Recent Experience in the Mechanical Design of a Halfwave Resonator

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on behalf of the ANL Linac Development Group

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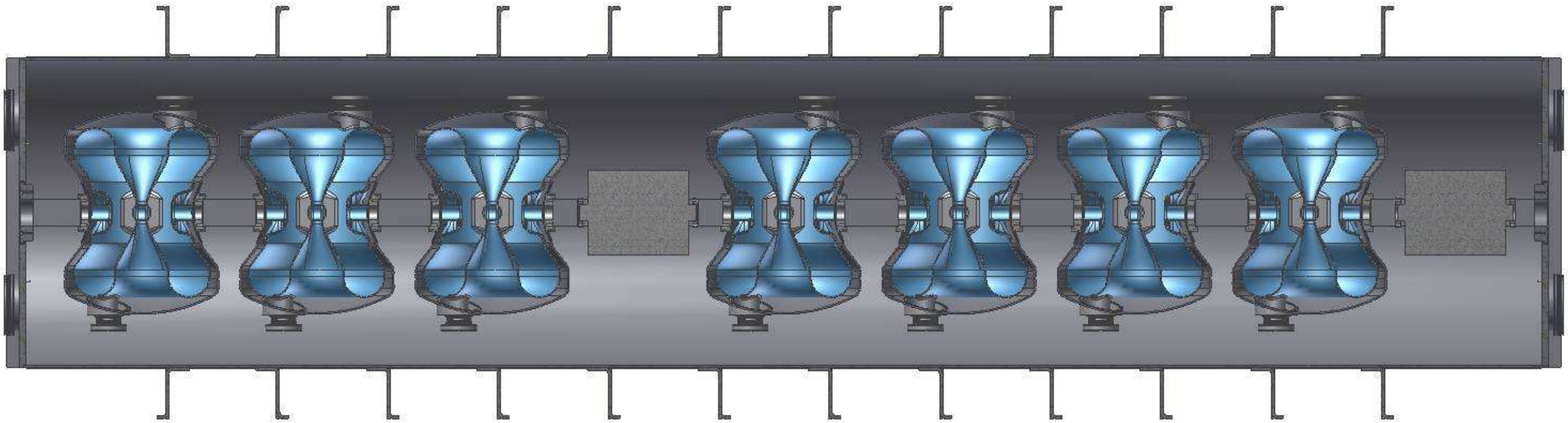
Outline

- Project Description: Design a Halfwave Cavity For MSU-FRIB
- RF Performance Preservation Checks
- Design Parameters and Criteria
- Cavity Mechanical Design

S.S. Helium Jacket
S.S. Flanges
Nb Cavity

A Halfwave Cavity for MSU-FRIB



Lattice β ~ 0.29	# of Cryos	# of Cavities /Cryo	# of Cavities	Cryo Length (m)	Section Length (m)	W-in (MeV/u)	W-out (MeV/u)
Existing	13	6	78	3.6007	51.7491	16.3	54.6
Proposed	8	7	56	4.0648	35.5584	16.3	55.8

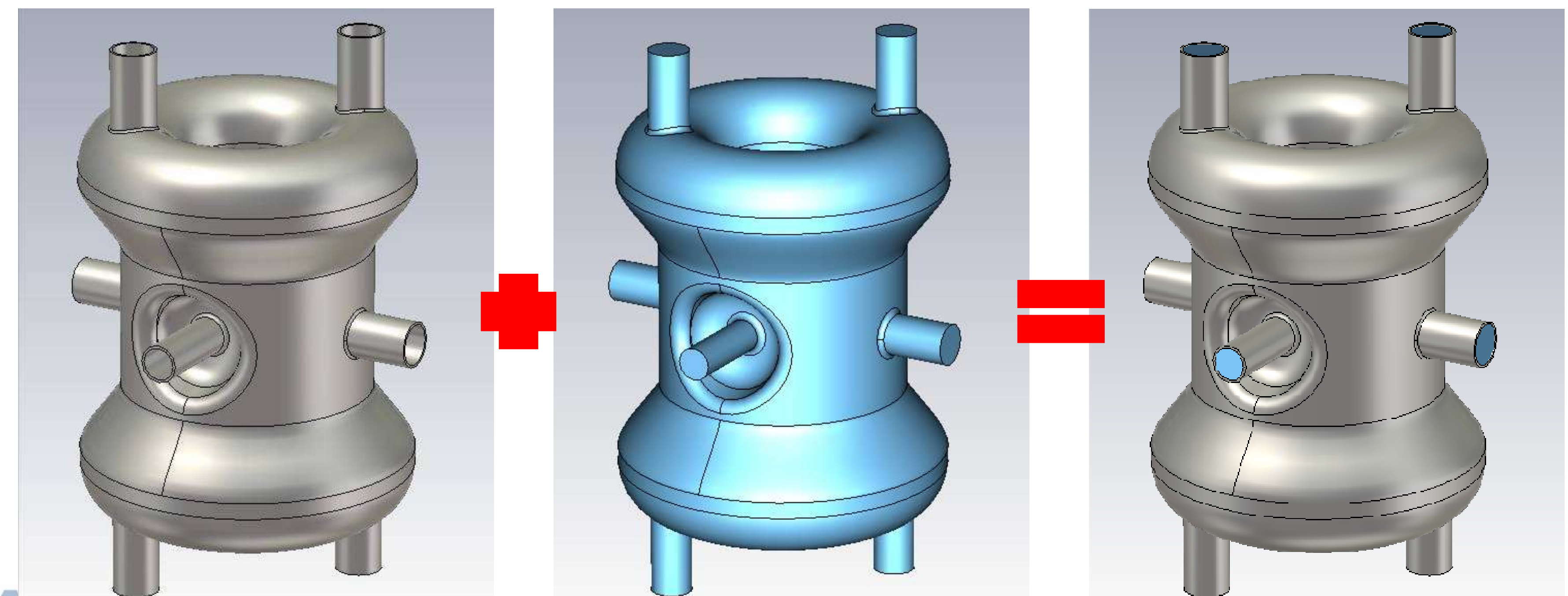
- The cavity mechanical design was part of a work-for-others project with MSU-FRIB.
- MSU asked us to design a 322 MHz cavity and accelerator lattice for β ~ 0.29 ions.

Model RF Check

Checks are performed throughout the modeling process. Models from both Autodesk Inventor and ANSYS are exported to MWS and checked to ensure we have not changed the model.

Example Inventor Check

	MWS-Original	MWS-Inventor
Frequency (MHz)	321.014	320.921
β	0.288	0.288
E_{pk}/E_{acc}	4.5	4.5
B_{pk}/E_{acc} (mT/(MV/m))	10.4	9.6
$G = R_sQ$ (Ω)	97	97
R_{sh}/Q (Ω)	194	194



Material Properties & Design Parameters Used Here

Material	Young's Modulus (KSI)	Poisson's Ratio	Density (lbs/in^3)	Maximum Allowable Stress (KSI)
Niobium	14,900	0.395	0.3096	7.0
304 Stainless Steel	29,000	0.270	0.286	20,000
Titanium, Grade 2	16,600	0.300	0.164	20,000

- Cavities designed with linear room temperature parameters
- Our parameter choices here are based upon extensive Argonne experience
- We will use the parameters put forth in the FNAL Technical Division Technical Note TD-09-005 for the design of the 162.5 MHz $\beta = 0.11$ halfwave resonator

