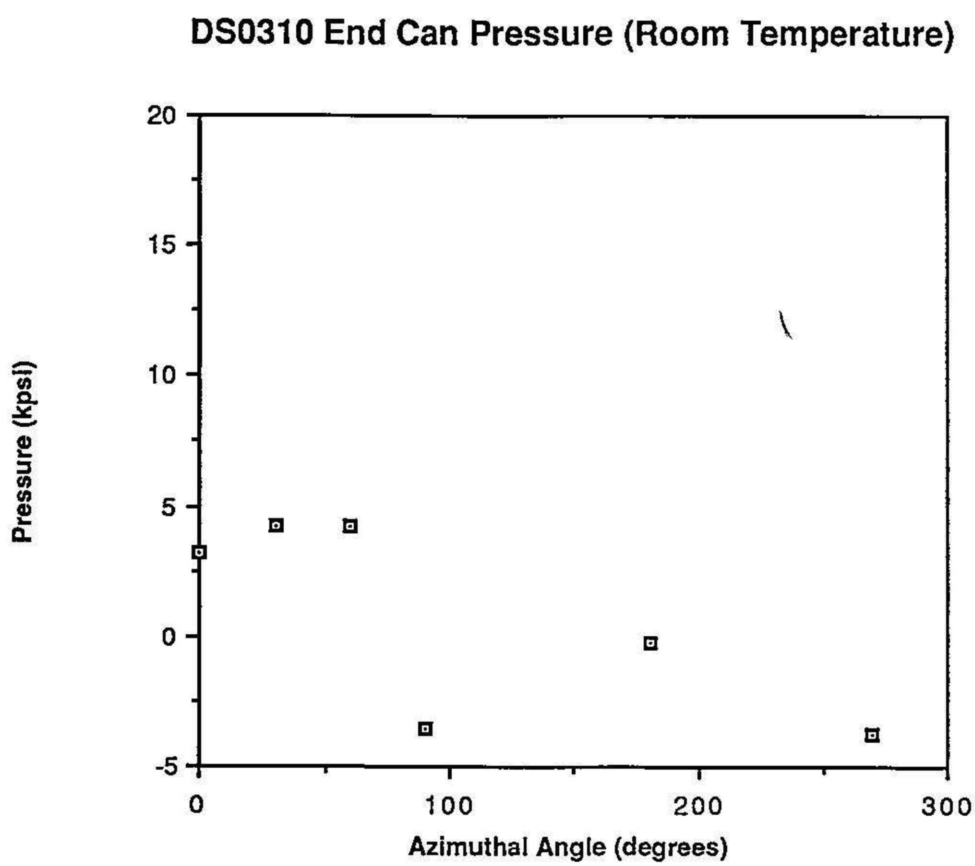

Figure 2b

DS0311 End Can Strain: Caliper vs. Gages

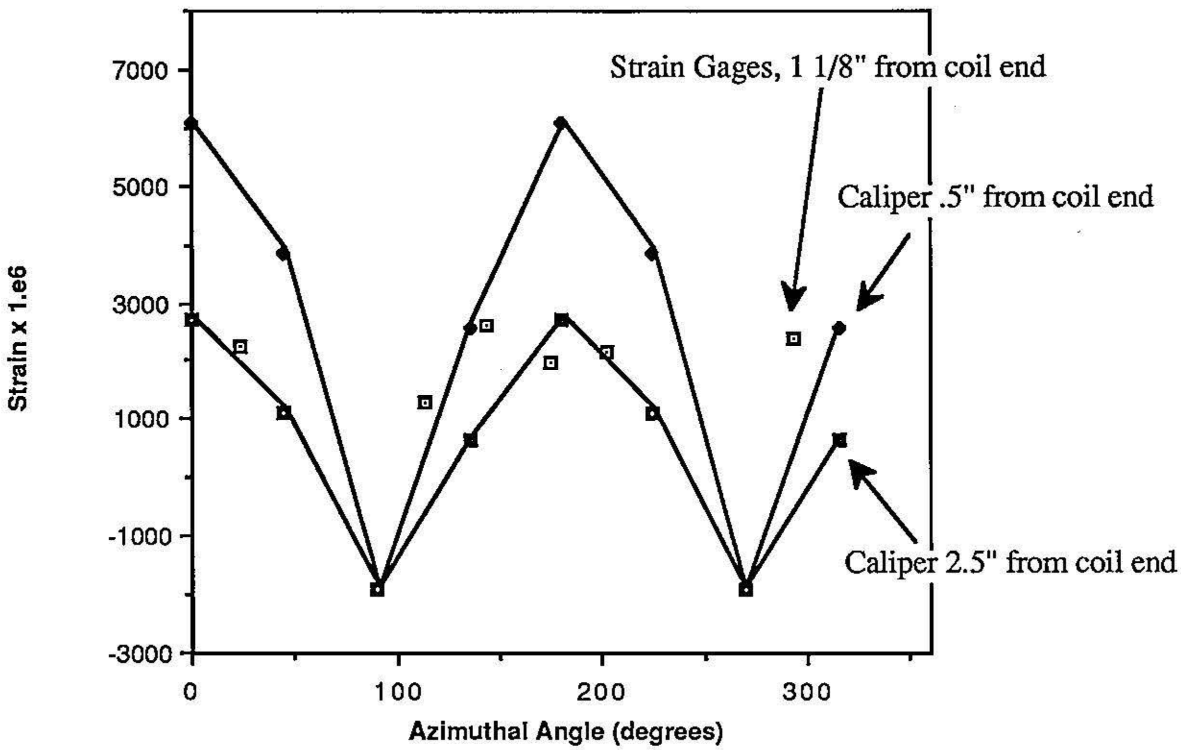

Figure 3a

