Fermilab

TTF Cryostat Modal Analysis

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Fermilab
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Introduction

This report summarizes a recent modal analysis of the TTF cryostat. The input geometry and component masses were provided by F. Alessandria (INFN-Milan) and represent the module cryostat being designed and built by E. Zanon Spa (Schio, Italy). Beams are used to simulate the suspension system components and the GHe return tube. Components which are supported by the tube, i.e. LHe vessels, quadrupole components, and module interconnections are modeled as lumped masses at the appropriate axial positions along the GHe tube. Components which connect at intermediate positions on the support posts, i.e. shields, insulation, and piping are ignored.

Geometry

Figure 1 is an isometric view of the cryostat beam model. Lumped masses are positioned along the length of the GHe tube as shown. The center support is assumed to be rigidly fixed at its 300K end. The outboard two supports are allowed to slide axially (x-direction) at their 300K ends to simulate the allowance for thermal contraction, but are fixed in all other directions. Figure 2 illustrates a detail of the support post and GHe return connections. The intermediate connections are included to accurately simulate the lever arm through which the weight of the GHe return tube and lumped masses act on the support posts.

Table 1 lists the positions and values of the masses supported by the GHe return. The total weight suspended from the GHe return tube is 11498 N. The weight of the GHe return tube is 5066 N (429.3 N/m). Table 2 lists

the positions of the support posts. Table 3 summarizes the material properties of the supports, intermediate connections, and GHe return tube.

Table 1 - Lumped mass positions	
x-pos (mm)	mass (N)
0.0	63
245.0	948
1045.0	415
1629.0	471
2429.8	462
3014.6	1000
3814.6	462
4399.4	470
5199.4	466
5782.2	1001
6584.2	462
7169.0	470
7969.0	462
8553.8	1000
9353.8	462
9938.6	470
10738.6	462
11296.3	1016
11601.3	873
11800.0	63

Table 2 - Support post positions	
support no.	x-pos (mm)
1	1696.0
2	6046.0
3	10414.0

Table 3 - Material properties			
	E (N/mm^2)	v	ρ (N/mm^3)
Supports	2.75E+04	0.2	1.89E-03 *
Connections	1.93E+05	0.3	0
GHe return	1.93E+05	0.3	7.75E-05

*: Equivalent density to account for weight of shield connection rings and disks.

Analysis

A finite element model was created with the referenced geometry and material properties (see Appendix 1). First a static analysis yielded

deflections due to the lumped masses and weight of the GHe return tube. Tables 4 and 5 list the vertical deflections of the GHe return tube and support post reaction forces from the static analysis. Figure 3 is a plot of the static analysis results.

Table 4 - Static analysis vertical GHe return tube deflections	
x-pos (mm)	y-defl (mm)
0.0	-0.222
245.0	-0.184
1045.0	-0.070
1629.0	-0.022
1696.0	-0.020
2429.8	-0.042
3014.6	-0.082
3814.6	-0.112
4399.4	-0.103
5199.4	-0.059
5782.2	-0.026
6046.0	-0.020
6584.2	-0.036
7169.0	-0.072
7969.0	-0.106
8553.8	-0.102
9353.8	-0.057
9938.6	-0.024
10414.0	-0.022
10738.6	-0.044
11296.3	-0.114
11601.3	-0.159
11800.0	-0.188

Table 5 - Static analysis support post vertical reaction forces	
support no.	reaction (N)
1	5312.5
2	5440.6
3	5810.7

Next a modal analysis was performed on the same geometry to extract all of the translational modes. The analysis was cut off at 100 Hz and yielded twelve resonant modes. The modes, frequencies, and deflection planes are summarized in table 6. Refer to figure 1 for axis orientations. The corresponding mode shapes are shown in figures 4 through 15.

Table 6 - Modal analysis results		
mode no.	frequency (Hz)	deflection plane
1	18.7	x-y
2	20.3	x-z
3	21.7	x-z
4	22.1	x-y
5	25.4	x-y
6	26.7	x-z
7	27.6	x-z
8	41.9	x-y
9	49.6	x-y
10	54.0	x-z
11	76.0	x-z
12	101.3	x-z

Summary

The tables and figures included in this report should be self-explanatory. The results from the static analysis are consistent with several other analyses performed during development of the suspension system design. Nearly all of the first twelve modes are associated with flexure of the GHe return tube. The exception is mode 6 at 26.7 Hz. This mode is almost exclusively associated with lateral deflection of the support posts and is consistent with an earlier detailed analysis of the support which predicted a lateral natural frequency of 25 Hz. Note that deflections are not relevant in the modal analysis, only the mode shapes themselves. It is possible to determine deflections at resonance only with a specific input load spectrum.