Mechanical Design

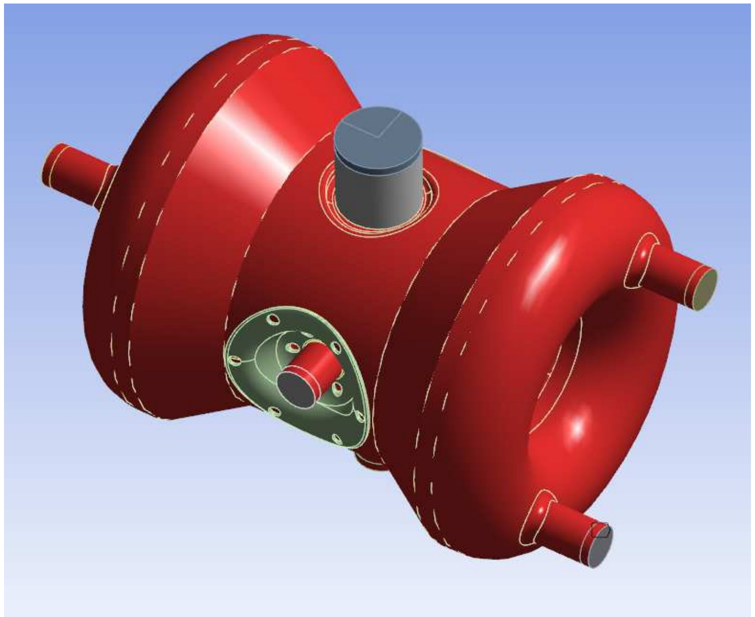
- Start with an RF volume from MWS
- Build the niobium cavity around the MWS vacuum model
- Build an integral 304 stainless steel helium jacket around the niobium cavity
- This model is used for:
  - Fabrication
  - Base Mechanical Model
- The models do get simplified to reduce the mesh size in ANSYS
  - Small features get removed or filled in
  - The niobium cavity is modeled in two pieces: the cavity and the reentrant nose doubler
- Design to:
  - Minimize microphonics, e.g., zero df/dP
  - Maximize slow tuner range
  - Maximize fast tuner range

$$\Delta f \propto \int_{\Delta V} \left[\mu_0 \left| \vec{H}_0(\vec{x}) \right|^2 - \varepsilon_0 \left| \vec{E}_0(\vec{x}) \right|^2 \right] d^3x$$

Early Modeling

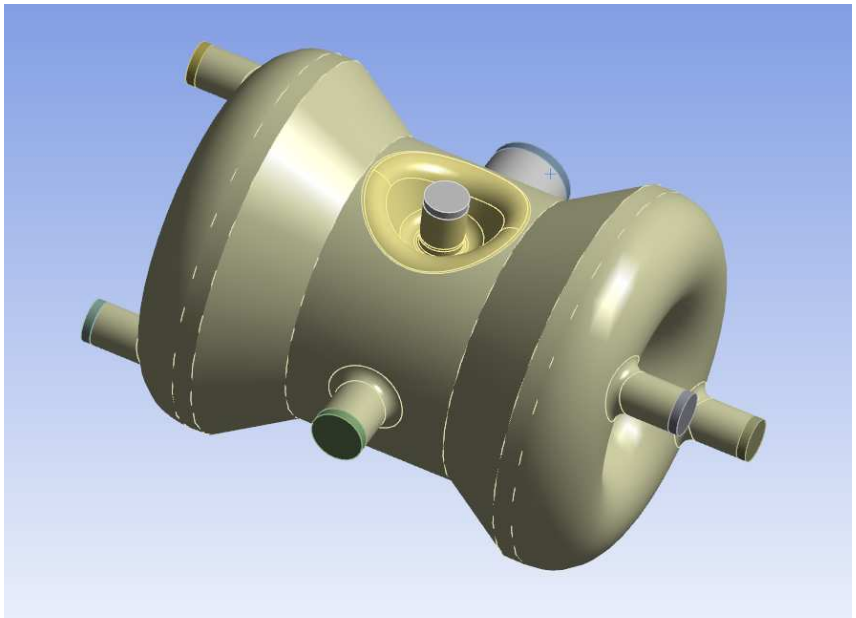
Initial Results

With Reentrant Nose Doublers



f1	320399114	Hz
f2	320382028	Hz
df/dp	-17.086	KHz/atm

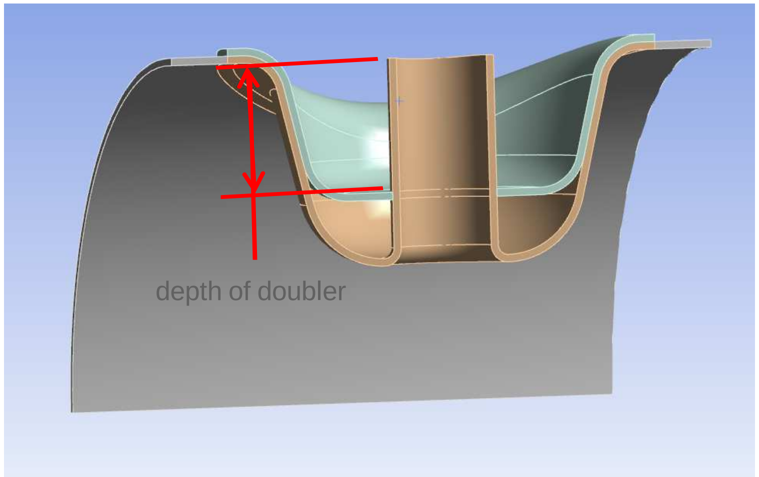
Without Reentrant Nose Doublers



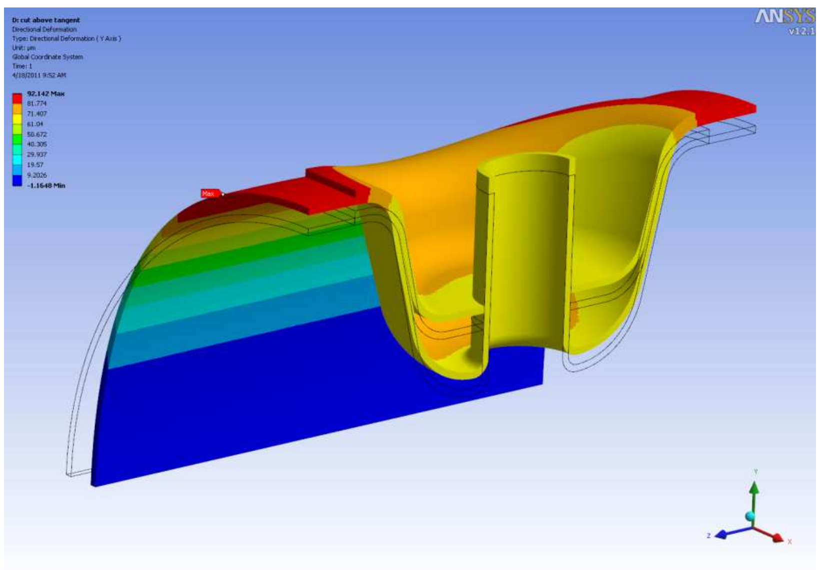
f1	320399114	Hz
f2	320361833	Hz
df/dp	-37.281	KHz/atm

- The single largest contribution to df/dP came from the cavity reentrant noses being squeezed. We optimized the doubler plate depth.
- Found that no reinforcing ribs were required on the toroids, the high magnetic field region

