Fermi National Accelerator Laboratory

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Spectrometer Beam Tube Dimensional Optimization

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SPECTROMETER BEAM TUBE DIMENSIONAL OPTIMIZATION

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ABSTRACT

This project examined the optimization of the design of a beam tube. An ANSYS model was used to find the minimum tube thickness and the best camber in a beam tube under vacuum and preloaded by a pair of magnet poles. After the tube was modeled one version of it was built for use in the accelerator. This beam tube was put under a vacuum and the dimensional changes were recorded and compared to the ANSYS predictions. These deflection results were quite close to the predicted numbers and would suggest that the stresses are similar to the predictions as well.

SPECTROMETER BEAM TUBE

A beam tube was required for a spectrometer magnet in the LINAC diagnostic line. In order to obtain accurate readings from the spectrometer as much beam as possible had to get through the tube. So, the thinner the tube walls, the more accurate the spectrometer readings would be. Also, because of the shape of the available space, the tube had to be as rectangular as possible. Since the tube was to be under an ultra high vacuum it would also have to be stable under the unbalanced atmospheric pressure.

A model of this structure was run through ANSYS a number of times in order to get an estimate of the stresses and the deflections that occur. From these results a tube size was chosen and a number of other dimensions were examined for their effect on the stresses and displacement of the tube walls. The final design was based on the simulation results, as well as the advice of the person who would shape the tube. The final design is shown in Figure 1. This design was built and vacuum tested early in January 1993. From the vacuum tests the deflections of the beam tube when under the unbalanced atmospheric pressure were recorded. This data set was compared to the ANSYS estimates, which were found to be quite similar. Since the displacement estimates and the forces are modeled quite accurately and the stresses are based on these two factors plus the material properties and geometry, it is quite likely that the stress predictions are also close to the ANSYS estimates.

Spectrometer Beam Tube

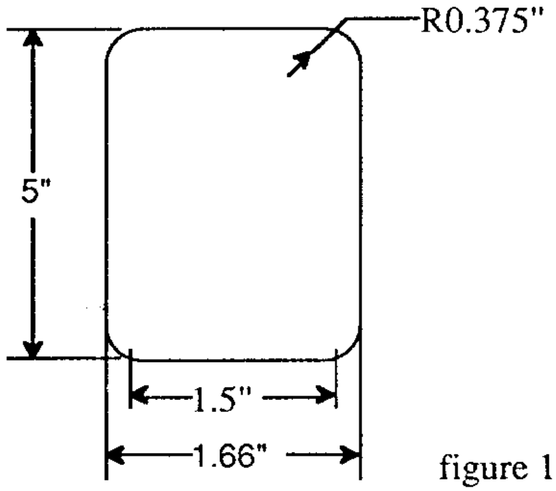

figure 1.

It was decided to use a parametric ANSYS file to simulate the beam tube under pressure. The main objective of the simulation was to find the minimum thickness of the tube wall with the minimum stress that would still hold the vacuum. At first a few tests were done to see how the general shape would hold up to the vacuum. From these tests it was found that the middle of the beam tube bent inward when the vacuum was applied. Thus, in order to increase the volume inside, it was decided to put a camber in the beam tube. It was also decided to preload the tube between the magnet poles. An ANSYS model was then setup to examine the reaction to a preload, a camber and the vacuum.

Since there were limited funds and equipment some dimensions of the tube would be fixed. Only a few tube wall thicknesses were available and the tube corner dimension was based on what could feasibly be built with Fermilab equipment. The width between the outside of the two corner radii of 1.5" was based on the magnet pole separation of 1.578" with an allowance for some camber when the vacuum is applied. From this base there were three tube wall thicknesses that were examined with a large range of possible cambers. A simple optimization procedure was used to find the best tube thickness and camber. These results are summarized below.

