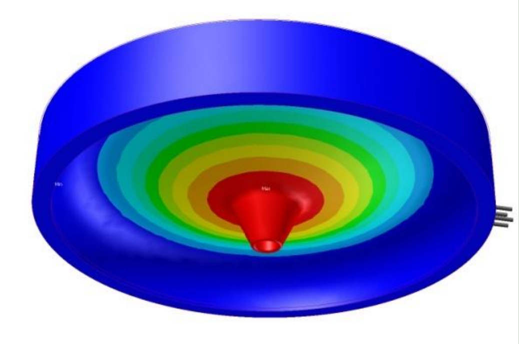
FETS Meeting @ Warwick

FETS MEBT Re-bunching Cavities

By P. Savage

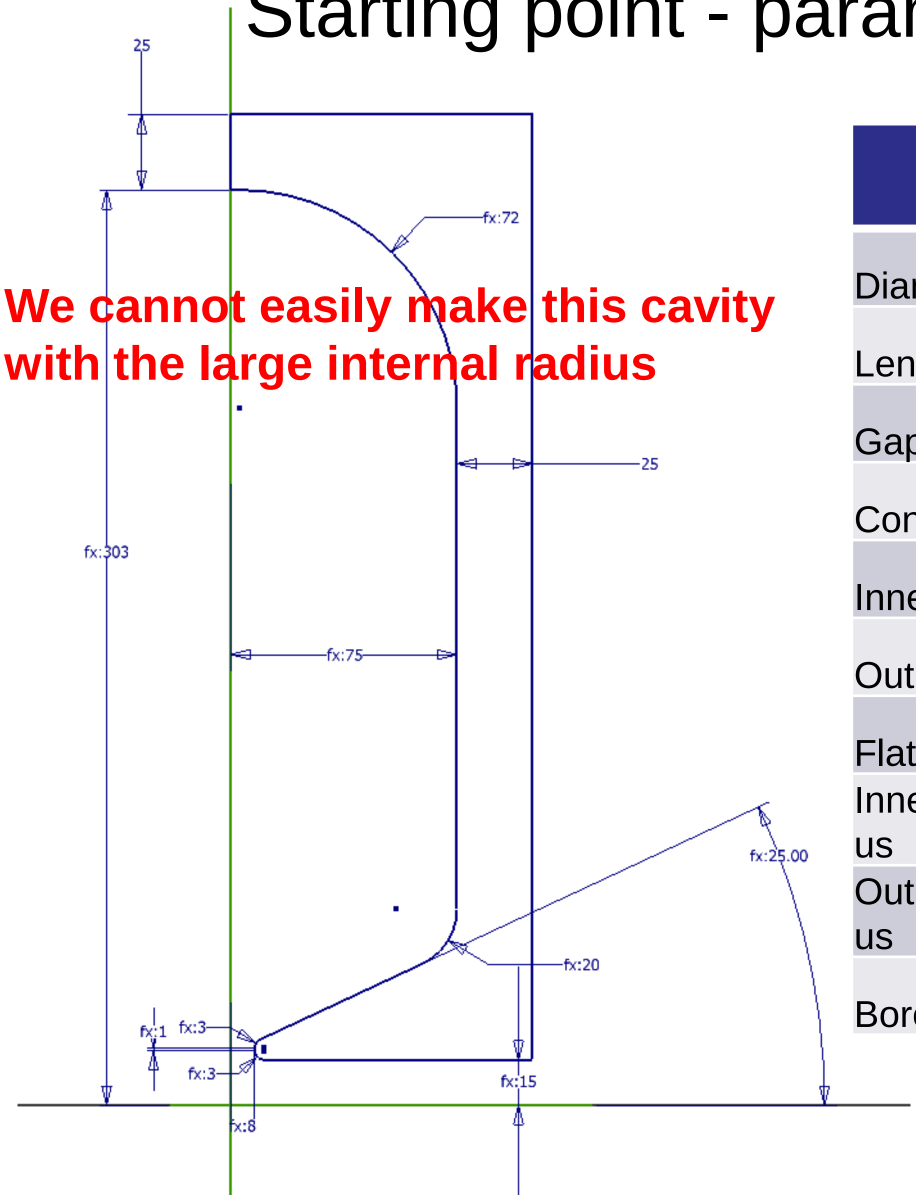
31st July 2013



Contents

1. Effect of port size on inner radius
2. Tuning range
3. Cavity cooling
4. Copper plating

Starting point - parameters from Ciprian

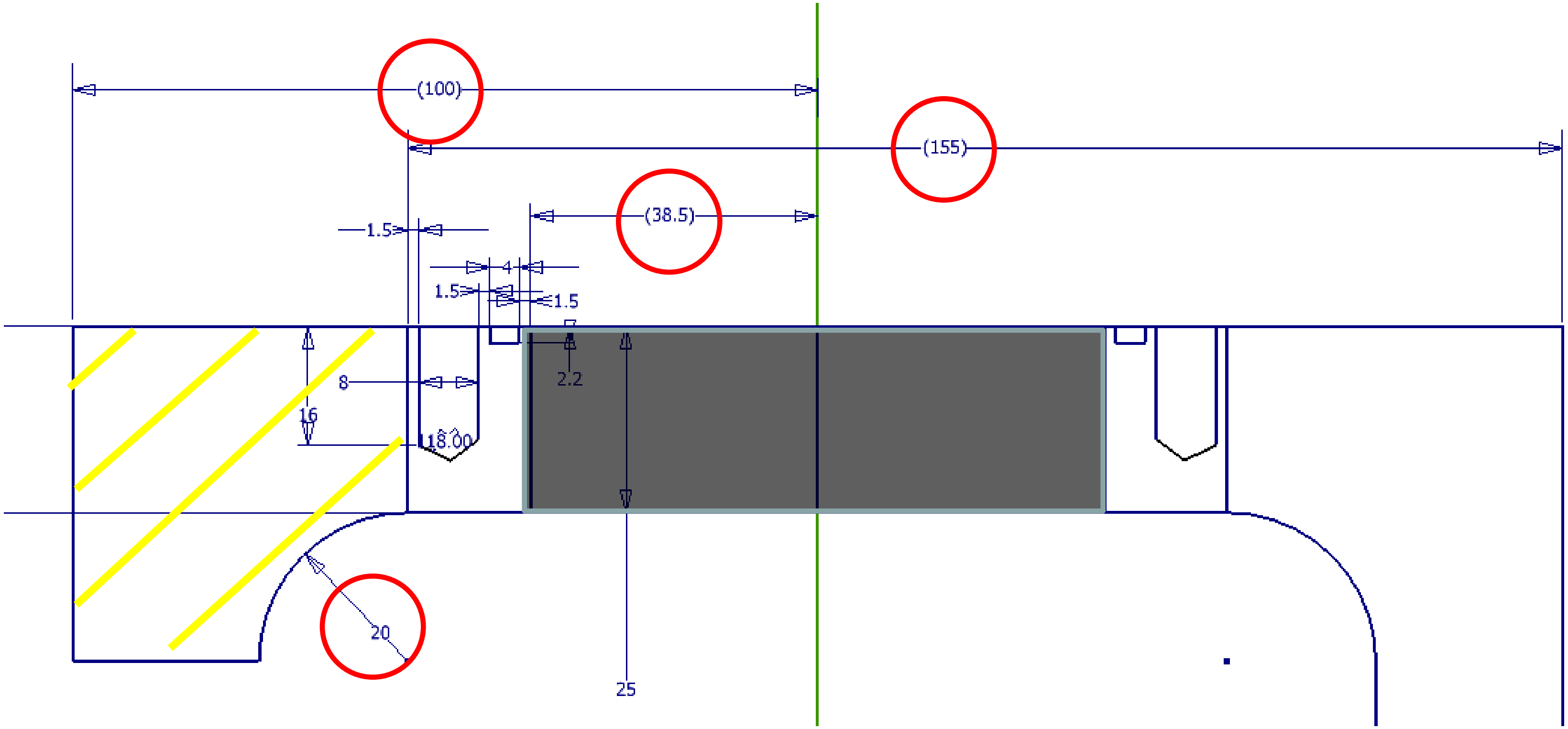


We cannot easily make this cavity with the large internal radius

Feature	Size	Unit	Description
Diameter	606	mm	Major diameter D
Length	150	mm	Length L (in Z direction)
Gap	16	mm	Nose to nose
ConeAngle	25	deg	
InnerCornerRadius	20	mm	Ric
OuterCornerRadius	72	mm	Roc
FlatLength	1	mm	F
InnerNoseConeRadius	3	mm	Rinc
OuterNoseConeRadius	3	mm	Ronc
BoreRadius	15	mm	Rb