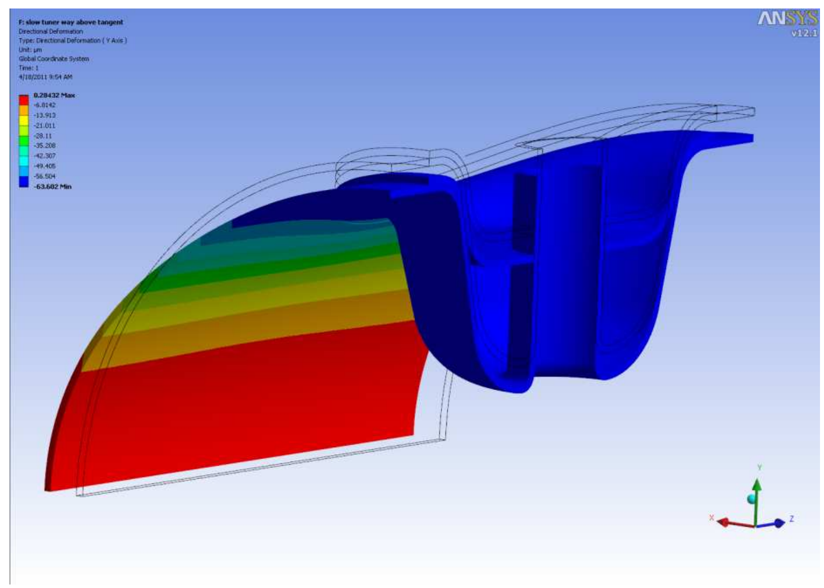
Reentrant Nose Depth Study



Depth of Doubler cm	Y Deflection @ 1 atm. microns	Y Deflection @ 100 N Slow Tuner Force microns
7.4825	74.51	-62.2
5.6825	70.72	-62.3
3.1825	61.82	-63.6



Y deflection at 1 atm.



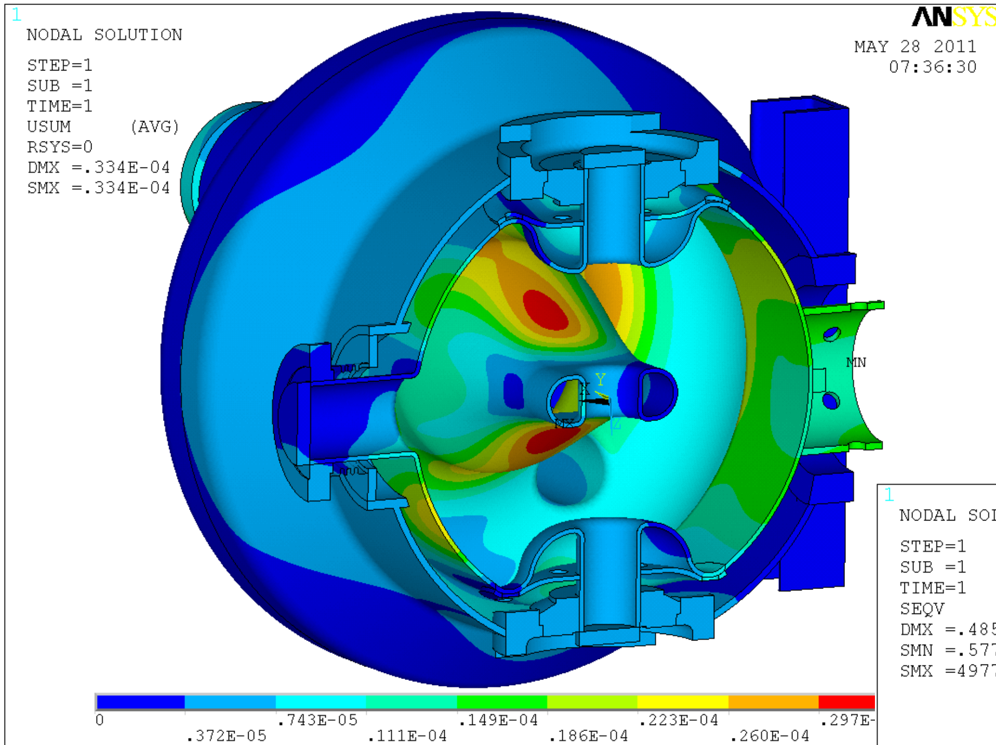
Y deflection at 100 N Slow Tuner Load

Final Cavity Geometry

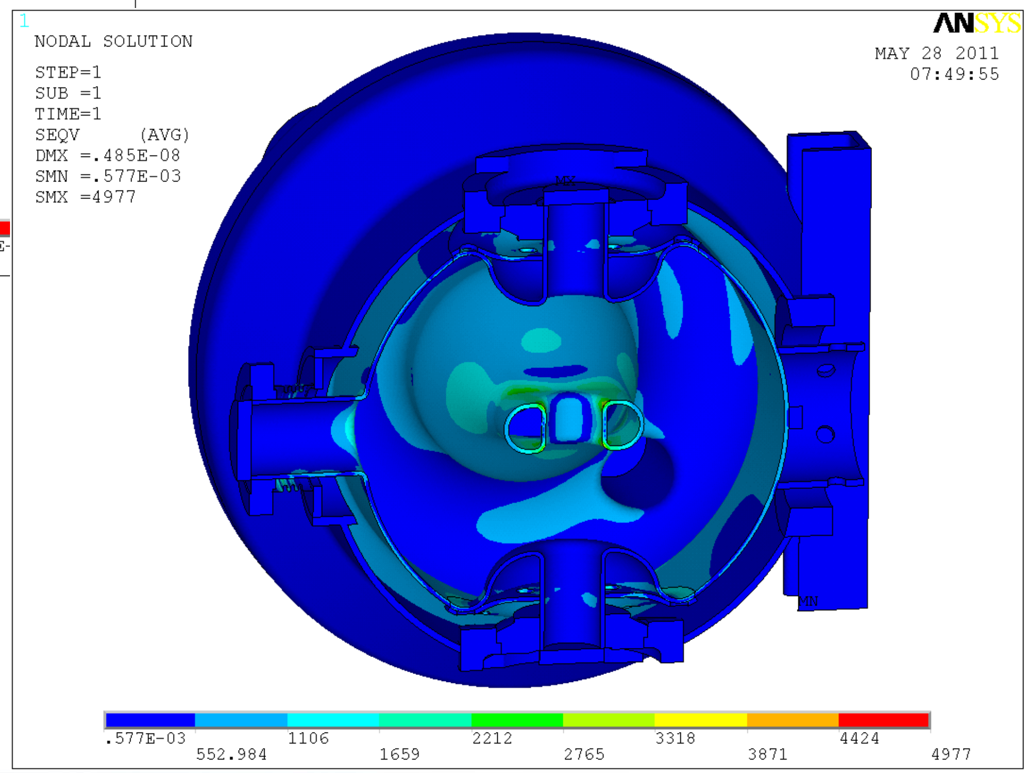
- Our preliminary models led to several changes:
  - Our preliminary attempt to completely decouple the niobium cavity from the stainless steel helium jacket lead to unacceptably large df/dP values. By coupling the beam ports to the stainless steel helium jacket we reduced df/dP to very small levels.
  - The fast tuner range was larger than expected so we eliminated the flat to save on fabrication costs
  - The reentrant nose doubler depth was reduced
  - We used no gussets to reduce df/dP further since it was already stiffened enough by the helium jacket

- The results characterizing the final model's mechanical properties are on the following slides.