References

1. T. Nicol, "TESLA Test Cell Cryostat - Support Post Thermal and Structural Analysis", TESLA Report 94-01.

2. T. Nicol, "TESLA Test Facility Cryostat - Gas Helium Return Tube Thermal Gradient Analysis", TESLA Report 94-12.

3. F. Alessandria, FAX communication, Nov 21, 1994.

List of figures

Appendix 1

Finite element modal analysis input file (ANSYS version 4.4a)

```
/prep7
/title,TTF cryostat modal analysis: Nov 1994
c***
c***  Filename: ttf_modal.026
c***
c***  Modal analysis of the TTF baseline cryostat design.  Input is from
c***  F. Alessandria.
c***
/show,x11,,1
tdbc,1
rdbc,1
c***
c***  Define analysis type  ****
c***
kan,2
c***
c***  Define element types  ****
c***
et,1,4  * 3-d elastic beams...
et,2,21,,,2  * 3-d masses w/out rotational inertia...
c***
c***  Define material properties  ****
c***
ex,1,27.5e+03   * frp composite (N/mm2)...
nuxy,1,0.2
dens,1,1.9219e-07 * equiv density to acct for rings and discs..
ex,2,193.0e+03  * stainless steel (N/mm2)...
nuxy,2,0.3
dens,2,7.8929e-09
ex,3,193.0e+03  * stainless steel for rigid links (dens=0) (N/mm2)...
nuxy,3,0.3
c***
c***  Define variable parameters  ****
c***
c***  x-positions  ****
c***
x1=0.0
x2=245.0
x3=1045.0
x4=1629.0
x5=1696.0
x6=2429.8
x7=3014.6
x8=3814.6
x9=4399.4
x10=5199.4
x11=5782.2
x12=6046.0
x13=6584.2
```

```
x14=7169.0
x15=7969.0
x16=8553.8
x17=9353.8
x18=9938.6
x19=10414.0
x20=10738.6
x21=11296.3
x22=11601.3
x23=11800.0
c***
c*** y-positions ****
c***
y1=0.0
y2=-122.0
y3=y2-150.0
c***
c*** lumped masses ****
c***
g=9.8146e+03
m1=63.0/g
m2=948.0/g
m3=415.0/g
m4=471.0/g
m5=462.0/g
m6=1000.0/g
m7=462.0/g
m8=470.0/g
m9=466.0/g
m10=1001.0/g
m11=462.0/g
m12=470.0/g
m13=462.0/g
m14=1000.0/g
m15=462.0/g
m16=470.0/g
m17=462.0/g
m18=1016.0/g
m19=873.0/g
m20=63.0/g
c***
c*** Define real constants (units are mm2, mm4, mm) ****
c***
r.1,m1  * lumped masses...
r.2,m2
r.3,m3
r.4,m4
r.5,m5
r,6,m6
r,7,m7
r,8,m8
r,9,m9
r,10,m10
r,11,m11
```

```
r,12,m12
r,13,m13
r,14,m14
r,15,m15
r,16,m16
r,17,m17
r,18,m18
r,19,m19
r,20,m20
r,21,1240.6,13.8e+06,13.8e+06,300.0,300.0,0.0  * supports (A, Izz, Iyy, Tkz, Tky)...
rmore,,,4.0,4.0
r,22,5541.8,59.9e+06,59.9e+06,300.0,300.0,0.0  * GHe tube...
c***
c*** Define nodes (locations in mm) ****
c***
csys,0
c***
c*** Support post bottom and top  ****
c***
c*** Post warm end  ****
c***
n,5,x5,y1
n,12,x12,y1
n,19,x19,y1
c***
c*** Post cold end  ****
c***
n,105,x5,y2
n,112,x12,y2
n,119,x19,y2
c***
c*** GHe return  ****
c***
n,201,x1,y3,0.0
n,202,x2,y3,0.0
n,203,x3,y3,0.0
n,204,x4,y3,0.0
n,205,x5,y3,0.0
n,206,x6,y3,0.0
n,207,x7,y3,0.0
n,208,x8,y3,0.0
n,209,x9,y3,0.0
n,210,x10,y3,0.0
n,211,x11,y3,0.0
n,212,x12,y3,0.0
n,213,x13,y3,0.0
n,214,x14,y3,0.0
n,215,x15,y3,0.0
n,216,x16,y3,0.0
n,217,x17,y3,0.0
n,218,x18,y3,0.0
n,219,x19,y3,0.0
n,220,x20,y3,0.0
n,221,x21,y3,0.0
```

```
n,222,x22,y3,0.0
n,223,x23,y3,0.0
c***
c*** Define elements ****
c***
c*** Posts ****
c***
type,1
mat,1
real,21
e,5,105
e,12,112
e,19,119
c***
c*** Rigid links ****
c***
type,1
mat,3
real,22
e,105,205
e,112,212
e,119,219
c***
c*** GHe return ****
c***
type,1
mat,2
real,22
e,201,202
egen,22,1,-1
c***
c*** Lumped masses ****
c***
type,2
real,1
e,201
real,2
e,202
real,3
e,203
real,4
e,204
real,5
e,206
real,6
e,207
real,7
e,208
real,8
e,209
real,9
e,210
real,10
e,211
```

```
real,11
e,213
real,12
e,214
real,13
e,215
real,14
e,216
real,15
e,217
real,16
e,218
real,17
e,220
real,18
e,221
real,19
e,222
real,20
e,223
c***
c*** Reorder wavefront ****
c***
wsort,x,0
c***
c*** Define displacement constraints ****
c***
d,5,uy,0.0
d,5,uz,0.0
d,5,rotx,0.0
d,5,roty,0.0
d,5,rotz,0.0
d,12,ux,0.0
d,12,uy,0.0
d,12,uz,0.0
d,12,rotx,0.0
d,12,roty,0.0
d,12,rotz,0.0
d,19,uy,0.0
d,19,uz,0.0
d,19,rotx,0.0
d,19,roty,0.0
d,19,rotz,0.0
c***
c*** Define load step info ****
c***
kay,2,12
kay,3,-1
m.201,ux,223,1,uy,uz
iter,1,1,1
```