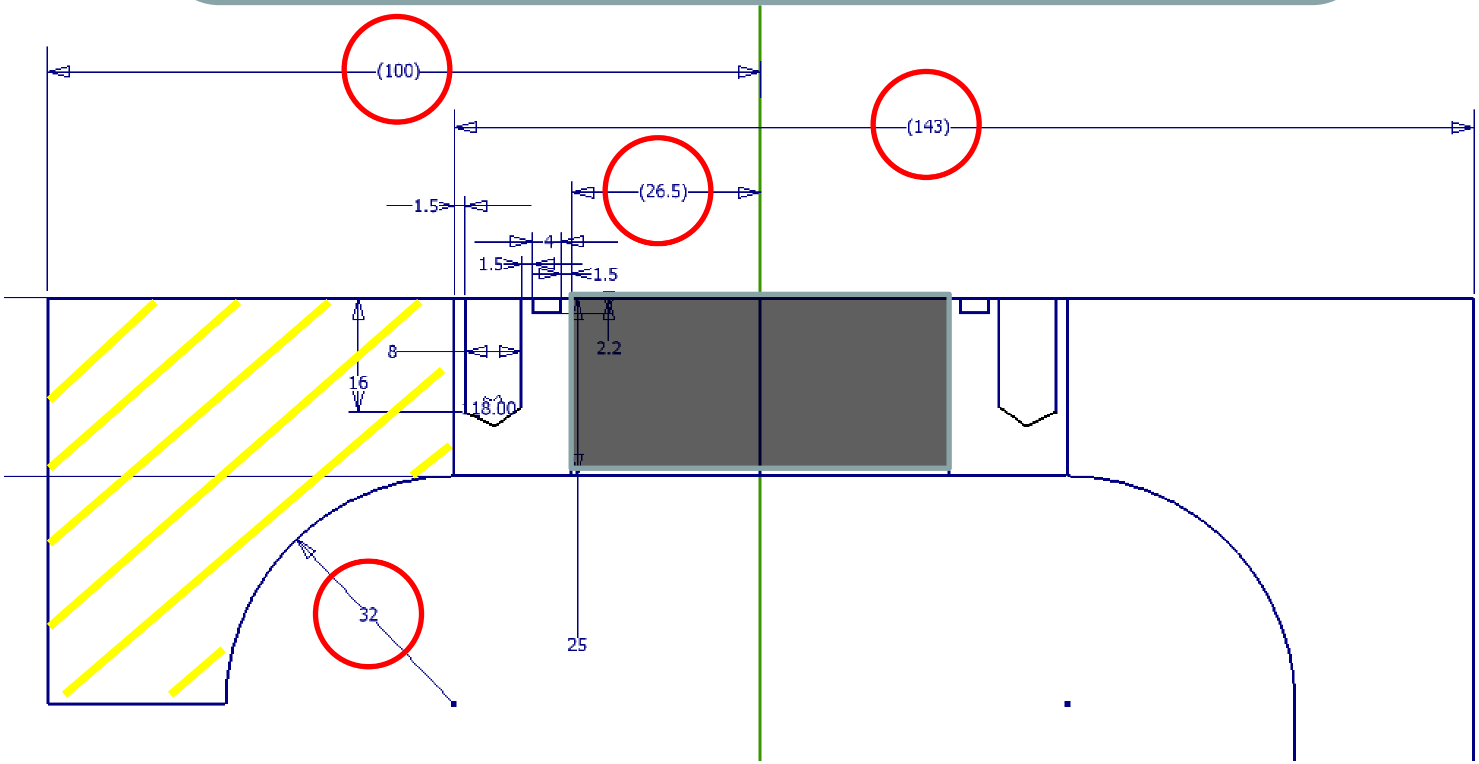
Effect of port size on inner radius

- Radius = 20.0 mm
- Max port radius= 38.5 mm
- Large billet thickness = 155 + 10 = 165.0 mm
- Small billet thickness = 100 + 10 – 8 = 102.0 mm



