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MINIMIZING DOUBLER DIPOLE SUSPENSION LOAD DUE TO SAGITTA BEND

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ABSTRACT

The sagitta bend in the Doubler Dipole is the source of the largest forces imposed on the suspension system. The bend presently matches the magnetic radius of the main ring. By altering the shape of this bend slightly, the forces on the suspension system can be drastically reduced.

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SUMMARY

Figure II shows the loading on each suspension station for the current sagitta bend and for the end loaded bend described in this paper. The end loaded case not only puts less force on the middle and end suspensions, but, more importantly, imposes no load on any of the other suspensions. It may be possible to reduce the size and, consequently, the heat leak of the suspension pads.

Figure III shows the difference in the curvature of the magnet for the two cases. The end loaded magnet follows an arc which differs from a circular arc by a maximum of .020".

ANALYSIS

Figure I[1] is a typical cross section of the Doubler Dipole Cryostat. A collared coil is slid into this cryostat, a beam tube is slid into the collared coil, and the assembly is surrounded by laminations to complete the magnet. Two items called the suspension and standoff in Figure I serve as the mechanical support for the coil assembly; they constrain the coil to its proper location under magnetic, gravitational, precompression and sagitta forces. The suspension and standoff will be referred to collectively as the suspension system, and are the object of this analysis.

The completed dipole magnet is made to conform to the curvature of the main ring by laying it on supports at varying elevations, clamping it down to follow the shape of these supports, and injecting epoxy through and between the laminations so that the magnet will retain this curved shape. Presently, this shape is designed to be a circular arc whose radius matches the magnetic radius of the main ring. This bend in the magnet is called a sagitta bend. The sagitta bend is the source of the largest force imposed on the suspension system (for comparison, precompression ≃ 500 lb./suspension[2], magnetic ≃ 500 lb./suspension, gravitation ≃ 100 lb./suspension).

As the sagitta bend is imposed on the magnet, the forces exerted on the outside of the magnet are transmitted through the cryostat, collared coil, and beam tube by the suspension system. Referring to Figure I, the suspension system must bend several components of the cryostat: the shield outer and inner tubes, the 1ϕ tube, and the 2ϕ tube. The suspension component will always be in greater compression than the standoff since it alone must bend the shield tubes. The forces calculated below are actually the forces on the suspension component; the forces on the standoff will be slightly less.

The suspensions are spaced 28.75" apart along the length of the magnet. There are a total of 9 suspension stations. The cryostat, collared coil, and beam tube can be considered a structural beam and each suspension a point load on that beam trying to deflect it. Any calculations on the "beam" will require knowledge of its stiffness, measured by EI where E - Young's Modulus of Elasticity, I = moment of inertia. The EI for each component of the "beam" is:

$$EI \text{ collared coil} = 7.1 \times 10^7 \text{ lb. in}^2$$ [3]

$$EI \text{ cryostat tubes} = E\pi R^3 t = 6.10 \times 10^8 \text{ lb. in}^2;$$

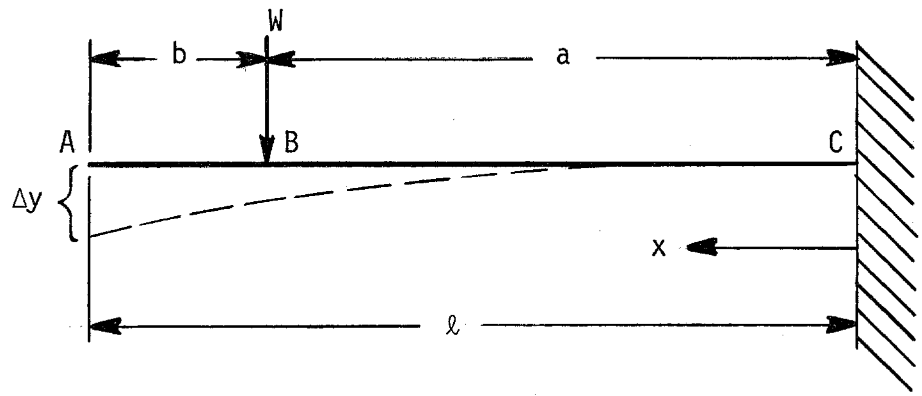
R = radius, t = wall thickness

$$EI \text{ beam tube} = E\pi R^3 t = 1.65 \times 10^7 \text{ lb. in}^2$$

The cryostat tubes and beam tube have been treated as perfect cylinders. The total EI for the "beam" is the sum of the above:

$$EI = 6.98 \times 10^8 \text{ lb. in}^2$$

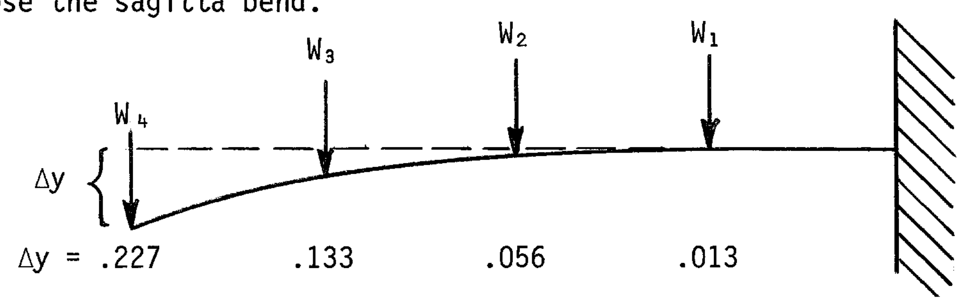
Each half of the magnet can be considered to be a cantilever beam with point loading for which the following drawing and formulae apply:[4]



$$\Delta y_{AB} = \frac{W}{6EI}\,(-a^3+3a^2\ell-3a^2x) \tag{1}$$

$$\Delta y_{BC} = \frac{W}{6EI}\left[(x-b)^3-3a^2(x-b)+2a^3\right] \tag{2}$$

Applying this to the magnet, each suspension acts like a weight bending a "beam". The deflections at each suspension are known from the fixture used to impose the sagitta bend.[5]



Knowing these deflections and applying equations (1) and (2) leads to four simultaneous equations in unknowns W_1, W_2, W_3, W_4:

W_1 = -1020 lb.

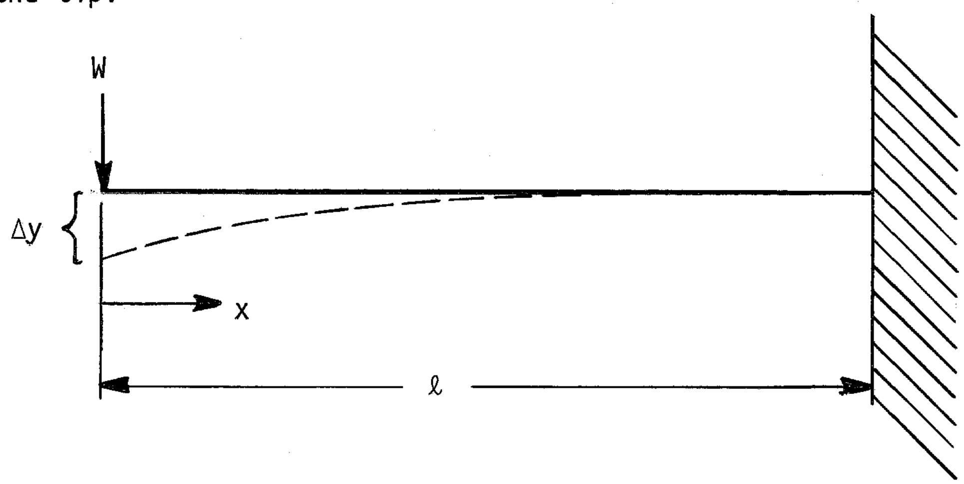
W_2 = - 378 lb.

W_3 = 96 lb.

W_4 = 457 lb.

The forces on the magnet suspension system are shown in Figure II.

An alternate sagitta bend will now be examined. Again, each half of the magnet is treated as a cantilever beam, but it is now deflected by loading only at the tip.[6]



$$\Delta y_{max} = \frac{W\ell^3}{3EI} \tag{3}$$

$$\Delta y = \frac{W}{6EI}\left(x^3-3\ell^2x+2\ell^3\right) = \frac{\Delta y_{max}}{2\ell^3}\left(x^3-3\ell^2x+2\ell^3\right) \tag{4}$$

Note that Δy can be expressed in terms of Δy_{max} only. Because EI does not appear, the conclusion is that all beams of the same length will assume the same shape when deflected an equal amount at the tip, regardless of how stiff they are. For the case of the Doubler Dipole, this means that only the middle and end suspensions must exert a force to put the sagitta bend in the magnet; all the other suspensions carry no load. The forces required will be calculated along with the resulting shape of the magnet so that it can be compared to the present shape. Inserting the same values for EI and Δy_{max} found in the current magnet into equation (3):

$$W = \frac{3EI\ \Delta y_{max}}{\ell^3} = 305\ \text{lb.}$$

The loading on the suspensions for this case is shown in Figure II.