List of figures

Appendix 1

Finite element modal analysis input file (ANSYS version 4.4a)

```
/prep7
/title,TTF cryostat modal analysis: Nov 1994
c***
c*** Filename: ttf_modal.026
c***
c*** Modal analysis of the TTF baseline cryostat design.  Input is from
c*** F. Alessandria.
c***
/show,x11,,1
tdbc,1
rdbc,1
c***
c*** Define analysis type ****
c***
kan,2
c***
c*** Define element types ****
c***
et,1,4  * 3-d elastic beams...
et,2,21,,,2  * 3-d masses w/out rotational inertia...
c***
c*** Define material properties ****
c***
ex,1,27.5e+03   * frp composite (N/mm2)...
nuxy,1,0.2
dens,1,1.9219e-07  * equiv density to acct for rings and discs..
ex,2,193.0e+03  * stainless steel (N/mm2)...
nuxy,2,0.3
dens,2,7.8929e-09
ex.3,193.0e+03  * stainless steel for rigid links (dens=0) (N/mm2)...
nuxy,3,0.3
c***
c*** Define variable parameters ****
c***
c*** x-positions ****
c***
x1=0.0
x2=245.0
x3=1045.0
x4=1629.0
x5=1696.0
x6=2429.8
x7=3014.6
x8=3814.6
x9=4399.4
x10=5199.4
x11=5782.2
x12=6046.0
x13=6584.2
```

```
x14=7169.0
x15=7969.0
x16=8553.8
x17=9353.8
x18=9938.6
x19=10414.0
x20=10738.6
x21=11296.3
x22=11601.3
x23=11800.0
c***
c*** y-positions ****
c***
y1=0.0
y2=-122.0
y3=y2-150.0
c***
c*** lumped masses ****
c***
g=9.8146e+03
m1=63.0/g
m2=948.0/g
m3=415.0/g
m4=471.0/g
m5=462.0/g
m6=1000.0/g
m7=462.0/g
m8=470.0/g
m9=466.0/g
m10=1001.0/g
m11=462.0/g
m12=470.0/g
m13=462.0/g
m14=1000.0/g
m15=462.0/g
m16=470.0/g
m17=462.0/g
m18=1016.0/g
m19=873.0/g
m20=63.0/g
c***
c*** Define real constants (units are mm2, mm4, mm) ****
c***
r,1,m1  * lumped masses...
r,2,m2
r,3,m3
r,4,m4
r,5,m5
r,6,m6
r,7,m7
r,8,m8
r,9,m9
r,10,m10
r,11,m11
```

