Optimum fabrication techniques for prototyping & 4R Crab Cavity Prototyping Status

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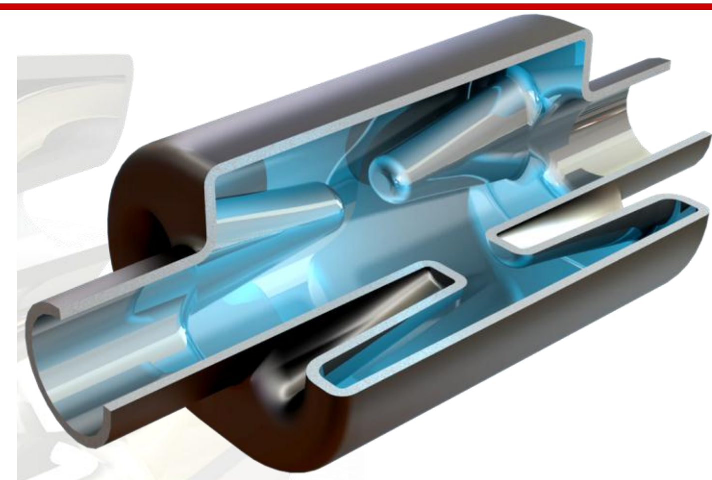
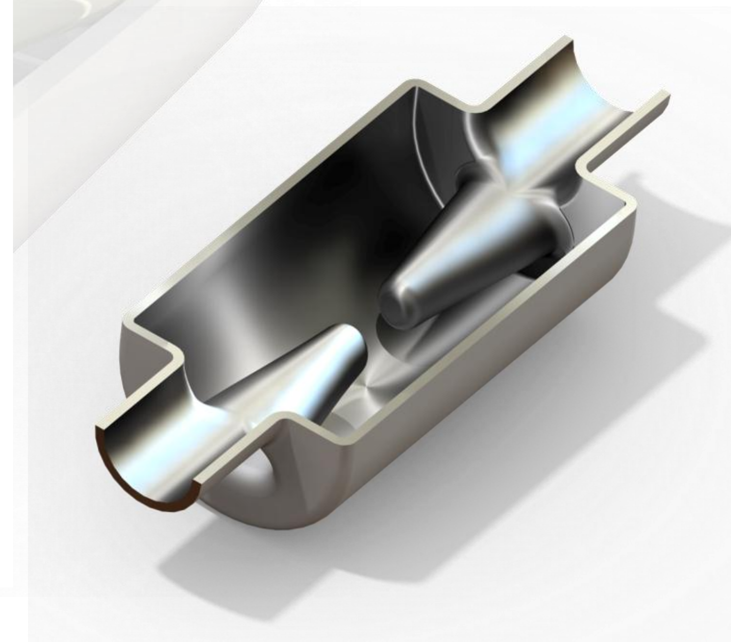
Cavity Prototype

- UK have some funding for a cavity prototype from the Cockroft Institute/ EUCARD.
- An order has been placed with Niowave for a Niobium prototype.
- This will be a proof of principle to show the cavity can be manufactured and cleaned and hence reach gradient.
- Vertical cryostat tests will be critical in verifying the cavity concept.



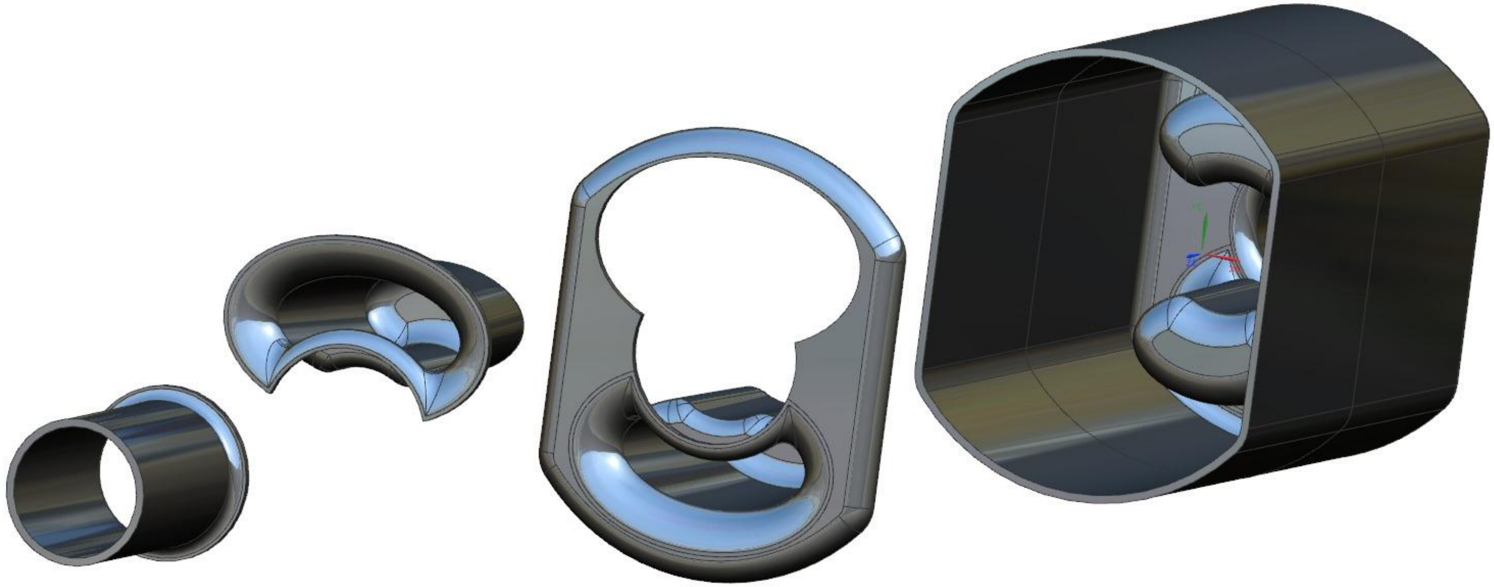


Some fabrication options

- 1. Sheet metal fabrication of ideal RF design
  - Multiple dies for complex shapes
  - Multiple EBW steps
    - EBW of rods into end plate is a difficult joint, no good sightlines
  - Modest material costs
- 2. Sheet metal fabrication of modified design for easier welds
  - Offset rods makes welding easier but impedance is low
  - Offset rods tapered inwards restores some efficiency
  - Offset base (bump) should restore efficiency but increase B_{pk}?
- 3. Machine end plates and rods from solid
  - Higher material costs (can mitigate with some design changes?)
  - Higher machining costs
  - No critical E-beam welds
  - Better tolerances, more design flexibility (stiffeners etc.)
  - Potential SRF benefits of “large grain” material

1. Conventional fabrication, ideal RF design

- Fabricate from multiple pressed sections (multiple dies)
- Multiple multi-axis e-beam welds (esp. rod to end plate joint)
- May be possible but weld development needed.



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1. Conventional fabrication, ideal RF design