df/dP Simulations 1



f1	321085069	Hz
f2	321086394	Hz
df/dp	1.325	KHz/atm

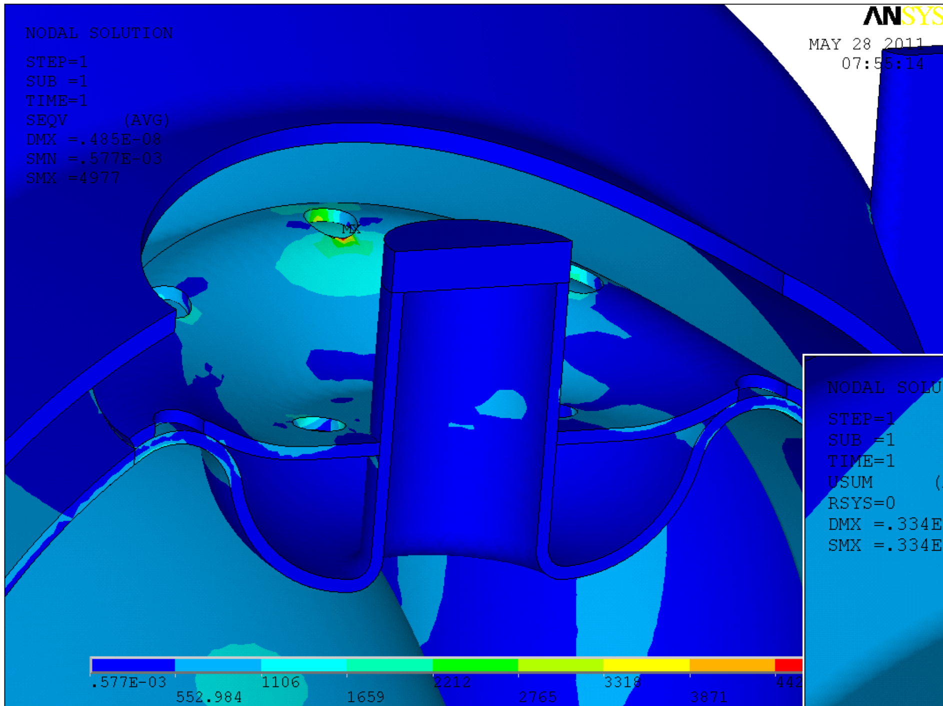


1 atm/0 atm pressure gradient across cavity niobium only. This is the case for the cavity being pumped down with the helium space vented to atmosphere.

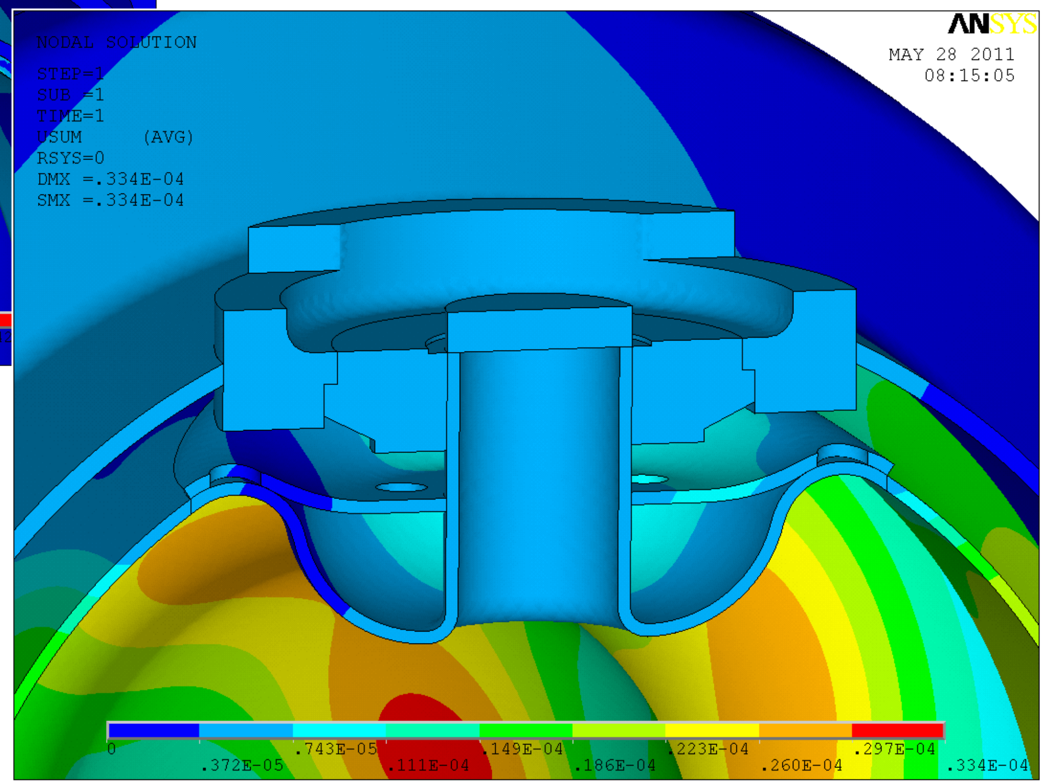
df/dP Simulations 1

Stress and deflections around the beam ports. Enlarge pictures for more resolution

Von Mises Stresses (psi)

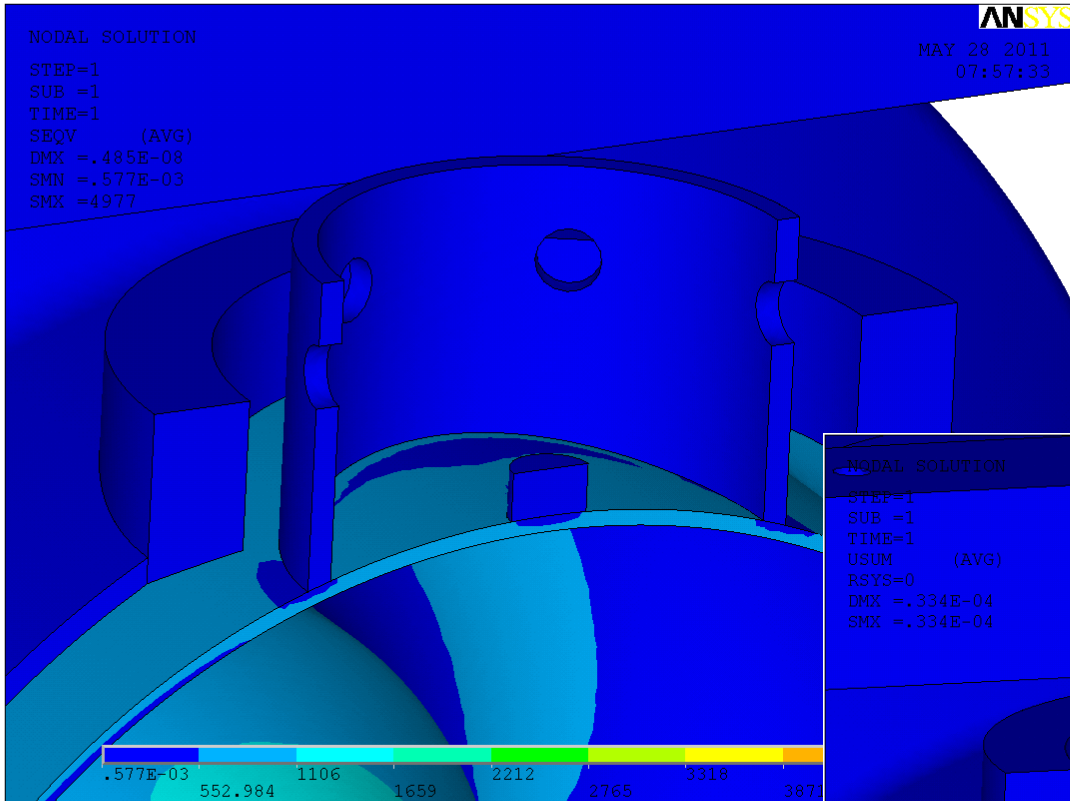


Deflections (in)