The actual shape for this case is found from equation (4). The deflections for both cases are given in Table I. Figure III summarizes the difference in displacement of the present magnet and the end loaded magnet.

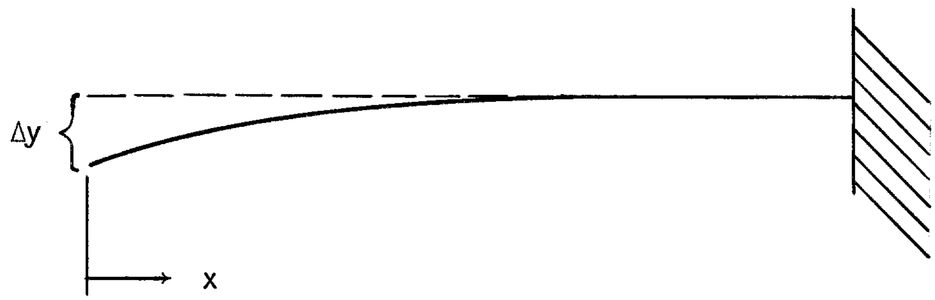
It has been assumed that the bend imposed on the outside of the magnet is actually the same bend which the beam tube finally assumes; this may or may not be the case due to elastic deformation of any of the components involved. For this reason the actual difference in the shape of the beam tube for the two cases may not be as great as the difference shown in Figure III. However, to be safe, one must assume the worst and decide if the shape of the beam tube for the end loaded case is acceptable for proper operation of the main ring.

My appreciation to George Biallas for inspiring this analysis and helping to clearly define the problem.

REFERENCES

1. Engineering Drawing #1620-MD-103010, Fermilab.
2. George Biallas (Private Communication).
3. George Biallas, Measurement made 8/17/77.
4. R. Roark, Formulas for Stress and Strain, 4th ed. (McGraw-Hill, New York, 1965), p. 104, Case 2.
5. Engineering Drawing #1620-MD-106502 and calculations by George Biallas.
6. R. Roark, Formulas for Stress and Strain, 4th ed. (McGraw-Hill, New York, 1965), p. 104, Case 1.

DEFLECTIONS IN DOUBLER DIPOLE DUE TO SAGITTA BEND



x (in)	Δy (in) Present Magnet	Δy´ (in) End Loaded Magnet	Δy´-Δy
0	.238	.238	.000
6	.208	.220	.012
12	.190	.202	.012
18	.169	.184	.015
24	.149	.166	.017
30	.133	.149	.016
37	.112	.132	.020
42	.097	.116	.019
48	.082	.100	.018
54	.069	.085	.016
60	.056	.071	.015
66	.044	.058	.014
72	.035	.046	.012
78	.026	.036	.010
84	.020	.026	.006
90	.013	.018	.005
96	.009	.011	.022
102	.004	.006	.002
108	.002	.002	.000
114	.000	.000	.000
117.8	.000	.000	.000