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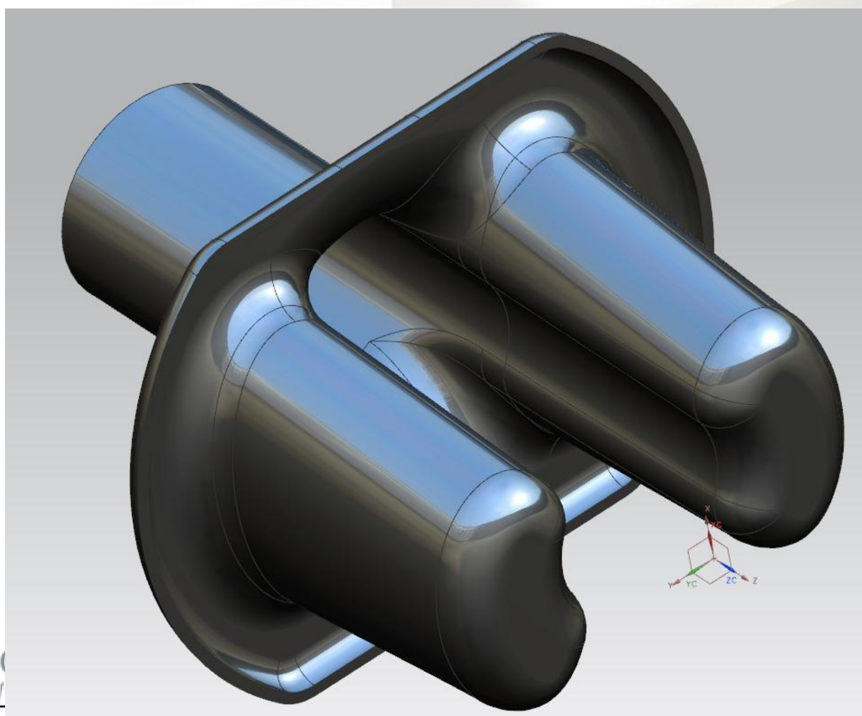
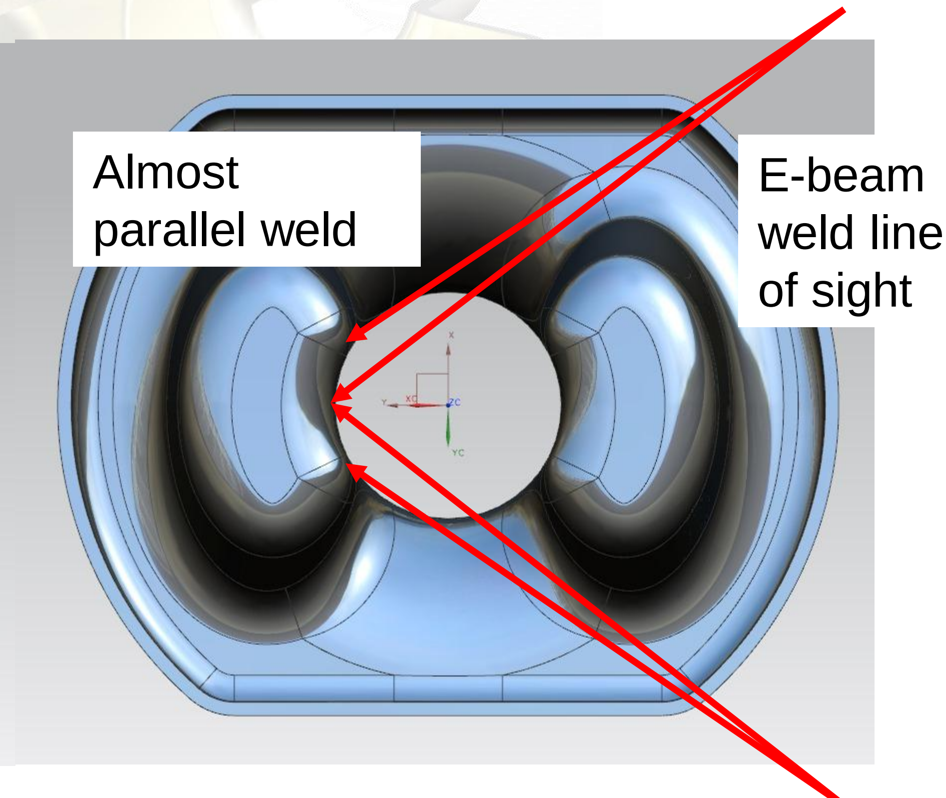
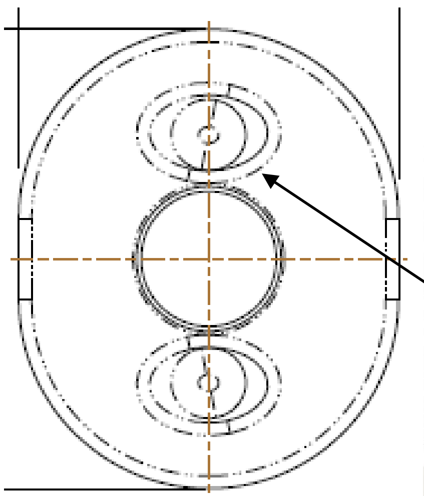
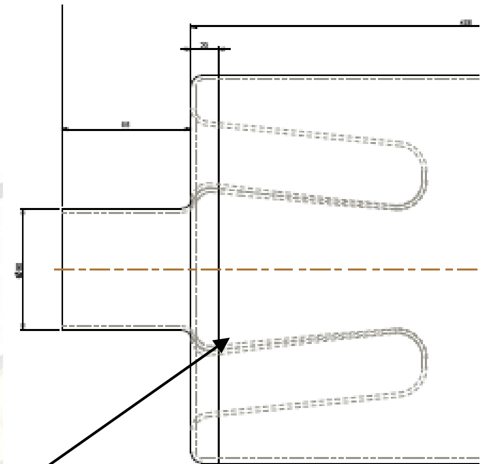


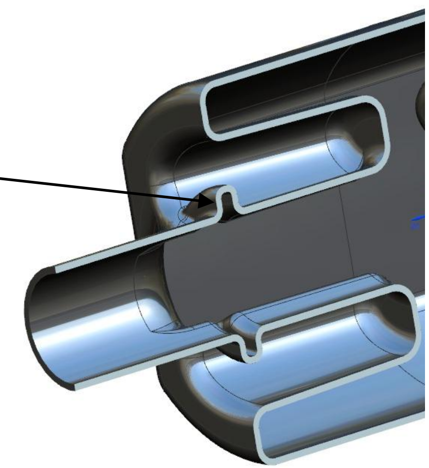


2. Conventional fabrication, modified RF design



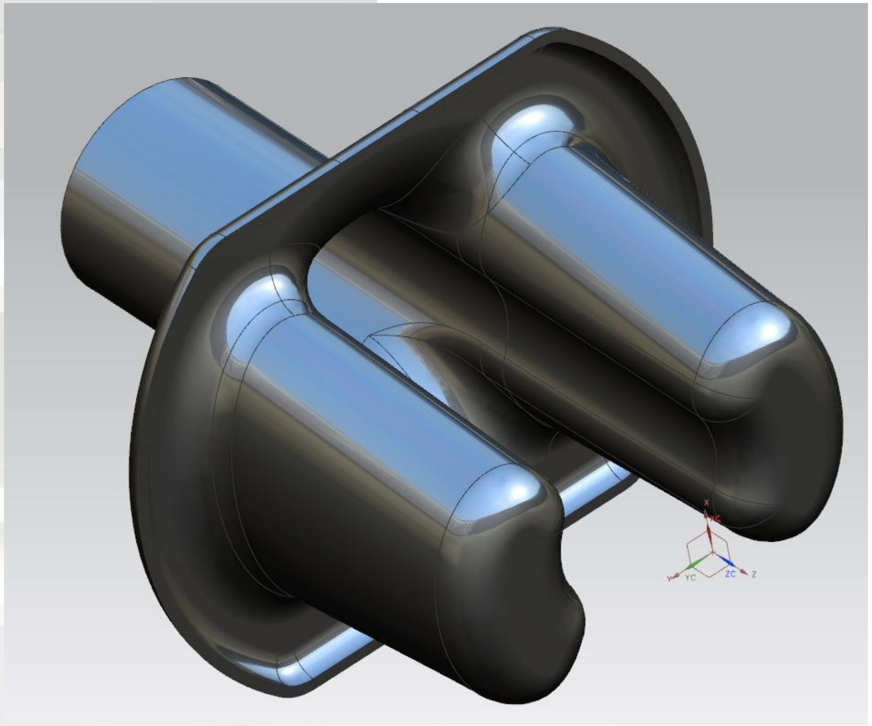
- We can reduce the weld complexity by modifying the geometry.
  - Can round the rods but this increases surface fields considerably
  - Can offset the rods at the base and slant the rods to increase the deflecting voltage.
  - Can reduce the fillet radii by introducing a bump but this also increases B_{surf}





3. Machine end plates and rods from solid

- Consider to make major parts from solid
  - Wire EDM pre-forms from ingot
  - Machine all surfaces
  - Add beam pipes and can
- This allows any material thickness or even a variable thickness. Also stiffeners can easily be added.
- This will also allow fine detail to be added to avoid multipactor (like the ridges suggested by SLAC for the 800 MHz elliptical cavity)
- However a substantial lump of Nb ingot is required (£50k worth)



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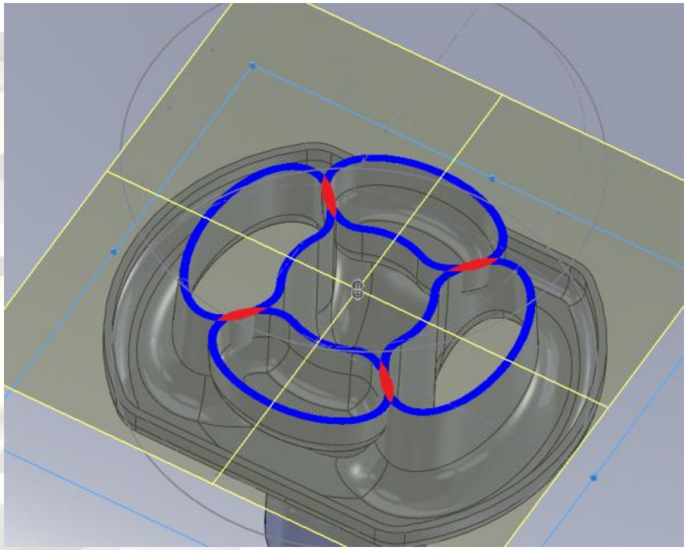
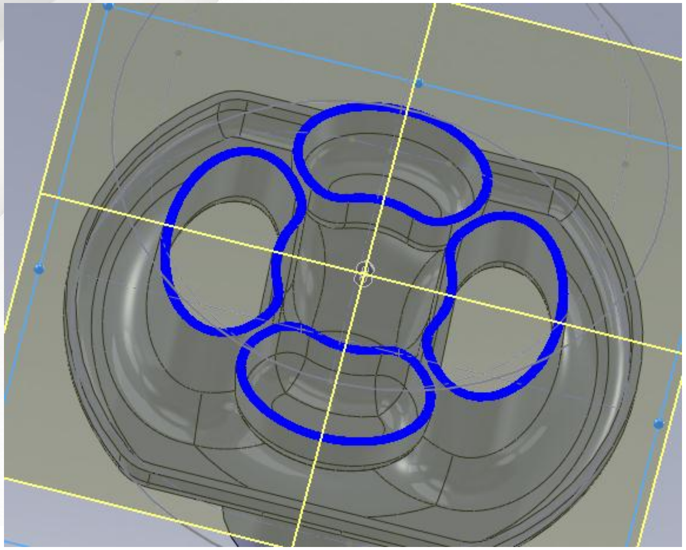
3. Alternative fab, slightly modified RF design

- Rod profile can be reduced to allow both base plates to be wire etched from a single block of niobium.
- This saves the amount of Nb required by 20%.
- Clearance of 2mm between both rods to allow wire EDM.