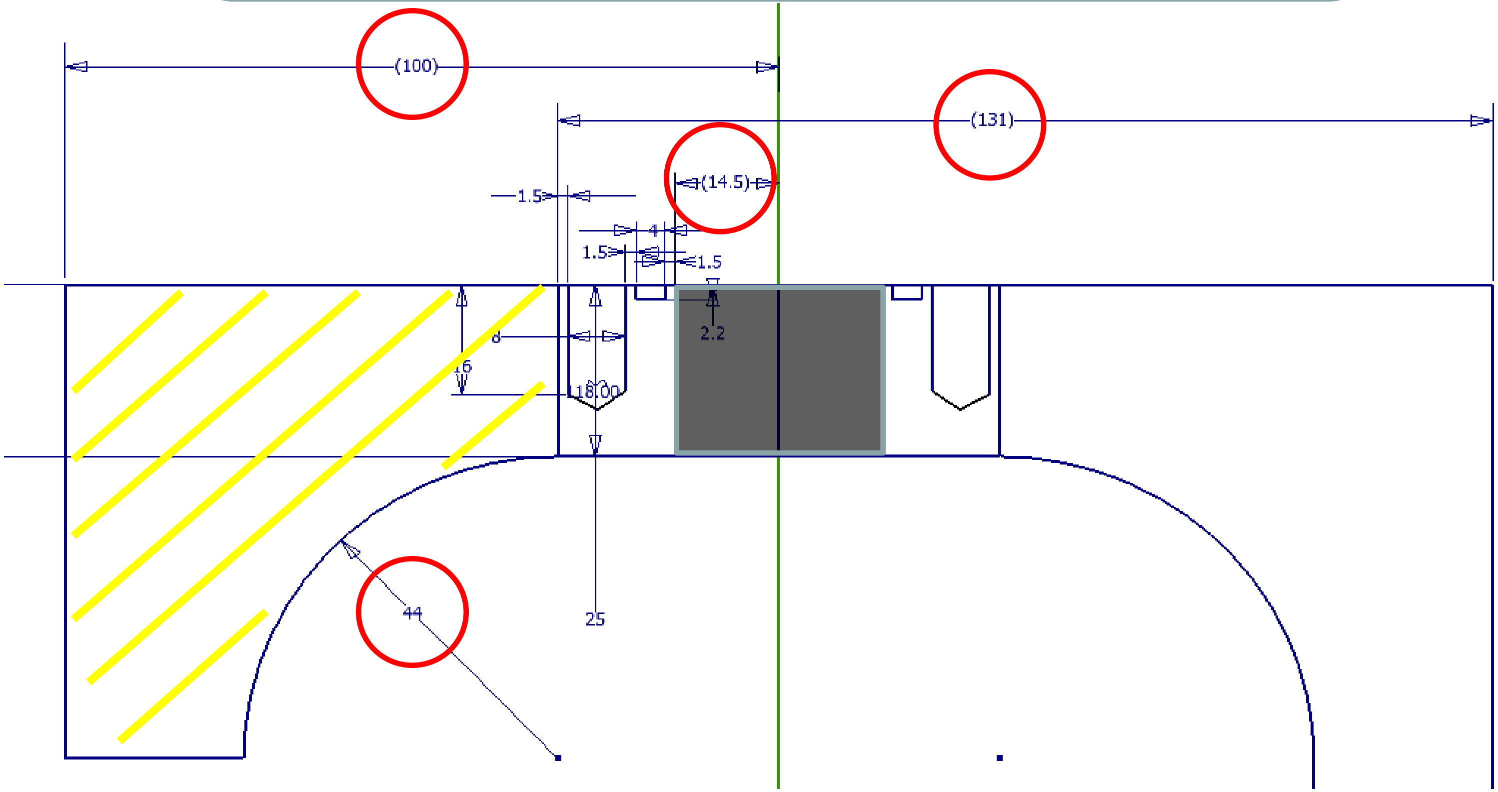
Effect of port size on inner radius

- Radius = 32.0 mm
- Max port radius= 26.5 mm
- Large billet thickness = 143 + 10 = 153.0 mm
- Small billet thickness = 100 + 10 – 8 = 102.0 mm



Effect of port size on inner radius

- •Radius = 44.0 mm
- •Max port radius= 14.5 mm
- •Large billet thickness = 131 + 10 = 141.0 mm
- •Small billet thickness = 100 + 10 – 8 = 102.0 mm



Effect of port size on inner radius

Radius (mm)	Max Port radius (mm)	Large billet thickness (mm)	Small billet thickness (mm)
20	38.5	165	102
24	34.5	161	102
28	30.5	157	102
32	26.5	153	102
36	22.5	149	102
40	18.5	145	102
44	14.5	141	102

Pumping speed ↑ .... Q value ↓ .... Material price ↑