2

```
r,12,m12
r,13,m13
r,14,m14
r,15,m15
r,16,m16
r,17,m17
r,18,m18
r,19,m19
r,20,m20
r,21,1240.6,13.8e+06,13.8e+06,300.0,300.0,0.0  * supports (A, Izz, Iyy, Tkz, Tky)...
rmore,,,4.0,4.0
r,22,5541.8,59.9e+06,59.9e+06,300.0,300.0,0.0  * GHe tube...
c***
c*** Define nodes (locations in mm) ****
c***
csys,0
c***
c*** Support post bottom and top  ****
c***
c*** Post warm end  ****
c***
n,5,x5,y1
n,12,x12,y1
n,19,x19,y1
c***
c*** Post cold end  ****
c***
n,105,x5,y2
n,112,x12,y2
n,119,x19,y2
c***
c*** GHe return  ****
c***
n,201,x1,y3,0.0
n,202,x2,y3,0.0
n,203,x3,y3,0.0
n,204,x4,y3,0.0
n,205,x5,y3,0.0
n,206,x6,y3,0.0
n,207,x7,y3,0.0
n,208,x8,y3,0.0
n,209,x9,y3,0.0
n,210,x10,y3,0.0
n,211,x11,y3,0.0
n,212,x12,y3,0.0
n,213,x13,y3,0.0
n,214,x14,y3,0.0
n,215,x15,y3,0.0
n,216,x16,y3,0.0
n,217,x17,y3,0.0
n,218,x18,y3,0.0
n,219,x19,y3,0.0
n,220,x20,y3,0.0
n,221,x21,y3,0.0
```

```
n,222,x22,y3,0.0
n,223,x23,y3,0.0
c***
c*** Define elements ****
c***
c*** Posts ****
c***
type,1
mat,1
real,21
e,5,105
e,12,112
e,19,119
c***
c*** Rigid links ****
c***
type,1
mat,3
real,22
e,105,205
e,112,212
e,119,219
c***
c*** GHe return ****
c***
type,1
mat,2
real,22
e,201,202
egen,22,1,-1
c***
c*** Lumped masses ****
c***
type,2
real,1
e,201
real,2
e,202
real,3
e.203
real,4
e,204
real,5
e,206
real.6
e,207
real.7
e,208
real.8
e,209
real,9
e,210
real.10
e,211
```

```
real,11
e,213
real,12
e,214
real,13
e,215
real,14
e,216
real,15
e,217
real,16
e,218
real,17
e,220
real,18
e,221
real,19
e,222
real,20
e,223
c***
c*** Reorder wavefront ****
c***
wsort,x,0
c***
c*** Define displacement constraints ****
c***
d,5,uy,0.0
d,5,uz,0.0
d,5,rotx,0.0
d,5,roty,0.0
d,5,rotz,0.0
d,12,ux,0.0
d,12,uy,0.0
d,12,uz,0.0
d,12.rotx,0.0
d,12,roty,0.0
d,12.rotz,0.0
d,19.uy,0.0
d,19.uz,0.0
d,19.rotx,0.0
d,19,roty,0.0
d,19.rotz,0.0
c***
c*** Define load step info ****
c***
kay,2,12
kay,3,-1
m,201,ux,223,1,uy,uz
iter,1,1,1
```