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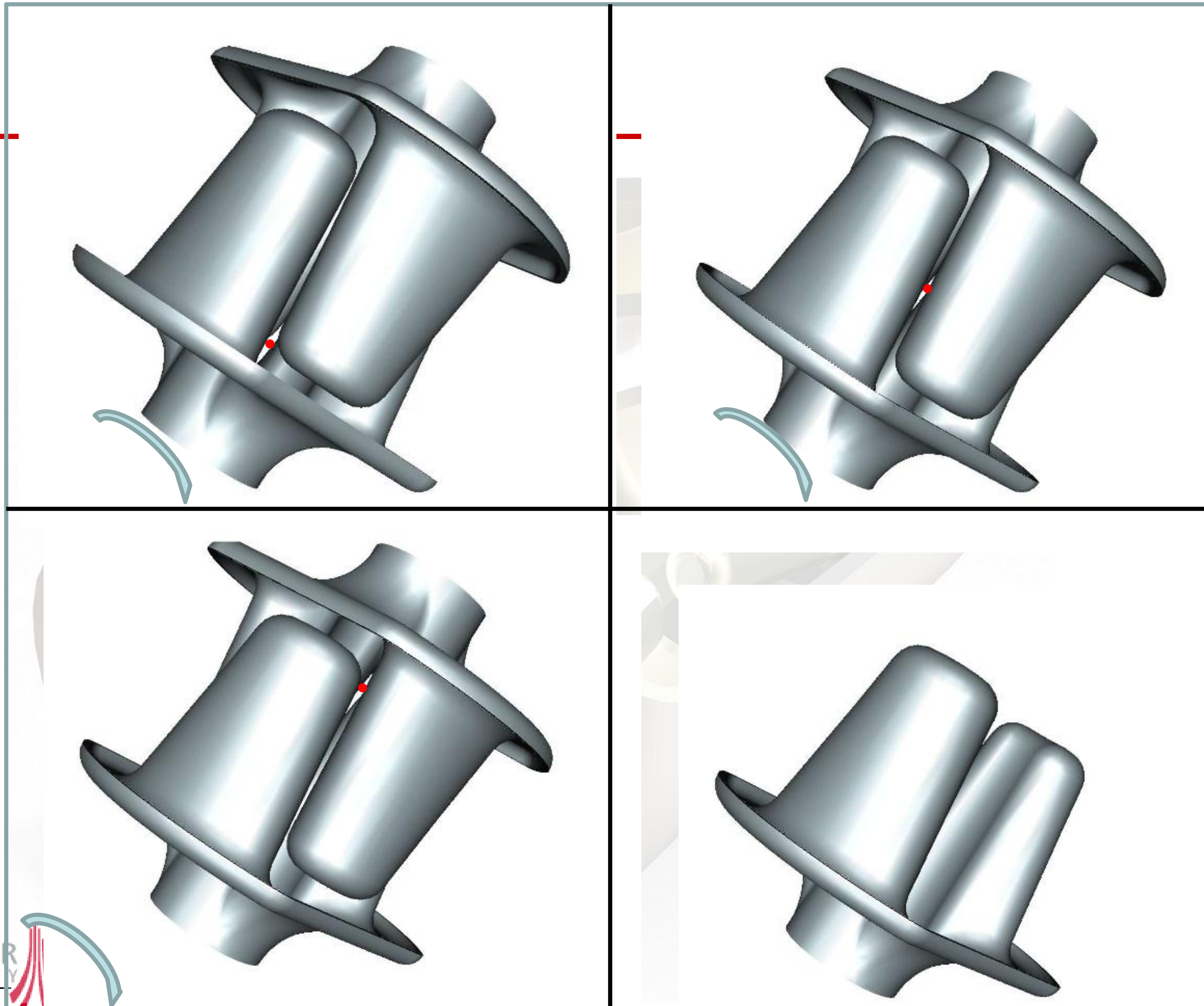
Wire EDM cutting to separate the electrode blocks

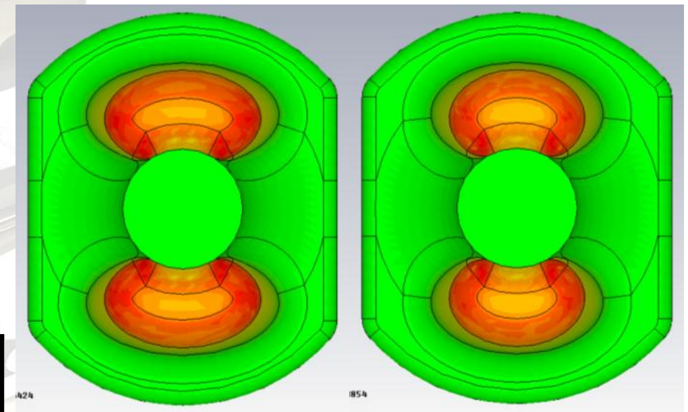


Modified Rod Shape

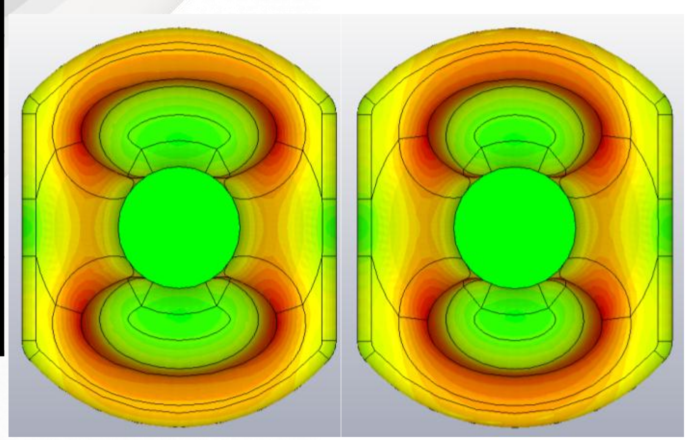
- Reduced tip size leads to a 10% increase in peak surface electric field.

	Original design	Reduced profile
Emax @3MV	32.0 MV/m	35.9 MV/m
Bmax @3MV	60.5 mT	60.1 mT
Transverse R/Q	915 Ohms	963 Ohms

E Abs



B Abs



Original | Reduced profile

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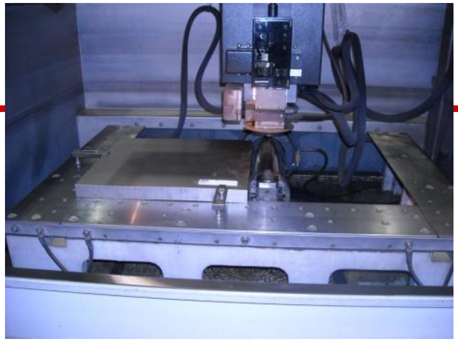
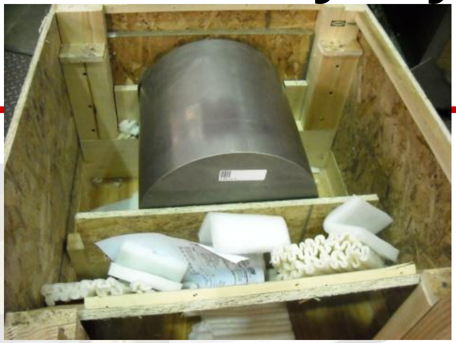
Fabrication of CC-A2 Cavity by CNC

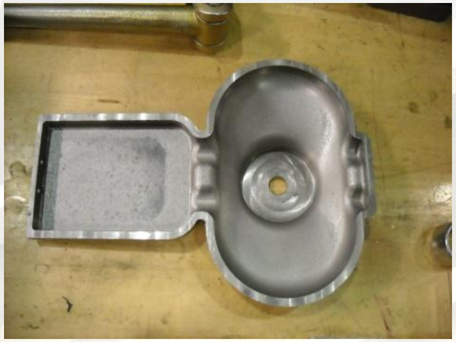

Cut fixture plate

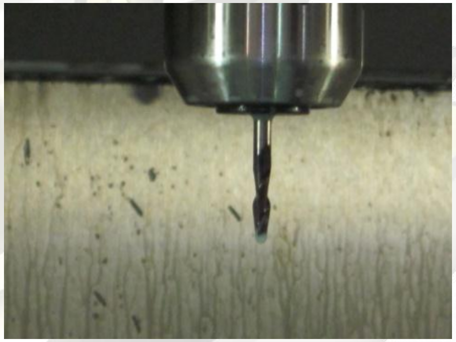

machined fixture base


RRR>250 large grain Nb ingor


EDM wire cut Nb template

Machine outside surface


Machine inside surface with 30um unfinished


Milling tool head for last inner finish


Machine inner surface on the base


Finished first half with 4mm wall thickness


Match to other Al model half


Outside finish of first half


EDM wire cut Nb template for Y WG

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Options for fabrication

- Option 1:
  - Ideal RF shape, minimum material
  - Many parts, complex welds
- Option 2:
  - Near ideal shape, easier welds
  - Increased B_{pk}?
- Option 3:
  - Ideal or near-ideal RF shape
  - More design options (stiffeners, variable wall thickness, etc.)
  - Higher material and machining costs
  - Possible benefits of large grain material (Q etc.)
- Other options?