As the port size increases the pumping speed increases but the space available for an internal radius decreases, which squares off the internal shape, lowering the Q. Additionally, the large billet gets thicker (extends further across the centre-line) and hence gets more expensive.

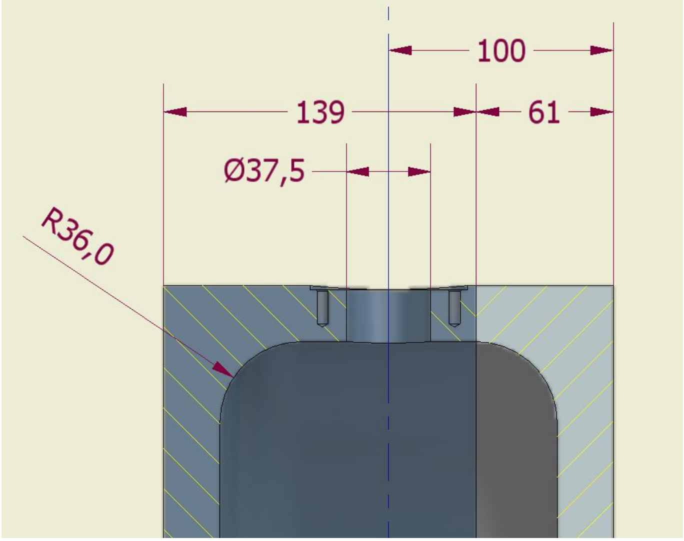
Frequency modelling

Model	Inner radius (mm)	Frequency MHz	Q	Q change (%)	Diameter (mm)	Max port diam (mm)	Purpose
51	72	323.95	28284	0	606	0	Baseline model with no ports
71	36	315.68	27963	1.15	606	45	To investigate effect of 36mm internal radius
72	36	321.17	27900	1.38	591	45	Reduced diameter to bring frequency up
73	20	321.85	27496	2.87	584	77	To investigate effect of 20mm internal radius
74	36	324.17	27861	1.52	583	45	To bring the frequency to 324MHz
75	36	324.06	27745	1.94	583	45	Model 74 with 4 diameter 45mm ports
76	36	323.97	27712	2.06	583	45	Model 75 with 1 port enlarged to 77mm diameter