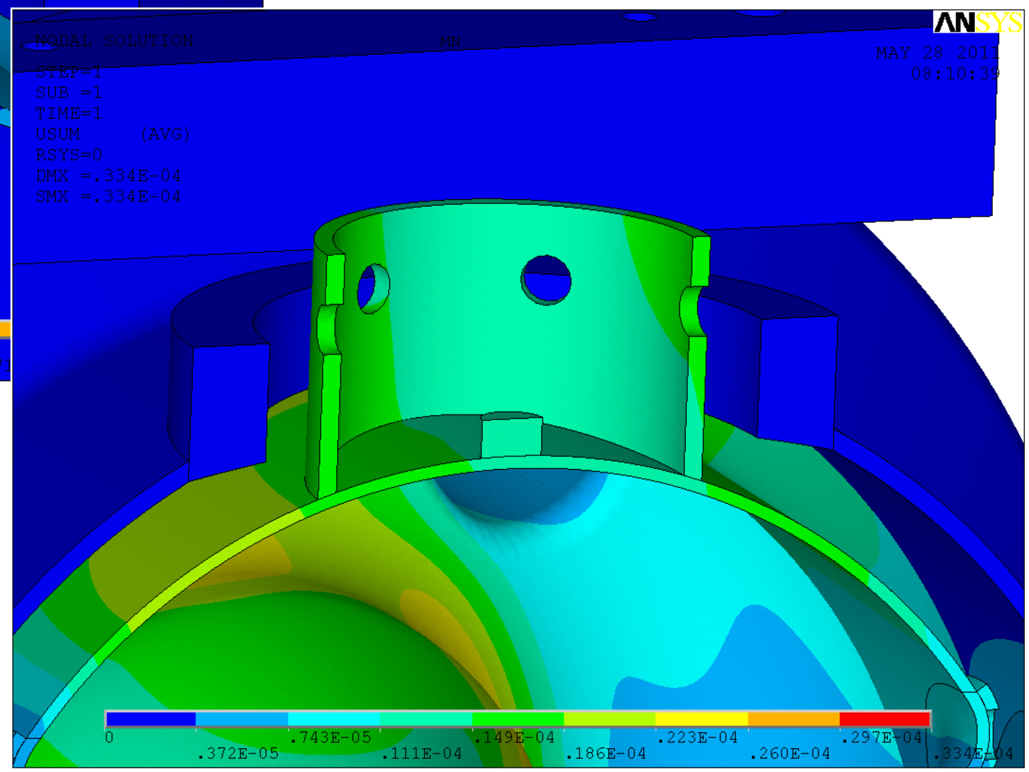
df/dP Simulations 1

Von Mises Stresses (psi)



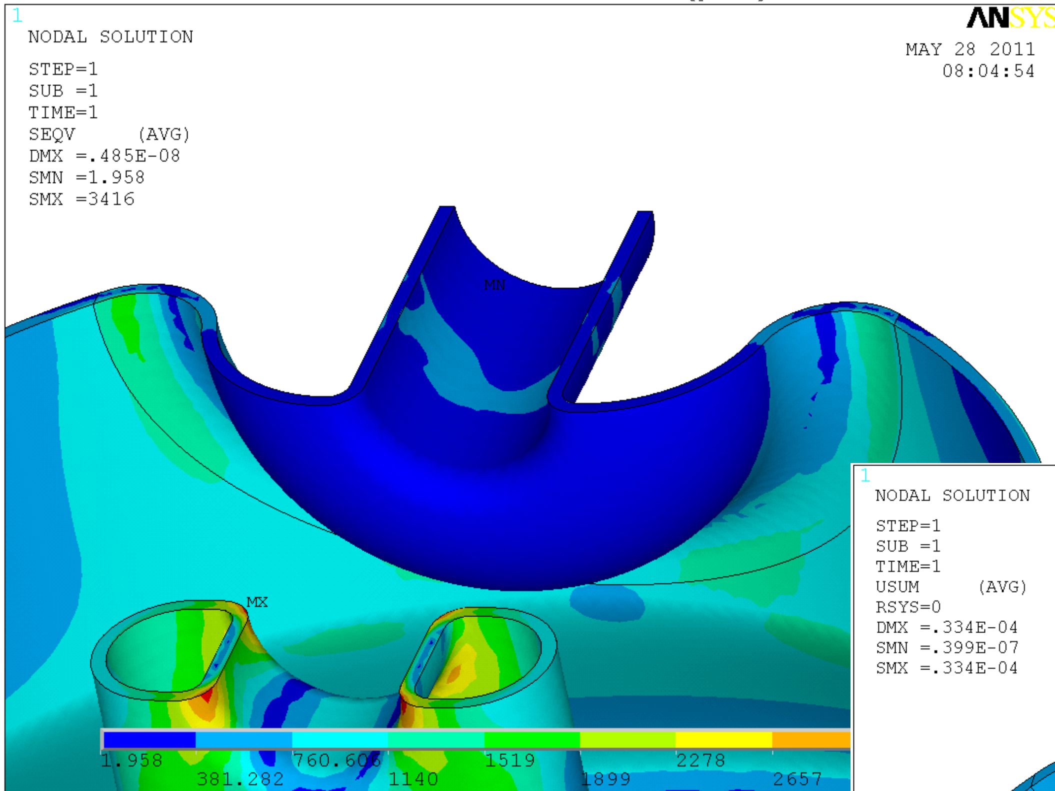
Stress and deflections around the fast tuner. Enlarge pictures for more resolution

Deflections (in)



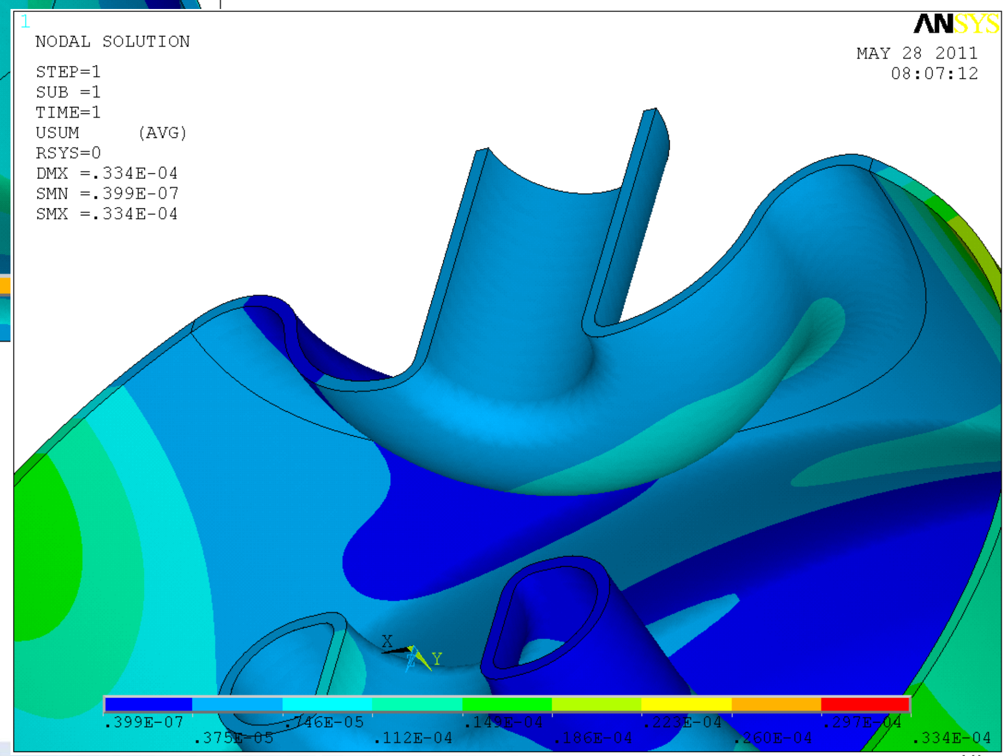
df/dP Simulations 1

Von Mises Stresses (psi)