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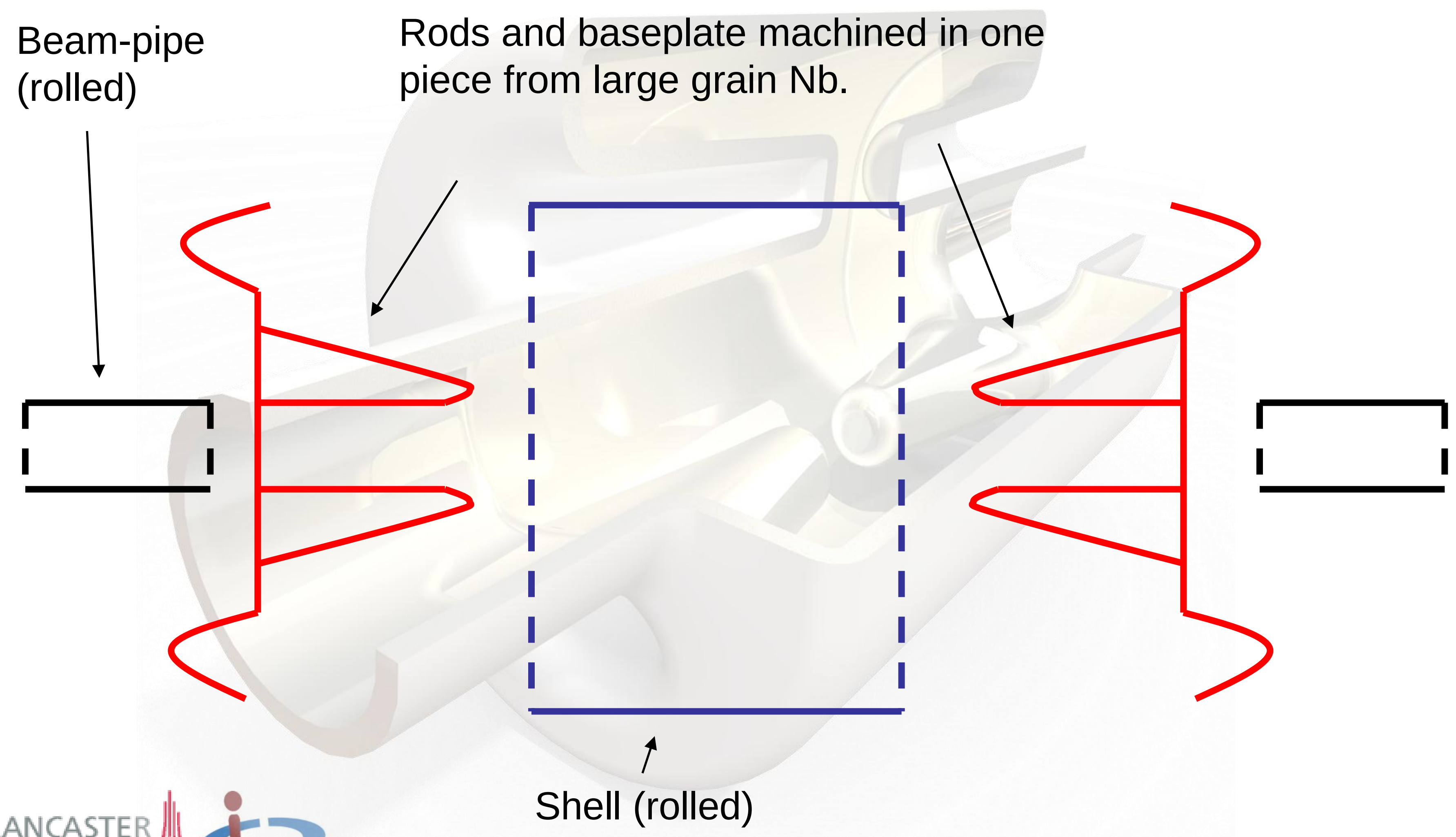
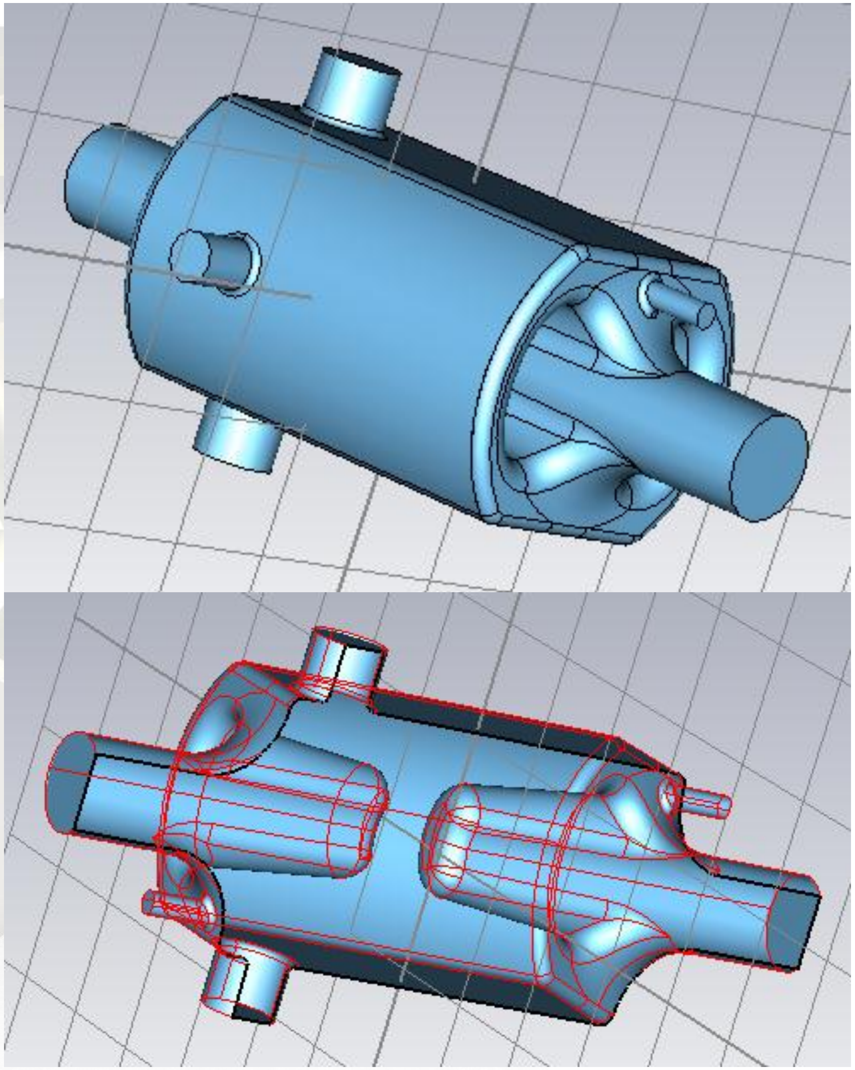
Cavity construction (without couplers)



High pressure rise

- It is important we can clean all parts of the cavity.
- Adding ports for demountable couplers also allows access for high pressure rise.
- We have also added two small ports to allow the water to drain from the base plates.