Conclusion

The cavity internal profile should be chosen to best balance the following items:

1. Internal radius which affects the Q value
2. Port size (and hence pumping speed)
3. Material billet size (cost and machining time)



The current cavity model has a 36mm internal radius and 4 identical 37,5mm diameter ports (that could be increased to 45mm diameter).

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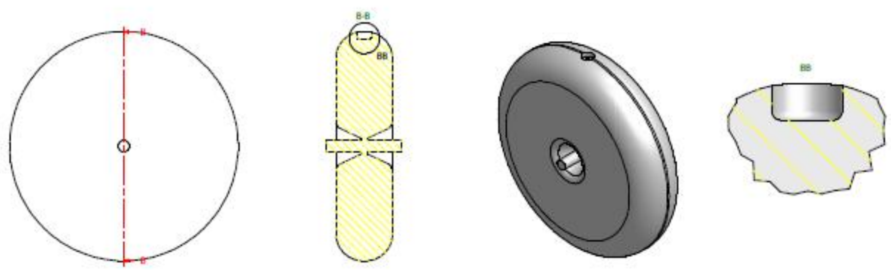
Tuning range

Model	Frequency MHz	Difference kHz	Description
51	323.953	0	No tuner port - baseline
52	323.949	- 4	Tuner flush with inside face
53	324.176	+223	Tuner in cavity by 40mm
54	323.938	-15	Tuner out of cavity 10mm
55			Tuner in cavity by 10mm
56			Tuner in cavity by 20mm
57			Tuner in cavity by 30mm



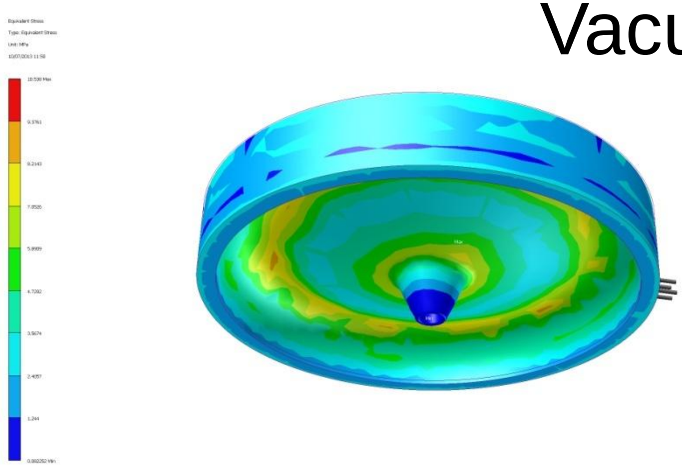
Filename: 56_ReBunchingCavity5_InnerVolume_TunerIn20mm

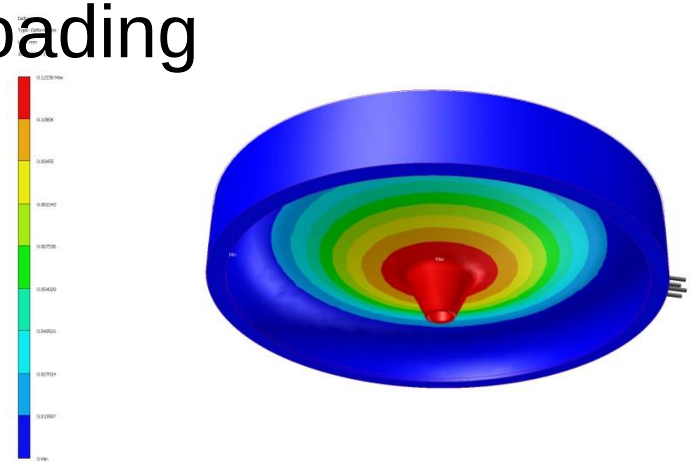
With a 50mm travel tuner drive and a tuner plug diameter of 37,5mm (same as RFQ) we have a tuning range of ~ 240kHz.