Figure 1: Isometric view of beam model

Vacuum vessel connection

Support post

Intermediate connection

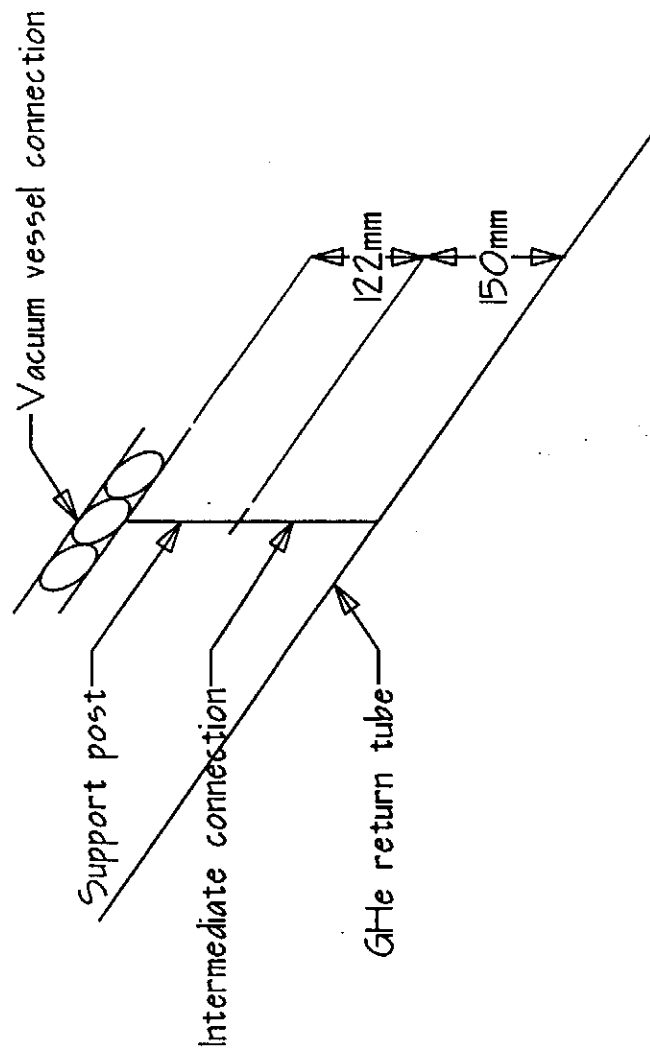GHe return tube

122mm

150mm

Figure 2: Detailed view of support post and GHe return connection

ANSYS   4.4A
NOV 29 1994
  9:02:46
PLOT NO.   1
POST1 DISPL.
STEP=1
ITER=1
DMX =0.221762

DSCA=2927
ZV =1
DIST=6490
XF =5900
YF =-136

TTF cryostat static analysis: Nov 1994

Figure 3:
Static analysis deflection plot

ANSYS   4.4A
DEC 1 1994
 9:00:52
PLOT NO.   1
POST1 DISPL.
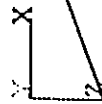STEP=1
ITER=1
FREQ=18.704
DMX =1.34