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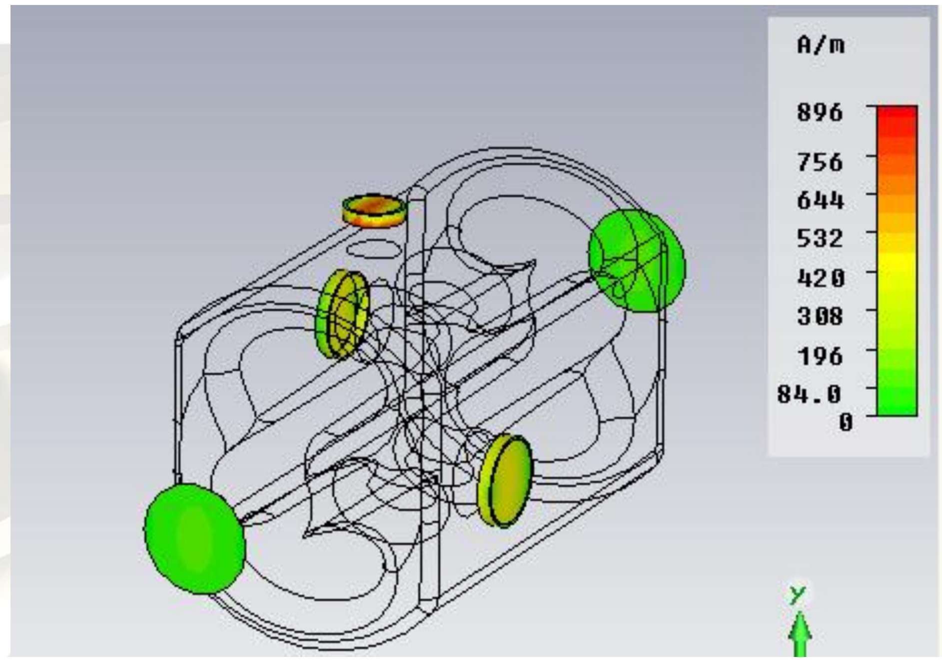
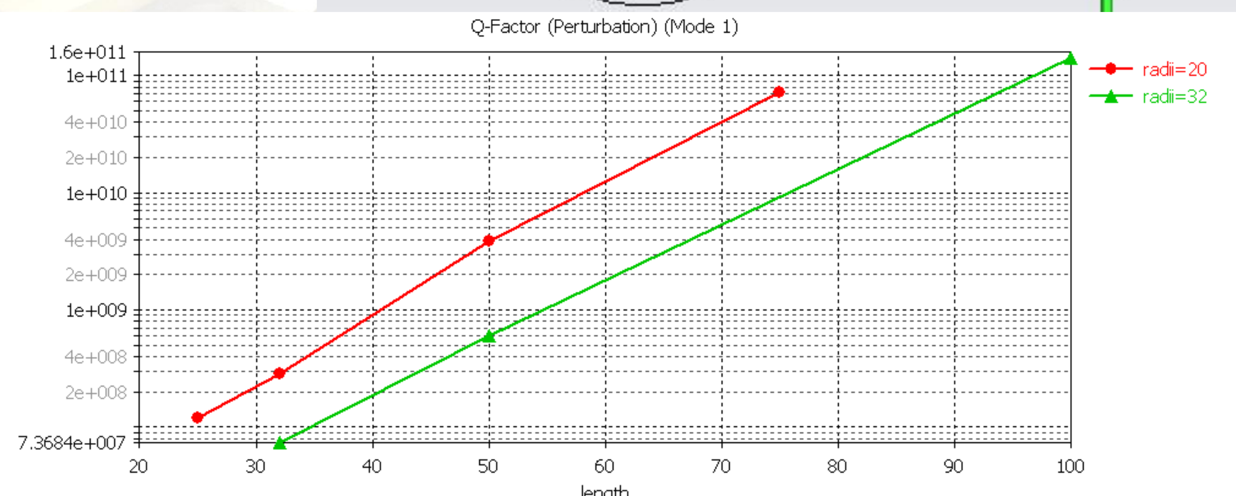
Additional heating on the ports

- The lengths of each port has to be carefully chosen to avoid excessive additional losses at the flanges which will make it impossible to measure the Qo of the cavity when testing

  50 mm is sufficient for our cavity





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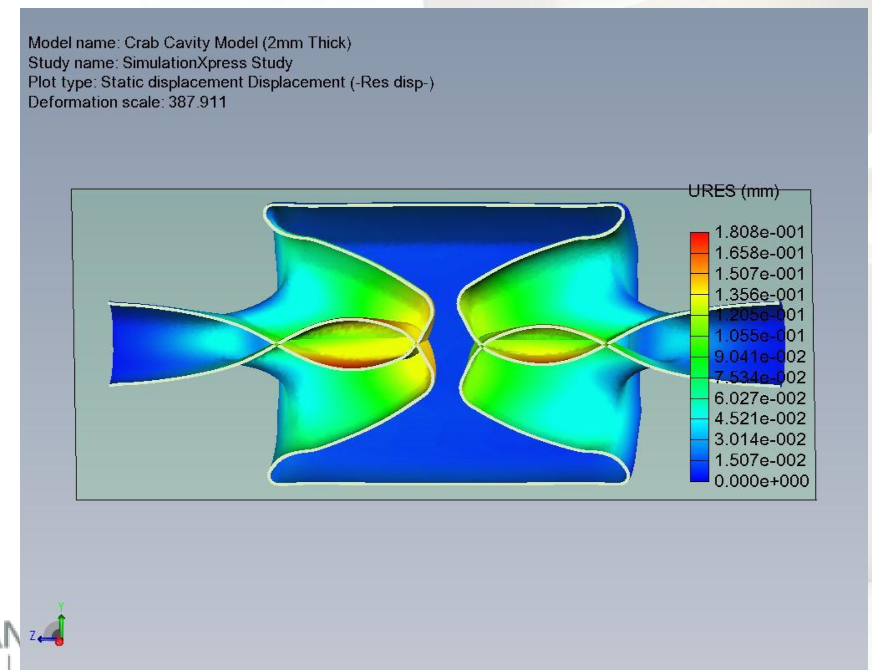
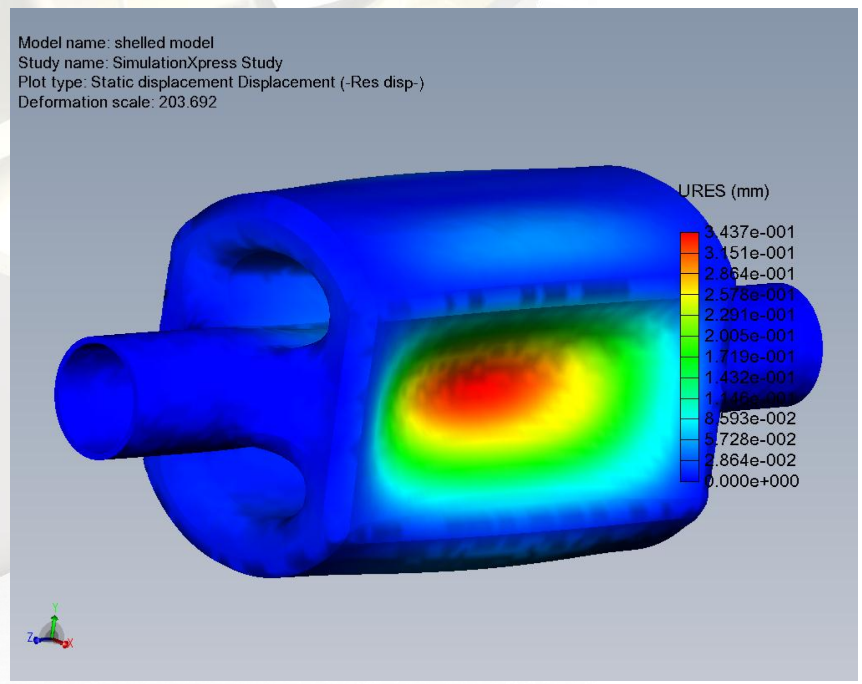
Deformation due to pressure

- Solidworks Simulation Xpress was used to look at the deformation of the cavity under vacuum.
- Different wall thickness are simulated.





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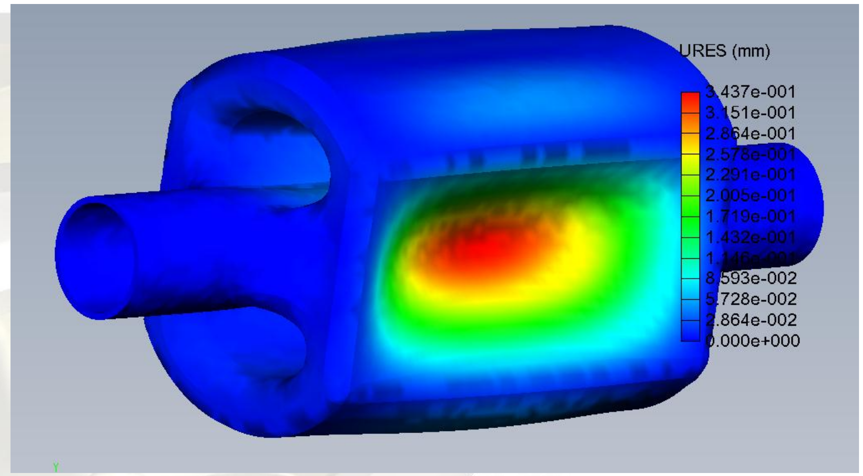
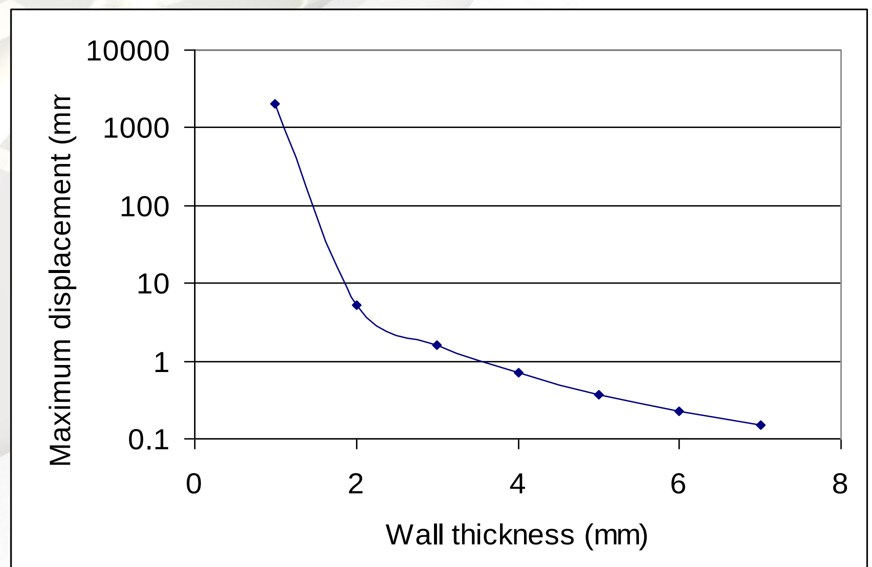
Deformation of the outer can