DS0310 End Can Strain: Caliper vs. Gages

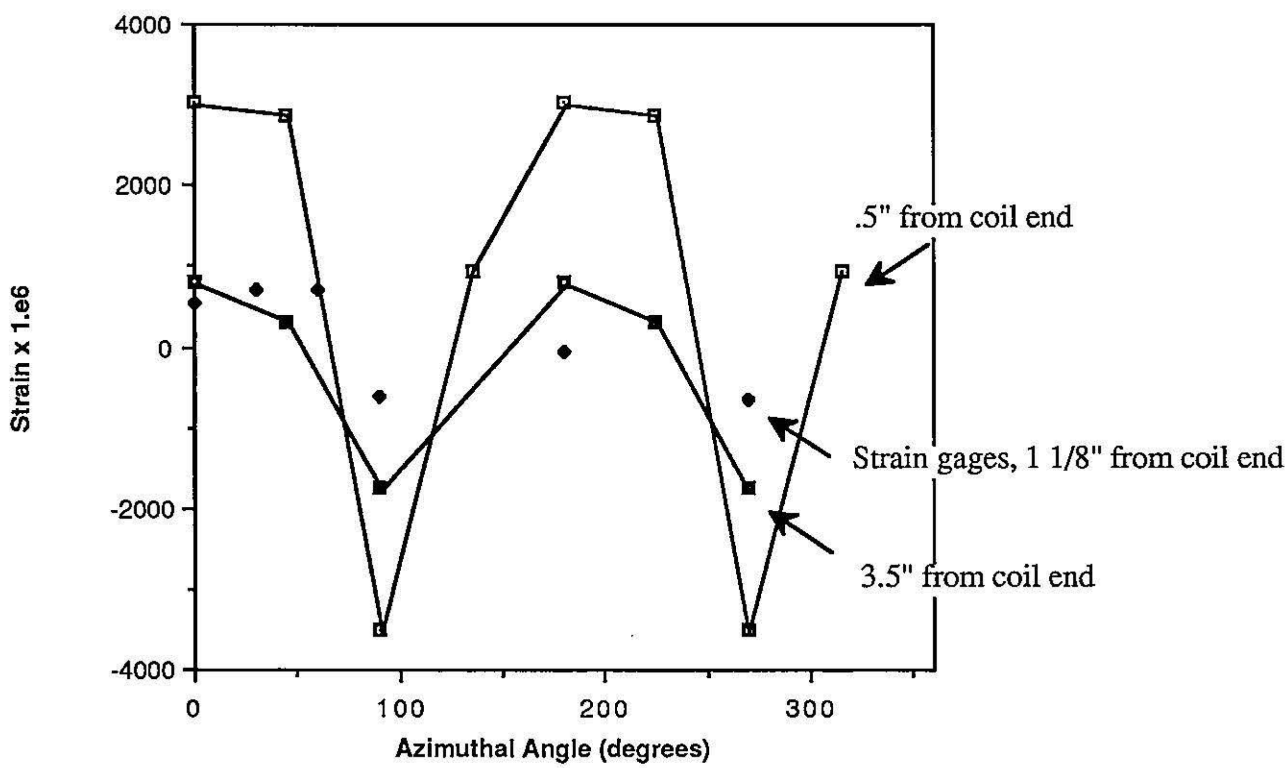

Figure 3b

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