DSCA=484.262
ZV =1
DIST=6490
XF =5900
YF =-136

Figure 4:
Mode shape 1

TTF cryostat modal analysis: Nov 1994

ANSYS 4.4A
DEC 1 1994
9:00:54
PLOT NO. 2
POST1 DISPL.
STEP=1
ITER=2
FREQ=20.347
DMX =1

DSCA=649
YV =1
DIST=6490
XF =5900
YF =-136

Figure 5:
Mode shape 2

TTF cryostat modal analysis: Nov 1994

ANSYS   4.4A
DEC 1 1994
   9:00:54
PLOT NO.   3
POST1 DISPL.
STEP=1
ITER=3
FREQ=21.724
DMX =1

DSCA=649
YV =1
DIST=6490
XF =5900
YF =-136

Figure 6:
Mode shape 3

TTF cryostat modal analysis: Nov 1994

ANSYS 4.4A
DEC 1 1994
9:00:54
PLOT NO. 4
POST1 DISPL.
STEP=1
ITER=4
FREQ=22.138
DMX =1.015

DSCA=639.233
ZV =1
DIST=6490
XF =5900
YF =-136

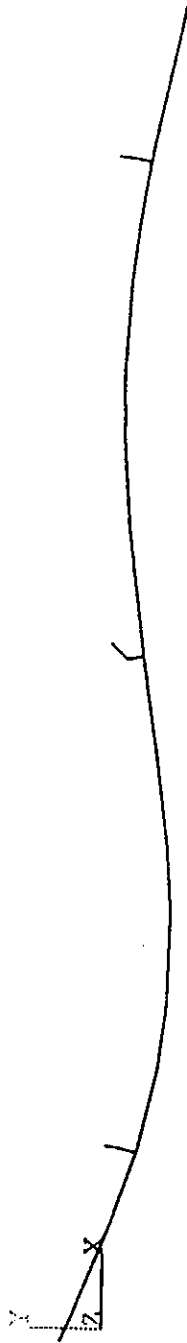TTF cryostat modal analysis: Nov 1994

Figure 7:
Mode shape 4

ANSYS 4.4A
DEC 1 1994
  9:00:54
PLOT NO.   5
POST1 DISPL.
STEP=1
ITER=5
FREQ=25.38
DMX =1

DSCA=648.716
ZV   =1
DIST=6490
XF   =5900
YF   =-136

Figure 8:
Mode shape 5

TTF cryostat modal analysis: Nov 1994

ANSYS   4.4A
DEC 1 1994
  9:00:54
PLOT NO.   6
POST1 DISPL.
STEP=1
ITER=6
FREQ=26.731
DMX =1

DSCA=649
YV =1
DIST=6490
XF =5900
YF =-136

Figure 9:
Mode shape 6

TTF cryostat modal analysis: Nov 1994

ANSYS 4.4A
DEC 1 1994
9:00:54
PLOT NO. 7
POST1 DISPL.
STEP=1
ITER=7
FREQ=27.635
DMX =1

DSCA=649
YV =1
DIST=6490
XF =5900
YF =-136

Figure 10:
Mode shape 7

TTF cryostat modal analysis: Nov 1994

ANSYS   4.4A
DEC   1 1994
9:00:54
PLOT NO.   8
POST1 DISPL.
STEP=1
ITER=8
FREQ=41.929
DMX =1.001

DSCA=648.63
ZV   =1
DIST=6490
XF =5900
YF =-136

Figure 11:
Mode shape 8

TTF cryostat modal analysis: Nov 1994

ANSYS 4.4A
DEC 1 1994
9:00:54
PLOT NO. 9
POST1 DISPL.
STEP=1
ITER=9
FREQ=49.587
DMX =1

DSCA=649
ZV =1
DIST=6490
XF =5900
YF =-136
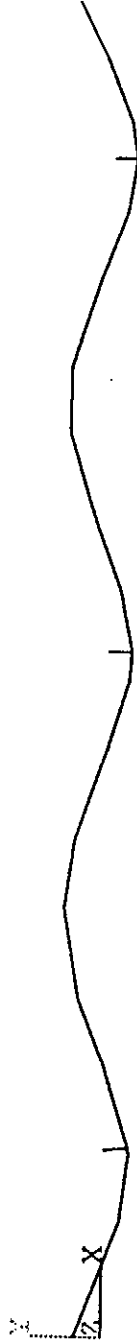
Figure 12:
Mode shape 9

TTF cryostat modal analysis: Nov 1994

ANSYS   4.4A
DEC 1 1994
  9:00:54
PLOT NO. 10
POST1 DISPL.
STEP=1
ITER=10
FREQ=54.004
DMX =1

DSCA=649
YV =1
DIST=6490
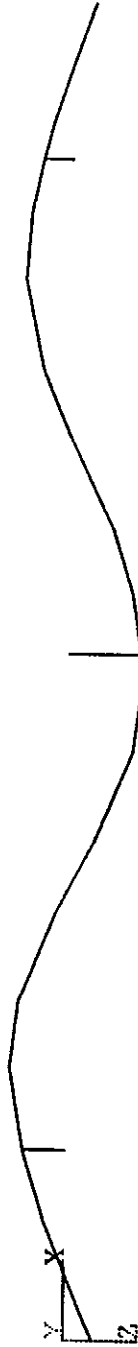XF =5900
YF =-136