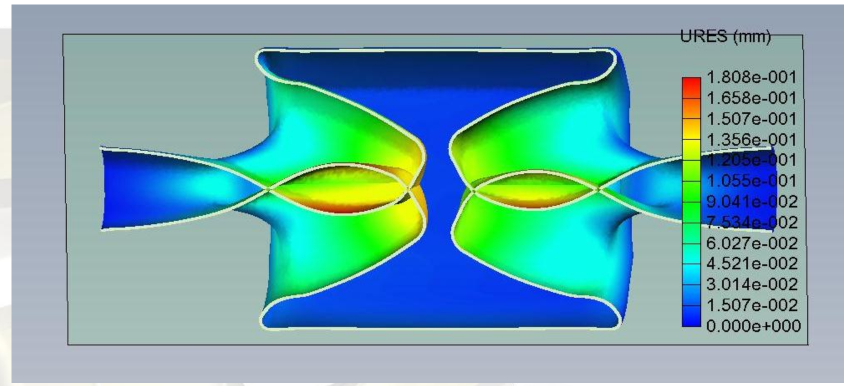
- The outer can is sucked in at the edges. This effect could be reduced by bending the outer can or adding ridges.
- Weak point could be used for tuning the cavity.

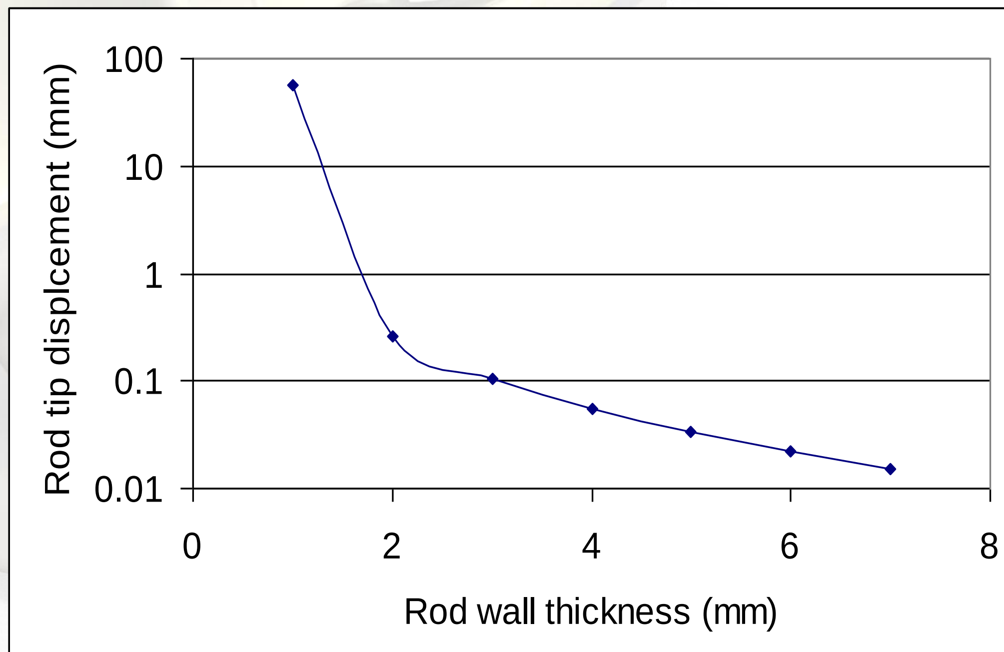




Deformation of the outer can

- The rods bend inwards slightly and expand transversely.
- The displacement is relatively small (for a reasonable thickness) and has little effect on frequency.





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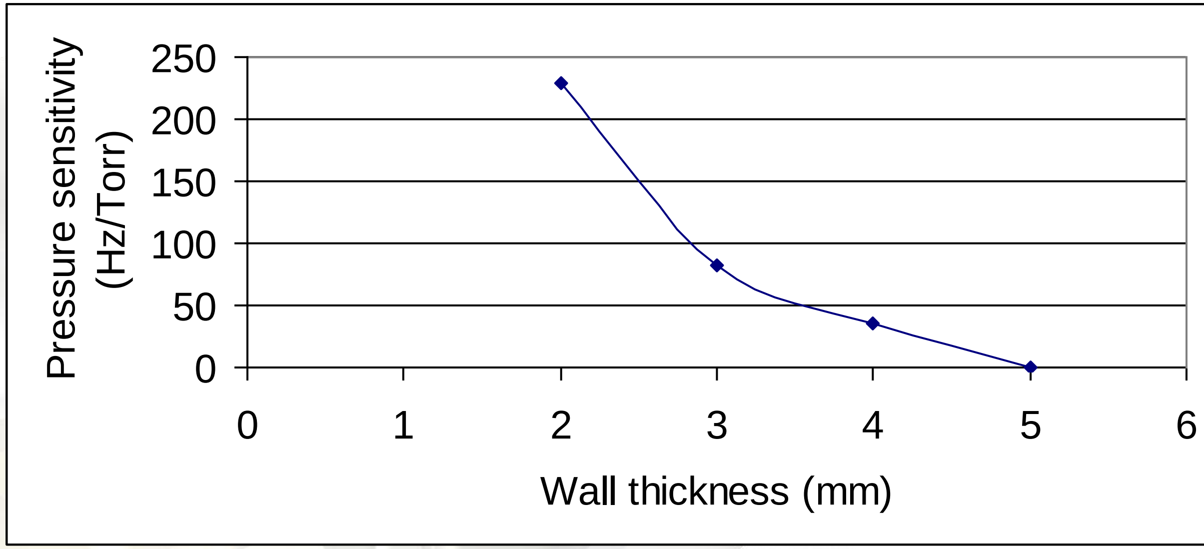
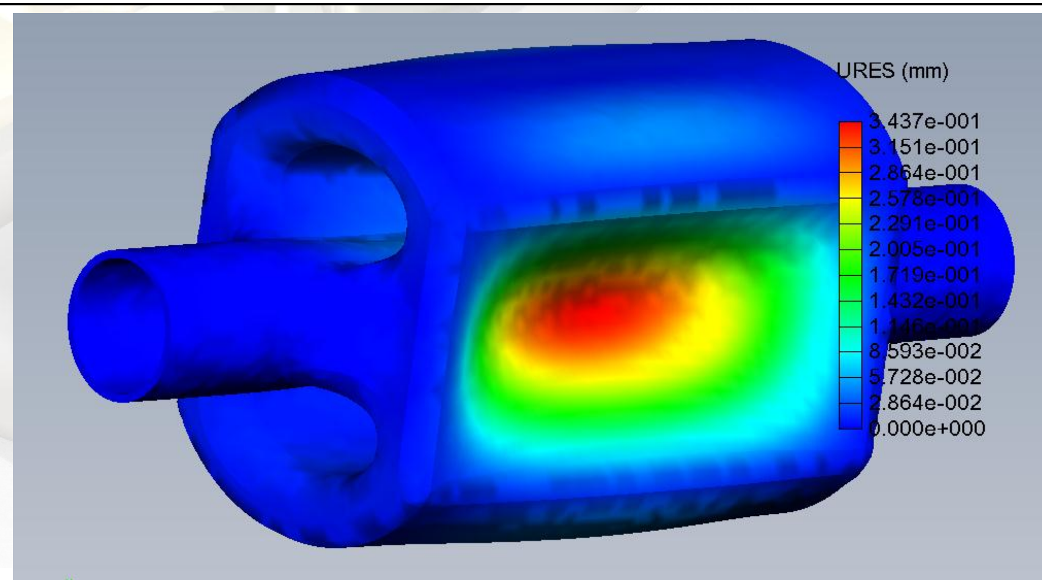
Pressure sensitivity

The outer can needs a thickness of at least 3 mm in order to minimise the pressure sensitivity to below 100 Hz/Torr.