Thickness (in)	Camber (in)	Max. Equivalent Stress (psi)
0.05	0.185	37959
	0.12	35062
	0.1	29809
	0.065	27238
	0.06	20807
	0.055	20106
	0.04	24036
0.042	0.185	37959
	0.1	30459
	0.08	30657
	0.07	27927
	0.065	26636
	0.06	27666
	0.055	29323
0.032	0.3	73000
	0.25	59001
	0.12	35942
	0.1	35897
	0.09	38000
	0.075	50400
	0.06	54360

From this data it appeared that a 0.055" camber with a 0.05" thick tube wall would be quite acceptable. However, to avoid special ordering because of the short length of the tube, an available tube size of 0.065" was used. Once this was decided a deflection test was run on ANSYS without the preloading. This gave a displacement of 0.0587" for the middle section of the 5" side on the quarter model. This was equivalent to 0.117" for the total model. Once the tube was actually built it was checked for leaks, and while under a vacuum the dimensional changes in the width were recorded. The average value for the displacement was 0.122" in the areas where there were standard tube sections. Of the nine measurements most were around 0.130", but one was very low at 0.060". With this one removed the average displacement was 0.129". These two averages gave an error in the ANSYS model of 4% and 10%.

From an examination of the dimensions of the tube it appears that the average width at nine points before the vacuum was applied is 1.665", compared to the requested dimension of 1.66". Thus, it appears that there is little variance between what was modeled and what was built. However, other things may account for the displacement. The tube weld on the edges may be weaker than expected. Also, Young's Modulus for the material may not be 29, 000, 000 psi or the tube may not have a constant curvature in the camber, but rather a couple of flat sections with a bent area in between.

On a final examination of all of the simulations and the measurements from the actual beam tube it appears that the ANSYS models were quite accurate in predicting the displacement of the beam tube. Since the beam tube's stresses are based on the loads and the displacements, they should have a similar degree of accuracy, making this optimization technique quite useful for future work with beam tube sizing.

```
/com, cam - camber of large radius, thi - thickness of tube, Rad - large radius
/com, h - height of right side of tube, the - angle of large arc in rad
/com, deg - angle in degrees,  del - degrees per divisions, dis - displacement
/com, of camber

cam=0.08
thi=0.0625
h=0.75
rsm=.375
w=2.5

/com,Rad=((cam*cam)+9+(rsm*rsm)-(6*rsm))/(2*cam)
Rad=((cam*cam)+((w-rsm)*(w-rsm)))/(2*cam)
the=acos((Rad-cam)/Rad)
deg=(the/(2*3.141592652))*360
del=deg/13
dis=-((cam-(.789-h))+0.01)

/prep7
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kan,0
et,1,42
et,2,1
et,3,12,,,,1
mp,ex,1,29e6
mp,ex,2,100e7
r,3,0,10e9
r,2,1

n,1,,h+cam
n,3,,h+cam-thi
fill
local,11,1,0,-(rad-cam-h)
ngen,13,3,1,3,,,-del
csys
n,40,w-rsm,h
n,42,w-rsm,h-thi
fill
local,12,1,w-rsm,h-rsm
ngen,6,3,40,42,,,-18
csys
ngen,5,3,55,57,,,-(h-rsm)/4

/com, top plate
n,100,0,h+cam+0.01
n,113,w-rms,h+cam+0.01
fill
TYPE,1
MAT,1
e,1,2,5,4
e,2,3,6,5
egen,21,3,1,2

/com, top plate
type,2
mat,2
real,2
e,100,101
egen,13,1,49
```

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fini
```

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PARAMETER= THE      0.7526E-01
PARAMETER= DEG       4.312
PARAMETER= DEL      0.3317
PARAMETER= DIS     -0.5100E-01
```