TTF cryostat modal analysis: Nov 1994

Figure 13:
Mode shape 10

ANSYS 4.4A
DEC 1 1994
9:00:56
PLOT NO. 11
POST1 DISPL.
STEP=1
ITER=11
FREQ=75.976
DMX =1

DSCA=649
YV =1
DIST=6490
XF =5900
YF =-136

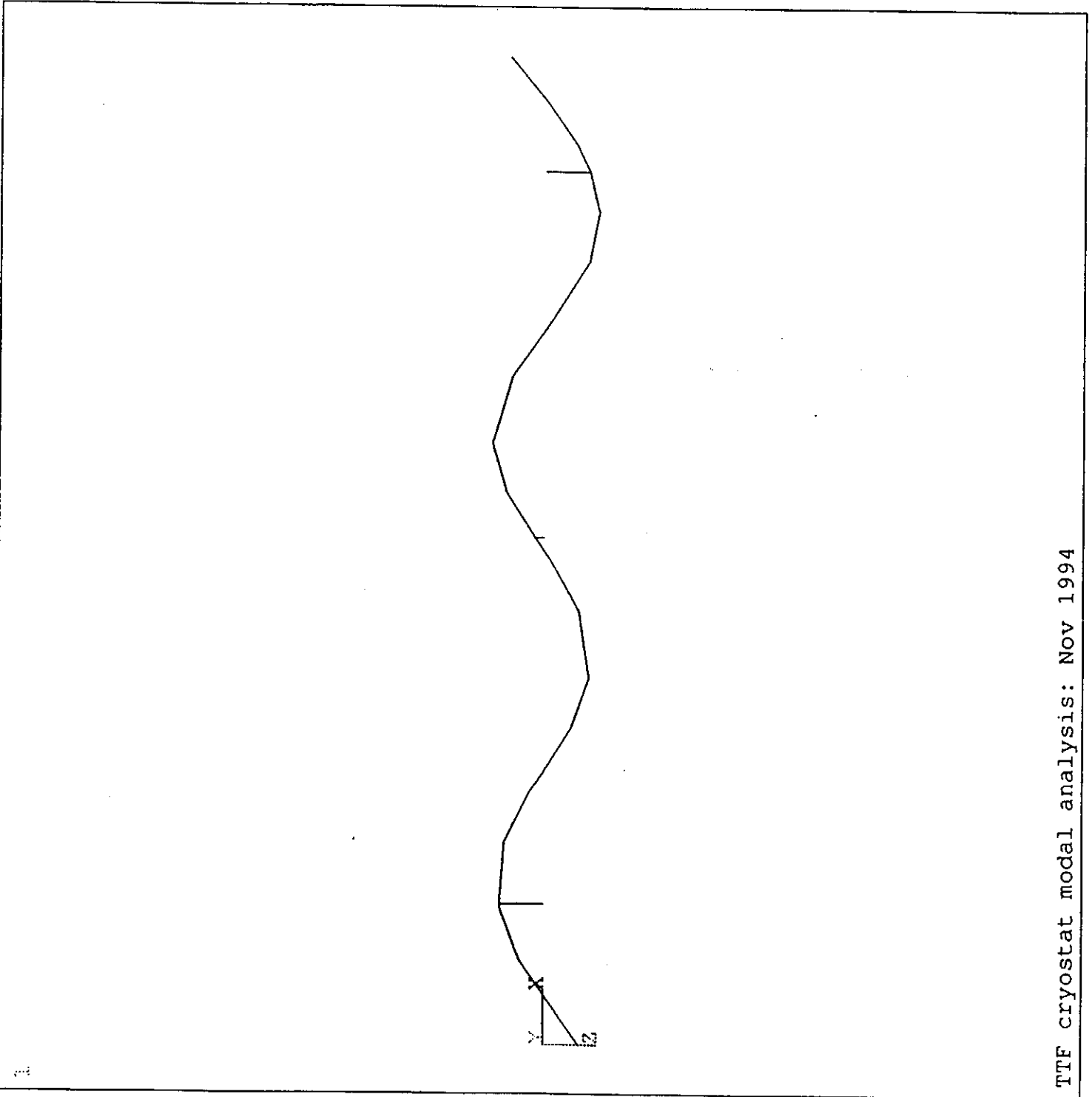TTF cryostat modal analysis: Nov 1994

Figure 14:
Mode shape 11

ANSYS 4.4A
DEC 1 1994
9:00:56
PLOT NO. 12
POST1 DISPL.
STEP=1
ITER=12
FREQ=101.347
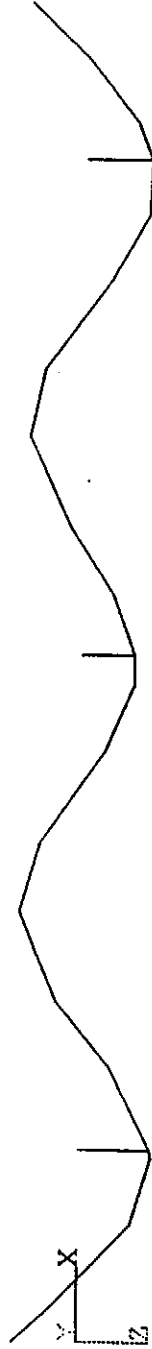DMX =1

DSCA=649
YV =1
DIST=6490
XF =5900
YF =-136

TTF cryostat modal analysis: Nov 1994

Figure 15:
Mode shape 12