This is a relatively small dependance and is due to the fact that the frequency is dependant on the cavity length and the cavity is quite stiff to longitudinal pressure.





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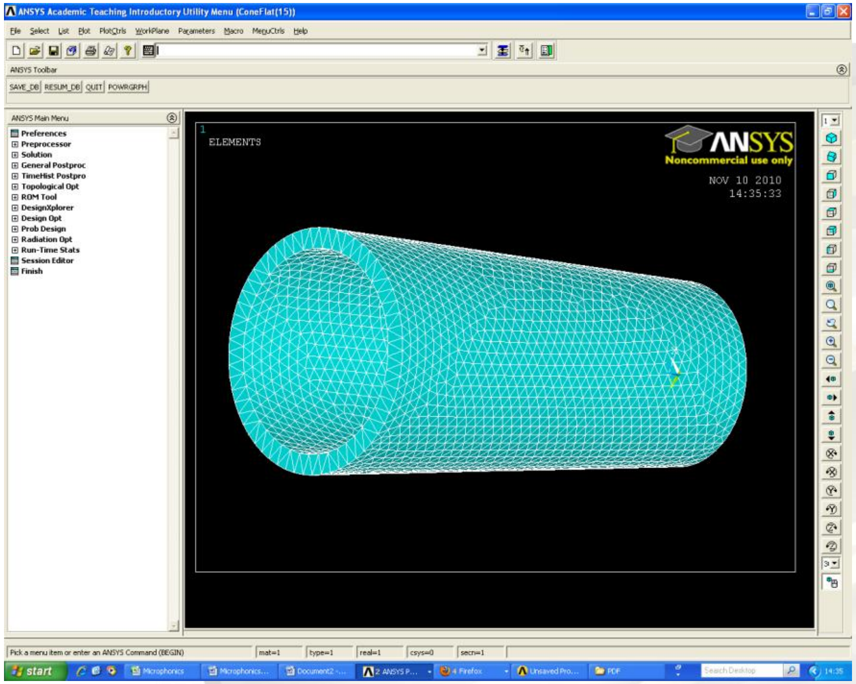
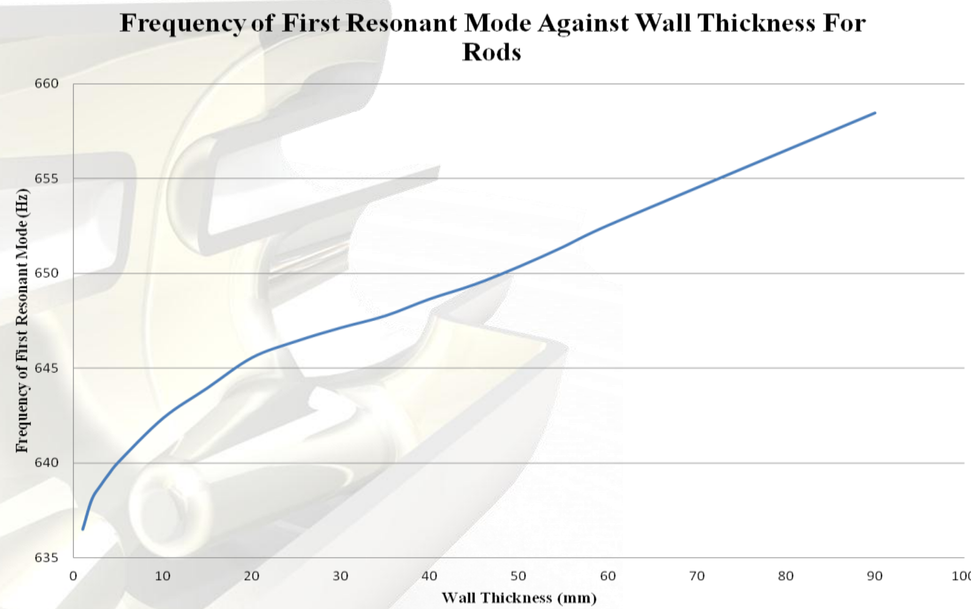
Microphonics studies





- FEM studies have begun looking at microphonics. Initially looked at individual components and then progressed into full cavity simulations.

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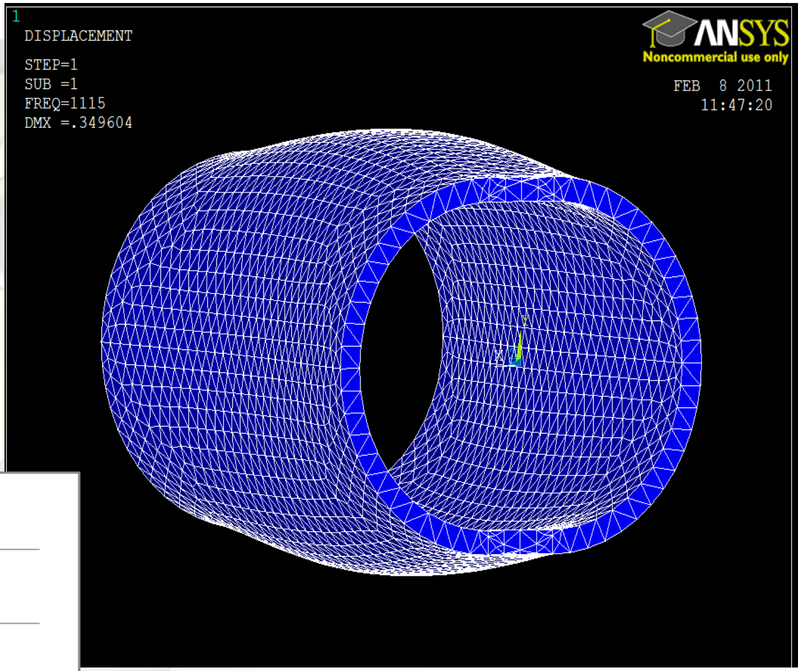
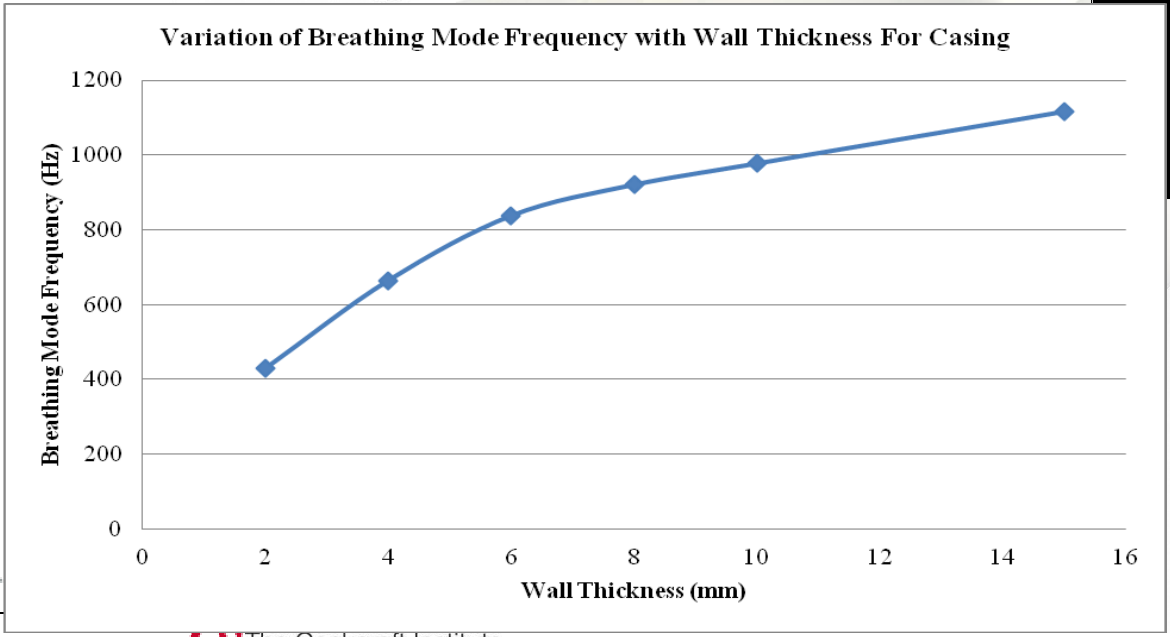
Outer Can Vibration

Transverse mode is at a much higher frequency (25 kHz).

First vibration mode is a breathing mode.

Frequency variation with wall thickness was studied in ANSYS for a cylindrical can.