TABLE I

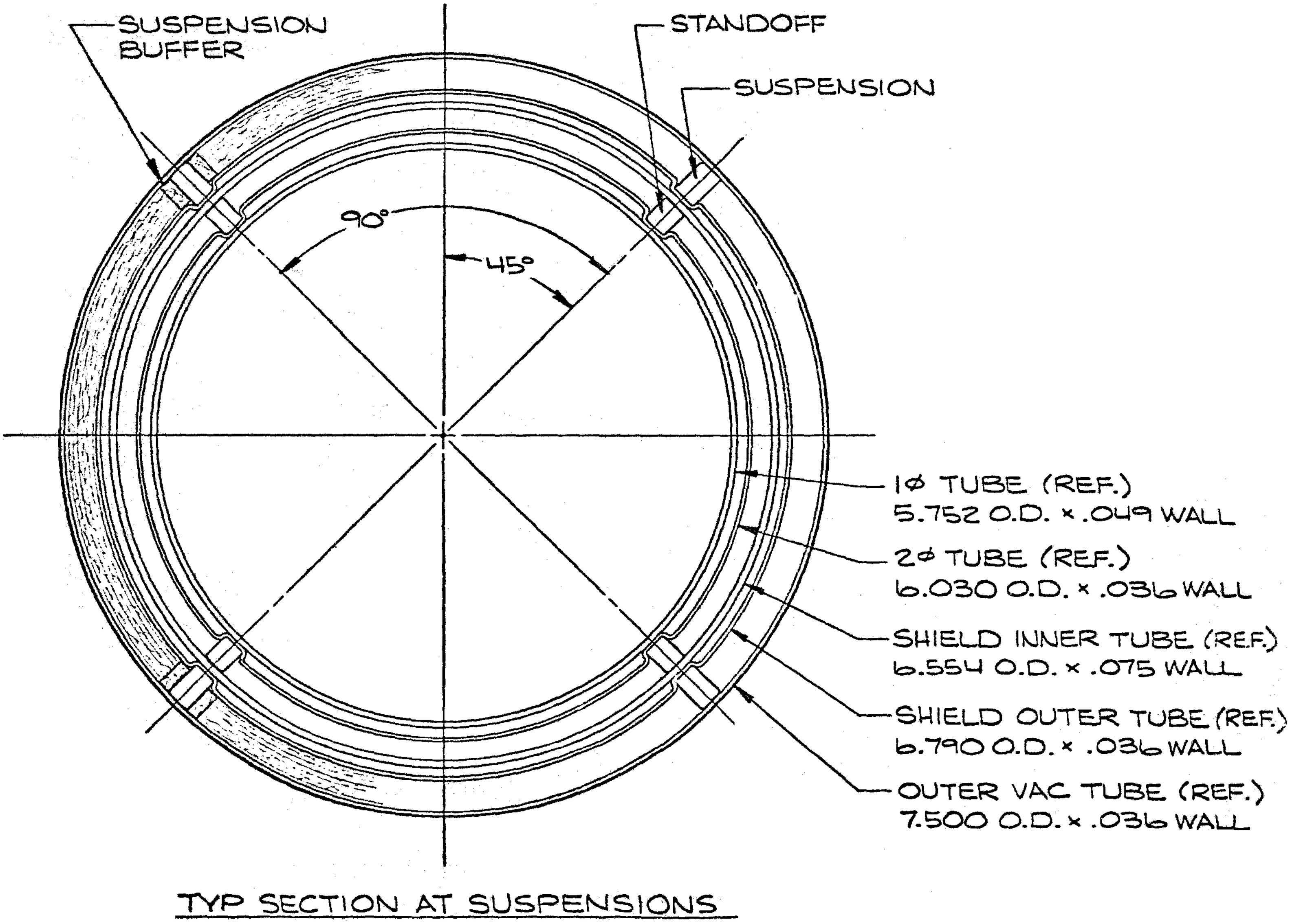
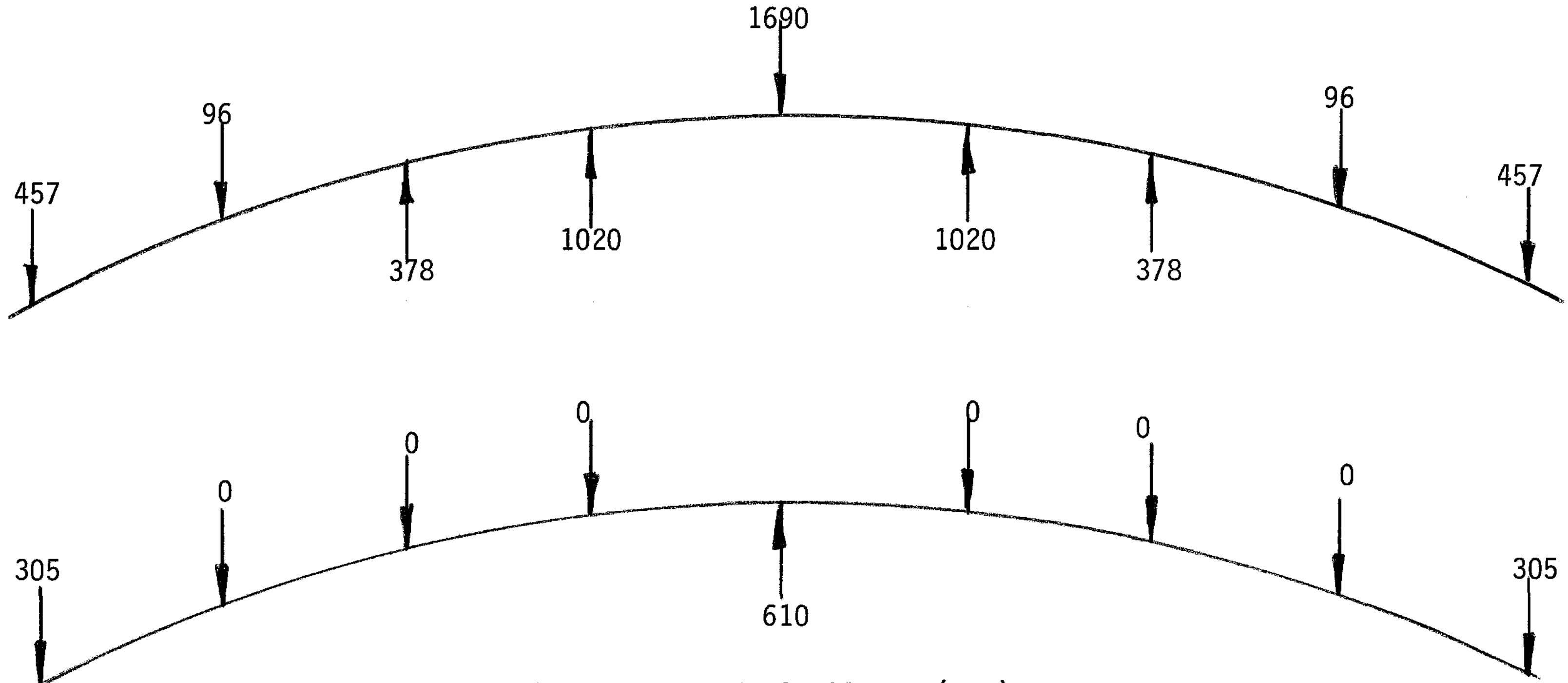