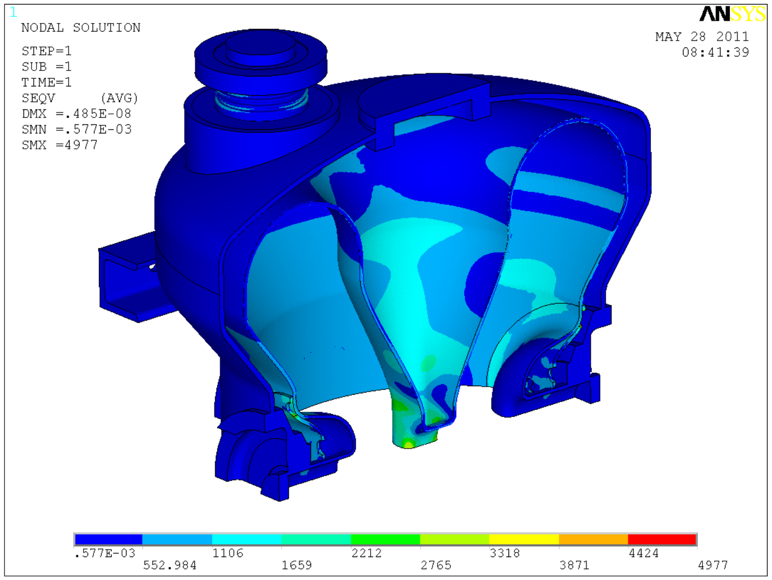
Stress and deflections around the beam ports. Enlarge pictures for more resolution. Helium jacket suppressed in these images only for clarity. Was part of simulation

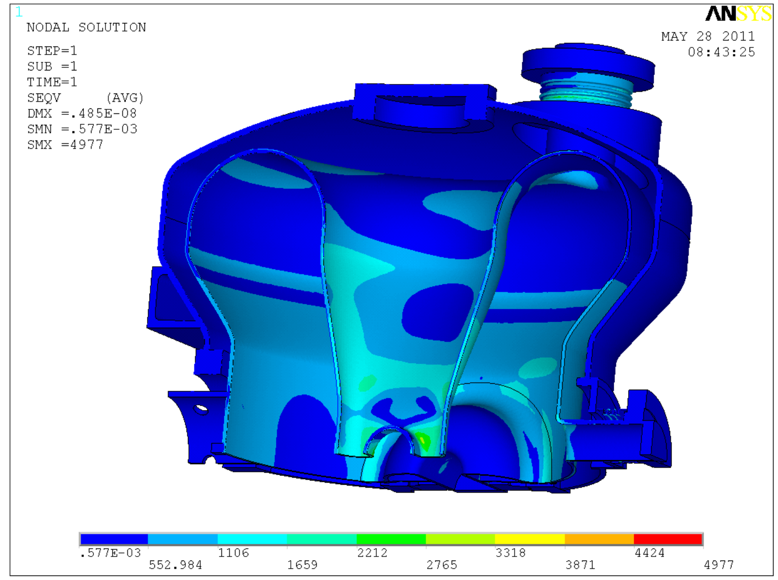
Deflections (in)



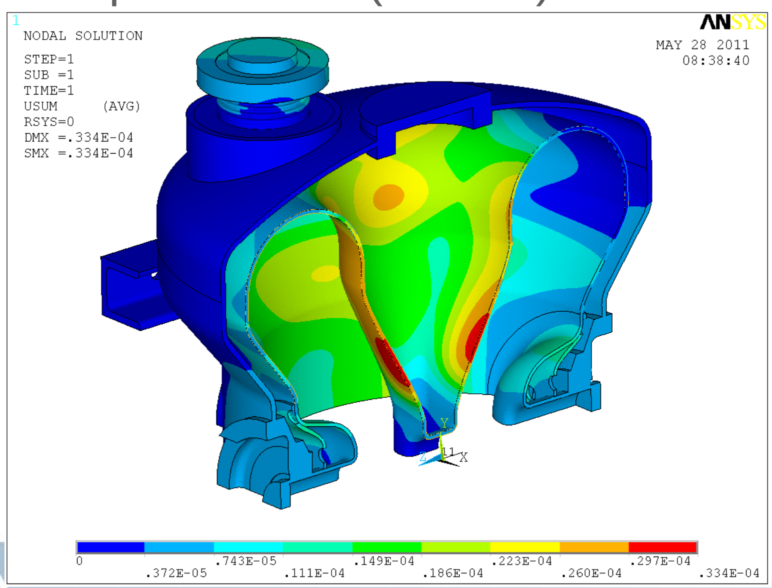
df/dP Simulations 1

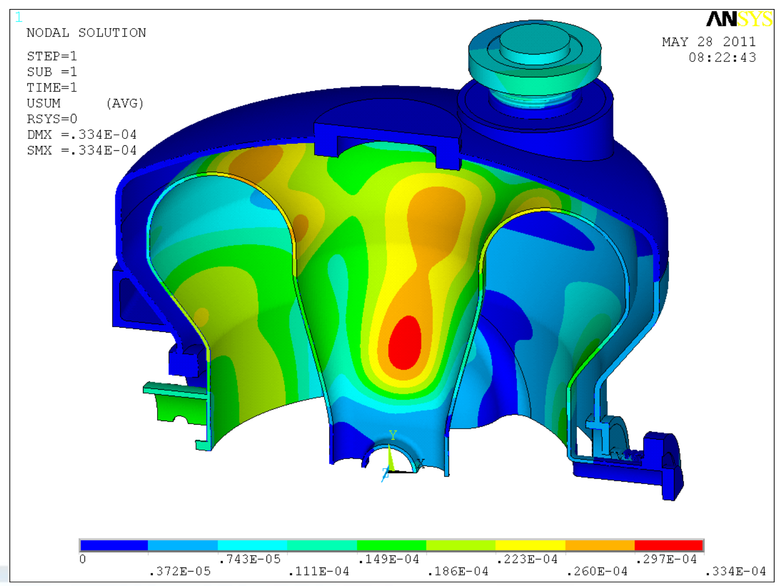
Stresses (Top)





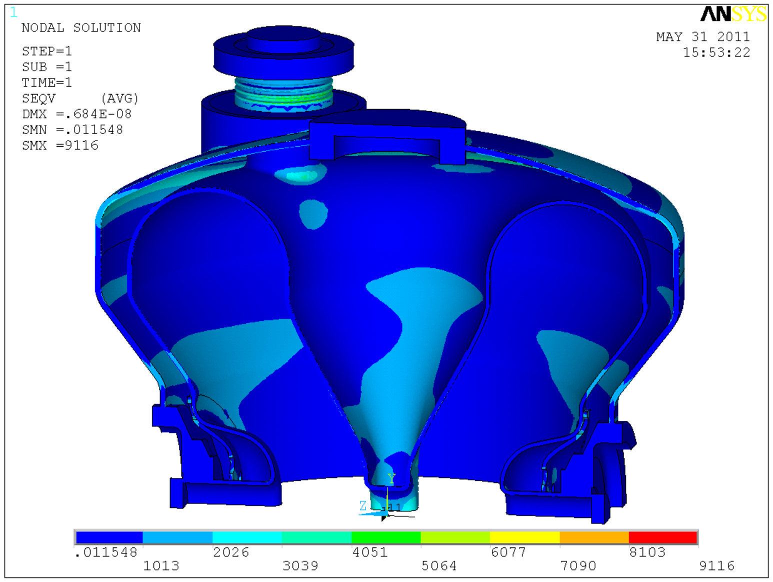
Displacements (Bottom)