THE FOLLOWING X,Y,Z DISPLACEMENTS ARE IN GLOBAL COORDINATES

NODE	UX	UY
1	0.00000000E+00	-0.58660898E-01
2	0.00000000E+00	-0.58665364E-01
3	0.00000000E+00	-0.58660551E-01
4	-0.16110167E-03	-0.58237922E-01
5	0.16540821E-06	-0.58243276E-01
6	0.16149188E-03	-0.58239446E-01
7	-0.30918307E-03	-0.56977738E-01
8	0.10037450E-04	-0.56985719E-01
9	0.32934392E-03	-0.56984803E-01
10	-0.43159605E-03	-0.54906585E-01
11	0.38890604E-04	-0.54918815E-01
12	0.50954625E-03	-0.54922624E-01
13	-0.51656516E-03	-0.52068176E-01
14	0.95259975E-04	-0.52086090E-01
15	0.70722193E-03	-0.52096247E-01
16	-0.55341361E-03	-0.48523699E-01
17	0.18636729E-03	-0.48548453E-01
18	0.92640152E-03	-0.48566310E-01
19	-0.53324600E-03	-0.44351766E-01
20	0.31799332E-03	-0.44384186E-01
21	0.11693457E-02	-0.44410749E-01
22	-0.44893157E-03	-0.39648427E-01
23	0.49366266E-03	-0.39688897E-01
24	0.14365601E-02	-0.39724754E-01
25	-0.29611281E-03	-0.34527086E-01
26	0.71485814E-03	-0.34575509E-01
27	0.17257964E-02	-0.34620731E-01
28	-0.72761562E-04	-0.29118466E-01
29	0.97970554E-03	-0.29174185E-01
30	0.20324828E-02	-0.29228335E-01
31	0.21933849E-03	-0.23570806E-01
32	0.12839696E-02	-0.23632331E-01
33	0.23482927E-02	-0.23694073E-01
34	0.57522733E-03	-0.18048485E-01
35	0.16183838E-02	-0.18114466E-01
36	0.26615962E-02	-0.18182640E-01
37	0.98681321E-03	-0.12737474E-01
38	0.19724700E-02	-0.12802245E-01
39	0.29582769E-02	-0.12871554E-01
40	0.14349408E-02	-0.78254676E-02
41	0.23282131E-02	-0.78235963E-02
42	0.32170189E-02	-0.78275242E-02
43	0.20220715E-02	-0.46777146E-02
44	0.27898137E-02	-0.49310670E-02
45	0.35548693E-02	-0.51919254E-02
46	0.34080976E-02	-0.21923267E-02
47	0.39764492E-02	-0.26086959E-02

48	0.45393335E-02	-0.30330784E-02
49	0.52114483E-02	-0.55749862E-03
50	0.55551302E-02	-0.10357928E-02
51	0.58896438E-02	-0.15197190E-02
52	0.70308980E-02	0.22434474E-03
53	0.71693481E-02	-0.21702469E-03
54	0.72974855E-02	-0.66143918E-03
55	0.85280441E-02	0.32880634E-03
56	0.85285487E-02	-0.58180180E-05
57	0.85184206E-02	-0.34471596E-03
58	0.93620321E-02	0.22021932E-03
59	0.93688192E-02	-0.35551575E-05
60	0.93641180E-02	-0.22695171E-03
61	0.98659293E-02	0.10950822E-03
62	0.98709845E-02	-0.20193294E-05
63	0.98649304E-02	-0.11337139E-03
64	0.10032527E-01	0.00000000E+00
65	0.10038068E-01	0.00000000E+00
66	0.10032434E-01	0.00000000E+00
100	0.00000000E+00	
101	0.00000000E+00	
102	0.00000000E+00	
103	0.00000000E+00	
104	0.00000000E+00	
105	0.00000000E+00	
106	0.00000000E+00	
107	0.00000000E+00	
108	0.00000000E+00	
109	0.00000000E+00	
110	0.00000000E+00	
111	0.00000000E+00	
112	0.00000000E+00	
113	0.00000000E+00	

MAXIMUMS

NODE	65	2
VALUE	0.10038068E-01	-0.58665364E-01

***** RUN COMPLETED ***** CP= 14.3400 TIME= 15.6160

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CPSIZE,22
cp,1,uy,100,101,102,103,104,105,106
cp,1,uy,107,108,109,110,111,112,113

/com,gap
type,3
real,3
e,1,100
e,4,101
e,7,102
e,10,103
e,13,104
e,16,105
e,19,106
e,22,107
e,25,108
e,28,109
e,31,110
e,34,111
e,37,112
e,40,113

d,64,uy,0,,66
d,1,ux,0,,3
/com, top plate
!d,100,ux,0,,,,uy,uz
!lwrite
!d,100,uy,dis/5
!iter,-10,0
!lwrite
!d,100,uy,dis*2/5
!iter,-10,0
!lwrite
!d,100,uy,dis*3/5
!iter,-10,0
!lwrite
!d,100,uy,dis*4/5
!iter,-10,0
!lwrite
!d,100,uy,dis
!iter,-10,0
!lwrite

iter,1,0
p,1,4,14.7,,61,3
/show,4211
LWRITE
afwrite
fini
/input,27
fini


/post1
!stress,volu
!set,7,1
!nsort,sige,
!*get,sige,max
!ssum
set,1,1
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