13.0 Cryostat Eddy Current Analysis

There is a concern that pulsing the magnet can induce eddy currents in the shells sufficient to cause a significant load. The eddy currents coupled with the large bore field, may significantly load the bore vacuum jacket. In addition the flut plenum plate does not have a curvature to stabilize it and would see bending stresses rather than hoop membrane stresses. To address this concern, an electromagnetic transient analysis was performed. The solution is a vector potential solution, that traces the current history at the right. The worst point will be the beginning of the ramp-down. An additional concern is the field loss due to the opposed currents in the bore shells, but this field loss is of the order of a few milli-Tesla. Stress Levels also turned out minor – of order 2 MPa. The ANSYS Input listing is included at the end of this section.

### Resistivity Values for Metals

<table>
<thead>
<tr>
<th>%IACS</th>
<th>Ohm-m</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFHC Copper</td>
<td>100</td>
<td>1.7074e-8</td>
</tr>
<tr>
<td>Stainless Steel 316</td>
<td>74e-8</td>
<td>MHASM1</td>
</tr>
</tbody>
</table>

Bob Weggel’s 10-14 analysis of the LN2 magnet operation

Structural Mode (Sub-Set of E-M Model) shown with Coils that are removed for structural analysis. The upper plot is the 30 degree cyclic symmetry model, below is a 7 segment symmetry expansion.

Electromagnetic Model with Air

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BSUM (Total Field) through Structural Elements

Eddy Currents At Max Stress Point. –Actually During Ramp-Down
Eddy Current Forces During Ramp-Up

Eddy Current Forces During Ramp-Down
Cryostat Eddy Current Analysis – Stress Pass

The nodal Lorentz forces are produced in the electromagnetic run and can be read into the structural model with an LDREAD ANSYS command. This was done. \( j \times B \times r \) should give an estimate of the hoop stress in any of the cryostat shells. With current densities of .2MA/m^2 and fields of 10 Tesla, and radii of .1 to .5 meters, the hoop stress should be only .2MPa. The peak stress is a bending stress and occurs in the plenum plate.

Structural Response to Eddy Currents. External Vacuum Jacket is only .5mm thick and will have to be made thicker. The internal Vacuum Jacket is loaded in hoop and axial Compression, and will have to be checked for buckling.
/batch
run=06
/com
/com

! CREATE BASE ELECTROMAGNETIC SOLUTION
/filnam,elect
/PREP7
antype,trans
/COM 11-25-98 Electrical/Thermal
analysis
ET,1,97,1 ! (Ax, Ay, Az, VOLT) EM for current regions
ET,2,97,0 ! (Ax, Ay, Az) EM for air
ET,3,97,0 ! (Ax, Ay, Az) EM for air
TREF,292.0
*create,matt
/COM MAT,1 Coil
/COM MAT,3 Coil
/COM MAT,5 Coil
/COM MAT,2 Channel
/COM MAT,4 Channel
/COM MAT,6 Channel
/COM MAT,7 Bore tube
/COM MAT,10
cpackf=.9
mp,dens,1,8950
mp,dens,2,8950
mp,dens,3,8950
mp,dens,4,8950
mp,dens,5,8950
mp,dens,6,8950
mp,dens,7,4000
mp,dens,90,0.0000001
mp,dens,91,0.0000001
mp,dens,92,0.0000001
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mp,murx,2,1.0
mp,murx,3,1.0
mp,murx,4,1.0
mp,murx,5,1.0
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mp,murx,92,1.0
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mp,kxx,5,1
mp,kxx,6,1
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mp,rsvx,2,0.0
mp,rsvx,3,0.0
mp,rsvx,4,0.0
mp,rsvx,5,0.0
mp,rsvx,6,0.0
mp,rsvx,7,0.0 ! G-10 Bore liner
mp,rsvx,8,74e-8
mp,rsvx,9,74e-8
mp,rsvx,10,74e-8
mp,rsvx,11,74e-8
mp,rsvx,12,74e-8
mp,rsvx,13,74e-8
mp,rsvx,14,74e-8
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mp,rsvx,91,0.0
mp,rsvx,92,0.0
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mp,c,2,100
mp,c,3,100
mp,c,4,100
mp,c,5,100
mp,c,6,100
mp,c,7,100
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mp,c,14,100
mp,c,15,100
mp,c,90,1.0
mp,c,91,1.0
mp,c,92,1.0
mp,c,93,0.0
mp,c,94,74e-8
mp,c,95,74e-8
mp,c,96,74e-8
mp,c,97,74e-8
mp,c,98,74e-8
mp,c,99,74e-8
mp,c,100,74e-8
mp,c,101,0.0
mp,c,102,0.0
mp,rsvx,1,0.0
mp,rsvx,2,0.0
mp,rsvx,3,0.0
mp,rsvx,4,0.0
mp,rsvx,5,0.0
mp,rsvx,6,0.0
mp,rsvx,7,0.0 ! G-10 Bore liner
mp,rsvx,8,74e-8
mp,rsvx,9,74e-8
mp,rsvx,10,74e-8
mp,rsvx,11,74e-8
mp,rsvx,12,74e-8
mp,rsvx,13,74e-8
mp,rsvx,14,74e-8
mp,rsvx,15,74e-8
mp,rsvx,90,0.0
mp,rsvx,91,0.0
mp,rsvx,92,0.0
*create,matt
/COM MAT,1 Coil
/COM MAT,3 Coil
/COM MAT,5 Coil
/COM MAT,2 Channel
/COM MAT,4 Channel
/COM MAT,6 Channel
/COM MAT,7 Bore tube
/COM MAT,10
cpackf=.9
*use,matt
/com
/input,vma6,mod
/com
/nall
eall
csys,12
esys,12
/com Coupled Flux Condition
esel,type,1
nelem
mrsel,y,16,-14
d,all,vol,0.0
esel,type,1
nelem
mrsel,y,14,16
d,all,vol,0.0
nall
eall
csys,0
Wsort,x
Wsort,y
LOCAL,12,1,0,0,0,-90.0,0.0
CSYS,12 $ROTAT,all
esys,12
/nall
eall
csys,0
Wsort,x
Wsort,y
Transient Current Parameters

t1= 0.10000   $i1= 10.0    $p1= .01e6

t2= 1.00000    $i2= 800.0    $p2= 1.0e6

t3= 2.00000    $i3= 2000.0    $p3= 1.0e6

t4= 3.00000    $i4= 3100.0     $p4= 1.5e6

t5= 4.00000    $i5= 4000.0     $p5= 1.0e6

t6= 5.00000    $i6= 4900.0     $p6= .5e6

t7= 6.00000    $i7= 5650.0     $p7= .001e6

t8= 7.00000    $i8= 6200.0     $p8= 0.0e6

t9= 8.00000    $i9= 6700.0     $p9= 0.0e6

t10=9.00000    $i10= 7050.0     $p10= 0.0e6

! SETUP TRANSIENT MACRO
*create,load

csys,0
curd= i%ls%*6375
esel,mat, 1

easel,mat, 3
easel,mat, 5
bfe,all,jis,1,0,0,curd
eall
nall
solve
save

*do,ldnum,1,15
ldread,forc,ldnum,,,,elect,rst

eusel,mat,90
eusel,mat,91
eusel,mat,92
eusel,mat,1
eusel,mat,2
eusel,mat,3
eusel,mat,4
eusel,mat,5
eusel,mat,7
nelem

solve
save

*end

! START TRANSIENT

*/exit
Cryostat Eddy Current Analysis – Temperature Pass

Heat-up due to the eddy current loading on the cryostat produces less than 1 degree K