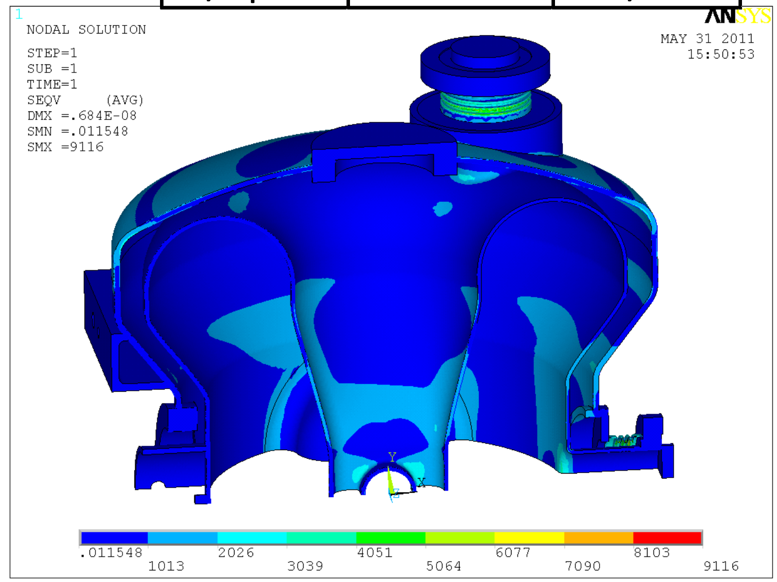


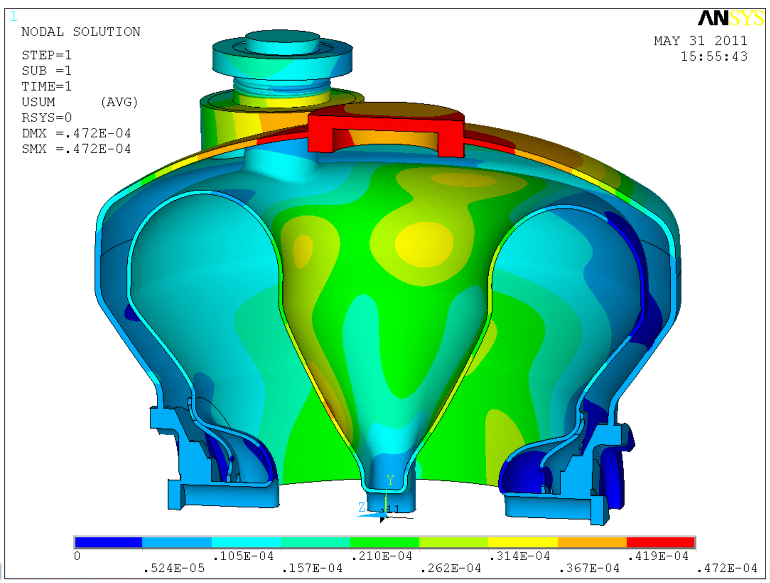


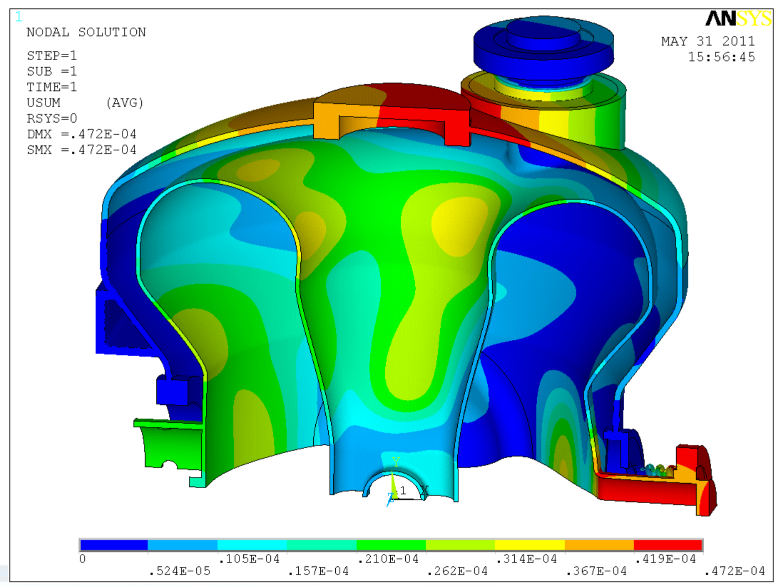
df/dP Simulations 2

f1	321085069	Hz
f2	321088862	Hz
df/dp	3.793	KHz/atm

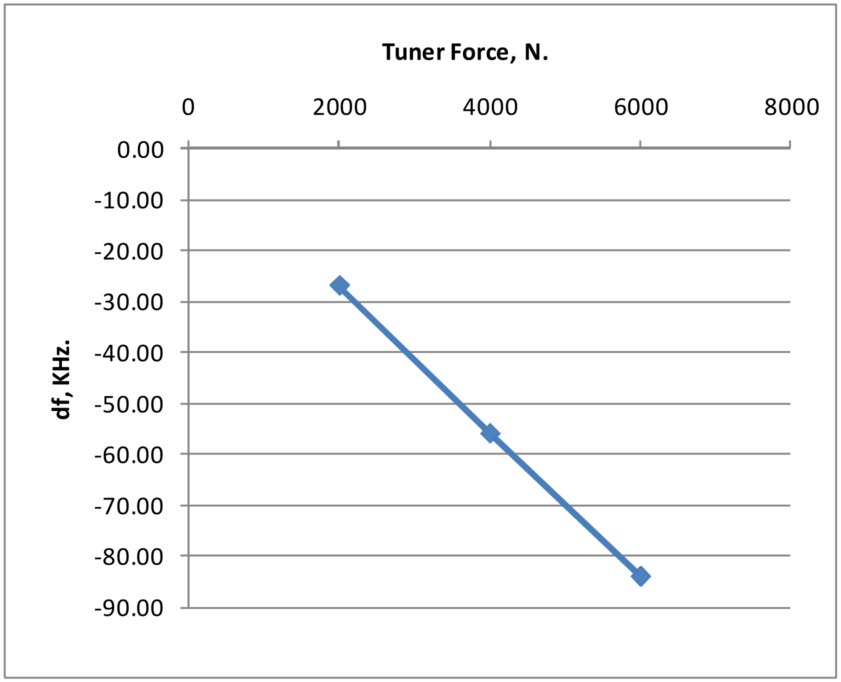






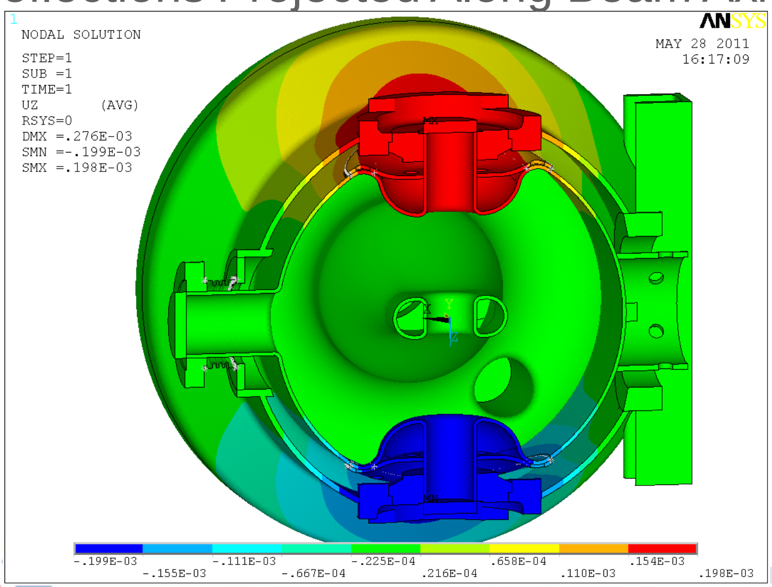


Slow Tuner Range Simulation

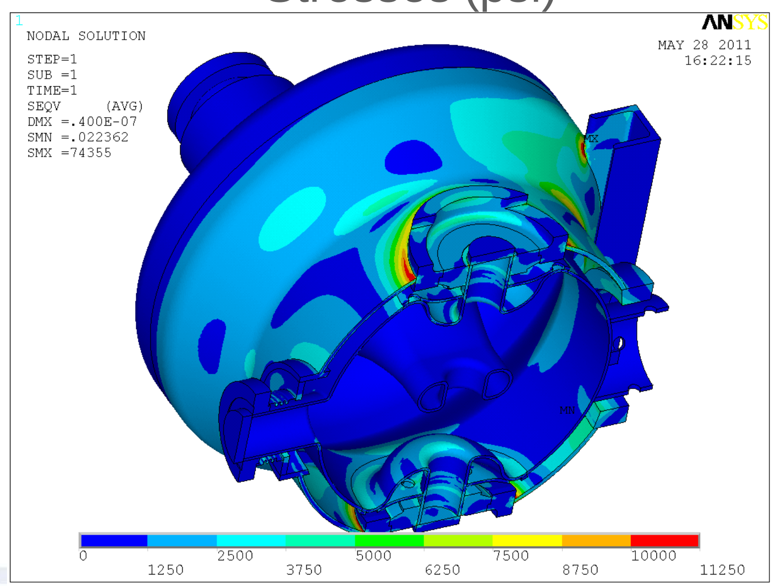


- Slow tuner squeezes cavity at beam ports
- Slow tuner simulated with up to 6000 N
- The slow tuner being used in the ATLAS Intensity upgrade has been tested to > 20,000N and may be scaled back for this cavity

Deflections Projected Along Beam Axis (in)

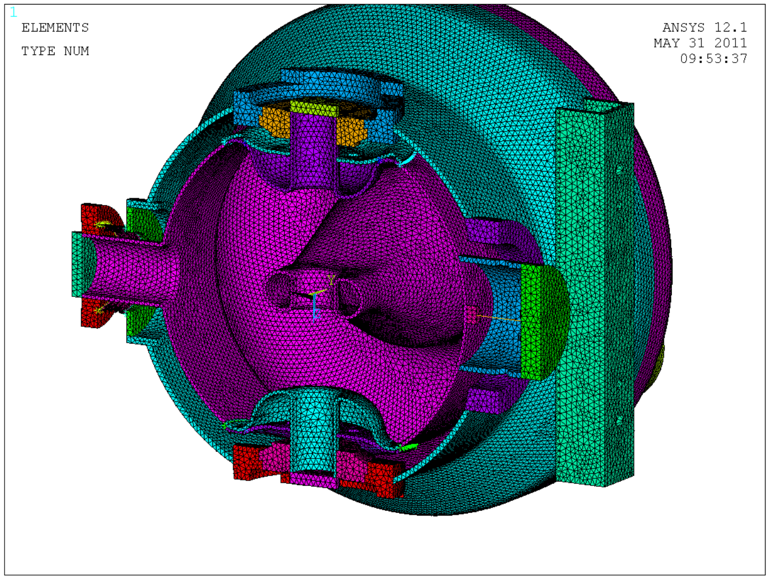


Stresses (psi)



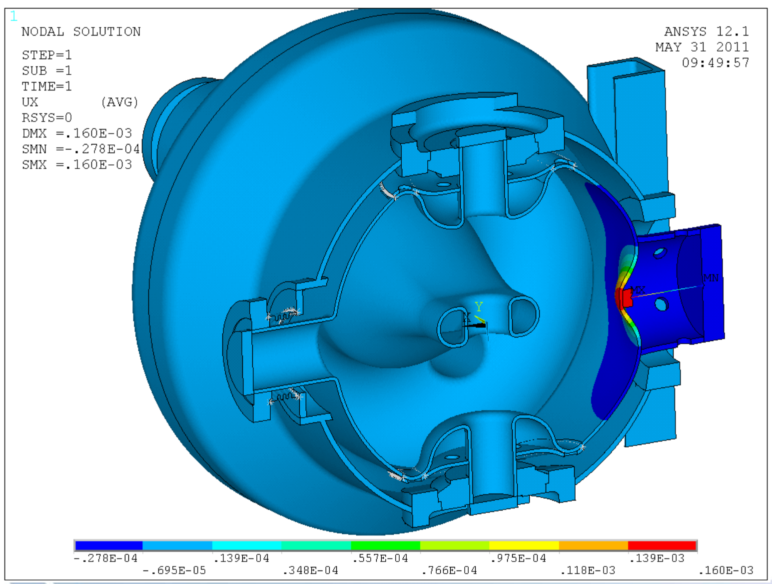
Fast Tuner Simulations

ANSYS Model

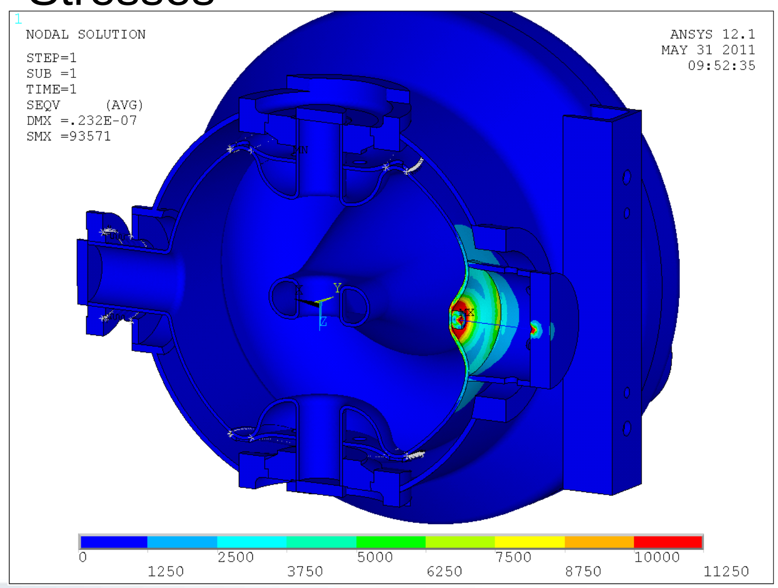


- The fast tuner sensitivity is currently estimated to be ~9 Hz/micron
- For a Noliac SCMAP10 peizoelectric actuator with an 80K stroke of ~20 microns the cavity frequency can be shifted 180 Hz, a good tuning window
- Please note that the simulations shown on this slide are for a 160 μm displacement of the cavity. The numbers shown on all scales should be divided by 8 for the 20 μm case.

Deformations



Stresses



Future Work

- We have designed and optimized another HWR for 325 MHz with a slightly higher β and improved the electromagnetic performance parameters.
- With this new HWR325 we expect to demonstrate V > 4.5 MV with B_{peak} > 120 mT
- Prototype finished summer 2012

Impact on FNAL

- Experience here is directly applicable to the mechanical design of FNAL PXIE 162.5 MHz halfwave cavity
- Majority of frequency detuning effects can be minimized or even eliminated by design (neglect can lead to an unusable system) = reliable operation
- Will modify material design constraints to satisfy FNAL requirements (straightforward)