SUSPENSION BUFFER
STANDOFF
SUSPENSION
90°
45°
1⌀ TUBE (REF.)
5.752 O.D. × .049 WALL
2⌀ TUBE (REF.)
6.030 O.D. × .036 WALL
SHIELD INNER TUBE (REF.)
6.554 O.D. × .075 WALL
SHIELD OUTER TUBE (REF.)
6.790 O.D. × .036 WALL
OUTER VAC TUBE (REF.)
7.500 O.D. × .036 WALL
TYP SECTION AT SUSPENSIONS

FIGURE I

FORCES ON DIPOLE SUSPENSION SYSTEM DUE TO
SAGITTA BEND

PRESENT SAGITTA LOADING (LB.)



ALTERNATE SAGITTA LOADING (LB.)

FIGURE II

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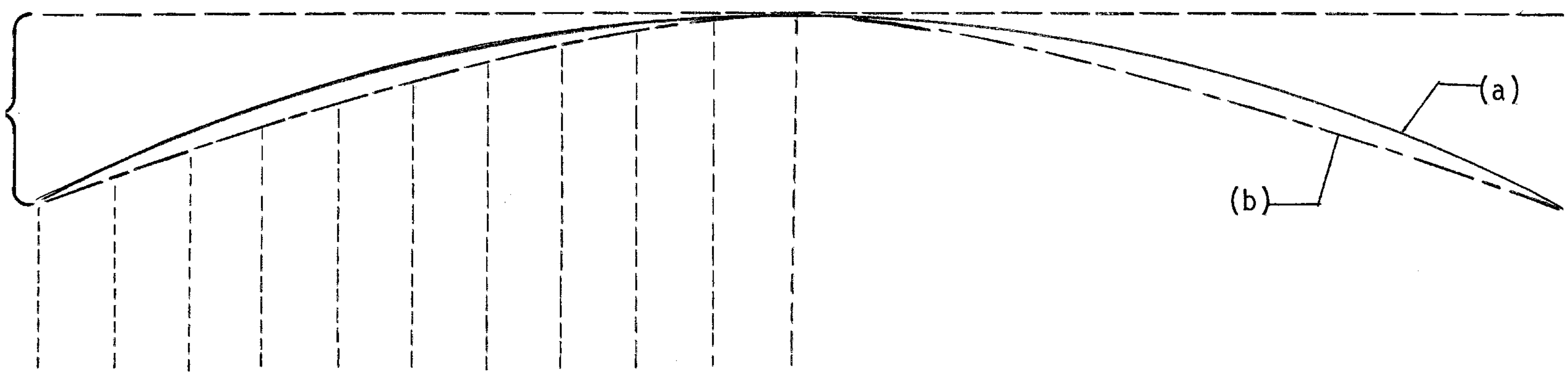
DEFLECTION OF DOUBLER DIPOLE DUE TO SAGITTA BEND

——— Deflection of magnet due to present sagitta loading (a)

— — — Deflection of magnet due to alternate sagitta loading (b)



(a) Δy	.238	.190	.149	.112	.082	.056	.034	.020	.007	.002	.000
(b) Δy	.238	.202	.166	.132	.100	.071	.046	.026	.011	.002	.000

FIGURE III