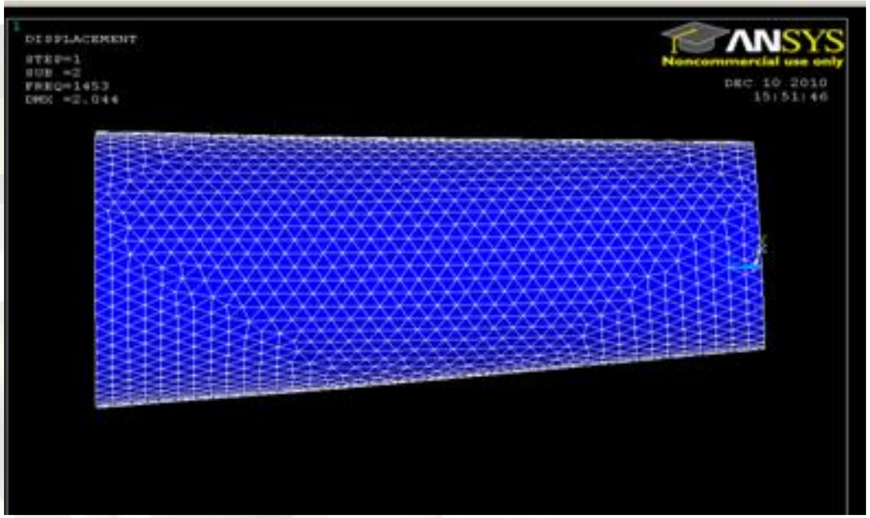
The resonant frequency is between 500-800 Hz for a realistic wall thickness.

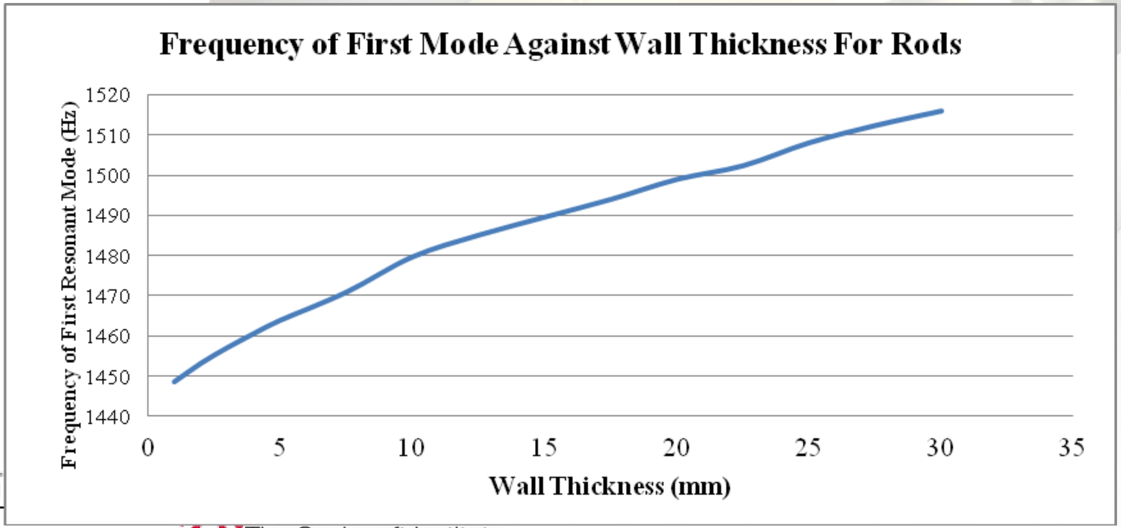
Inner Rod Vibration

As a starting point conical rods have been studied.

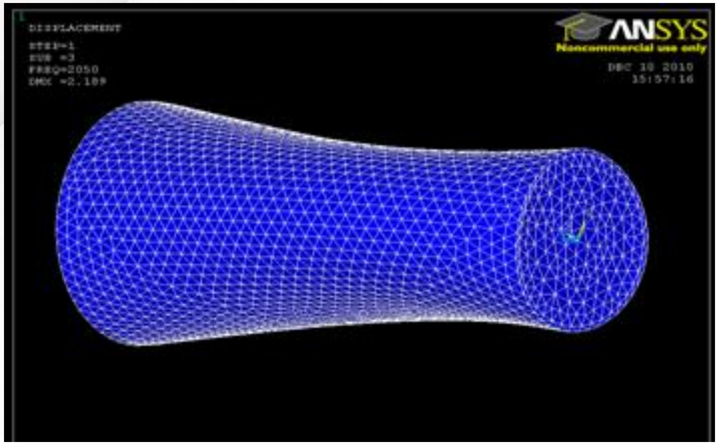
The first mechanical resonance is a transverse mode (1.5 kHz).

Frequency is only weakly related to wall thickness.



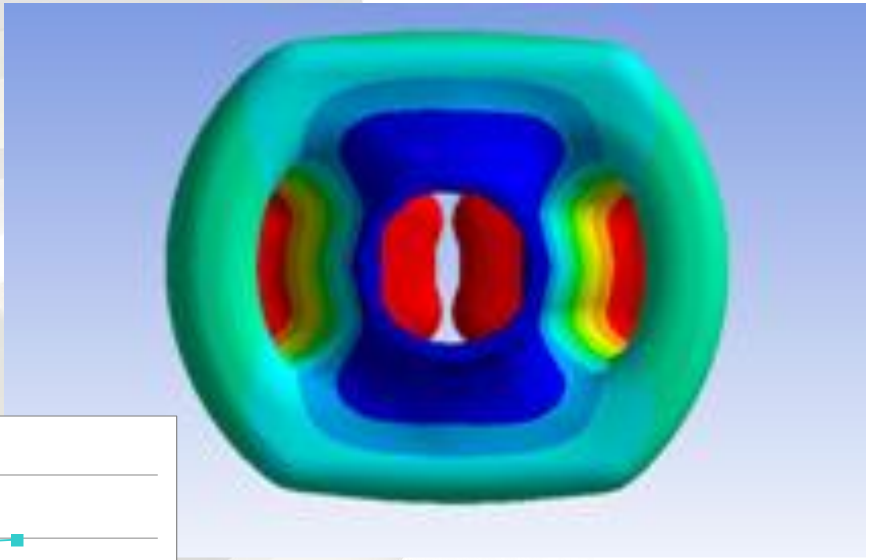


Breathing mode also found at 2 kHz

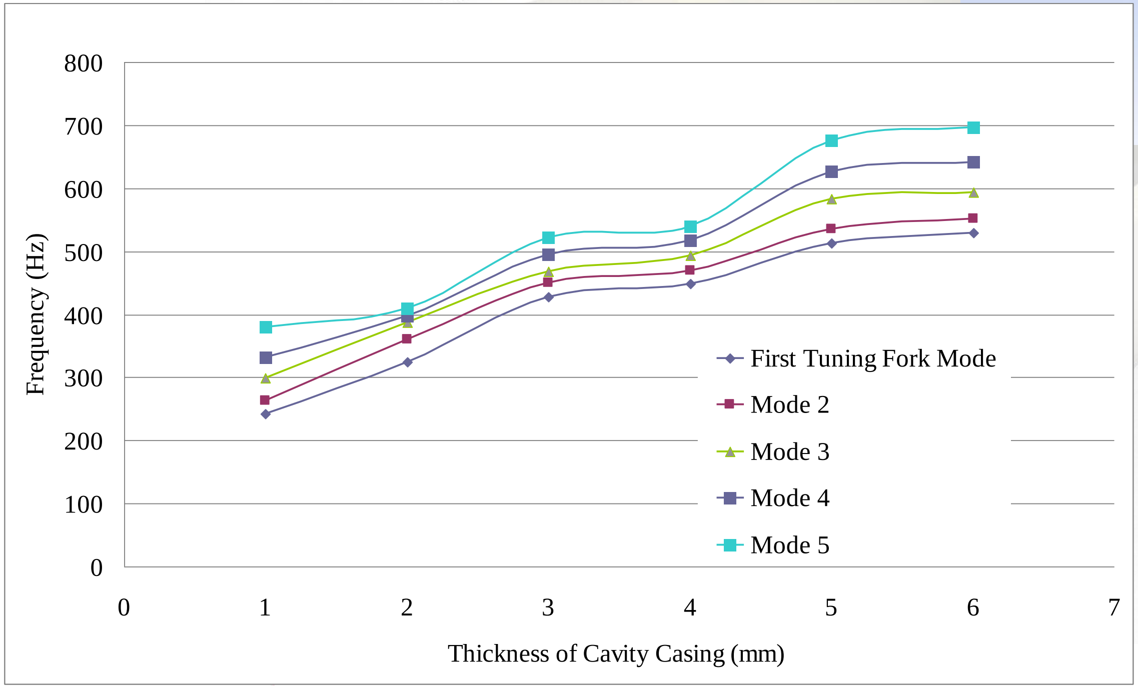


Tuning fork mode

- As the baseplate has some give, the frequency of the rod vibration is much lower (450 Hz) when we model the full cavity



With a 4 mm wall thickness all resonances are pushed up above 450 Hz.



Conclusions

- Nb 4R Crab cavity prototype order has been placed.
- The rods will be machined out of a solid Nb ingot.
- Rod profile modified to allow both sections to be made from a single ingot.
- 4 mm wall thickness seems appropriate based on microphonics and pressure sensitivity calculations.
- Machining the rods allows a variable thickness to be used if required.
- The outer can has several ports to allow additional HPR.