Need to ensure that tuner can compensate for cavity deformation due to vacuum and cavity growth due to thermal expansion

ISIS Imperial College London THE UNIVERSITY OF WARWICK ESS bilbao ASTeC Royal Holloway University of London J.A.I. UCL

Vacuum loading





Material	Max equ. stress (MPa)	Deformation (microns)
Copper	10.6	70
Aluminium 6061	10.5	120
Mild steel	10.2	40
Stainless steel	10.4	44

- The deformation is per half cavity.
- Cooling channels are not included and will increase stress and deformation.
- Need to model change in frequency due to deformation.
- Vacuum loading deformation may be outside of tuning range.

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ESS Rebunching cavity parameters

Peak power	**14 kW**
Average power	1.4 kW*
Temperature rise (at nose)	2^0C
Water mass flow rate	0.077 kg/s (in each channel)
Channel diameter	7 mm
Water velocity - after elbow	3.6 m/s
Water velocity - average	2.2 m/s
Stress	Negligible
Material	Stainless Steel (304)
Plating	Copper, 30 microns thick
RF / vac seal	HELICOFLEX

[2]35 kW peak power for a 4% duty, giving thus a 2.5 safety factor respect to the simulated dissipated power on the walls. See Table 3.

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ESS Rebunching cavity parameters

MOP235 Proceedings of HB2012, Beijing, China

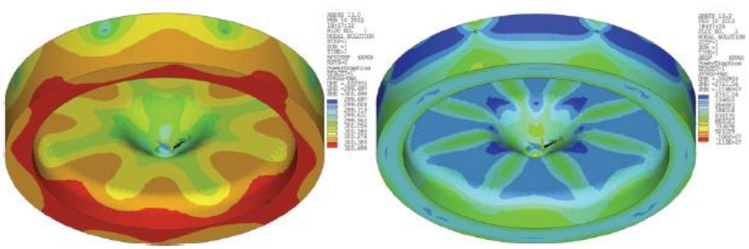
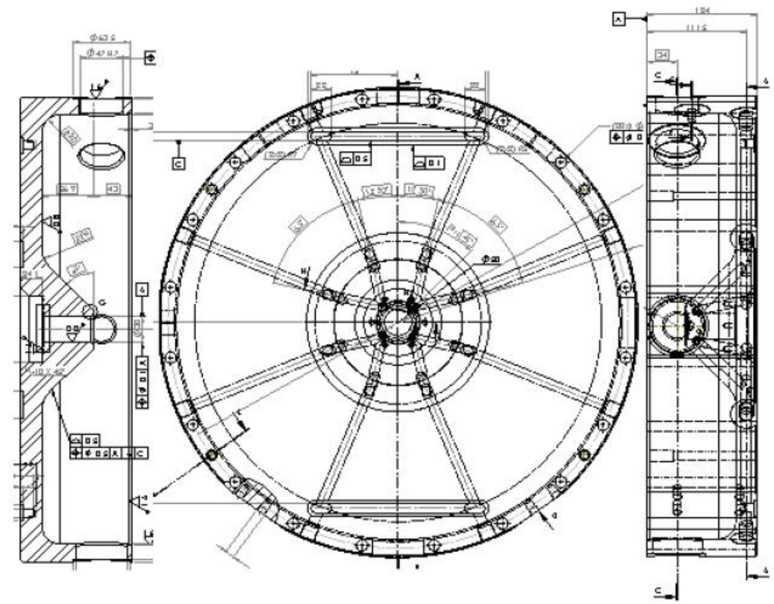


Figure 7: Ansys temperature (left) and stress (right) fields.

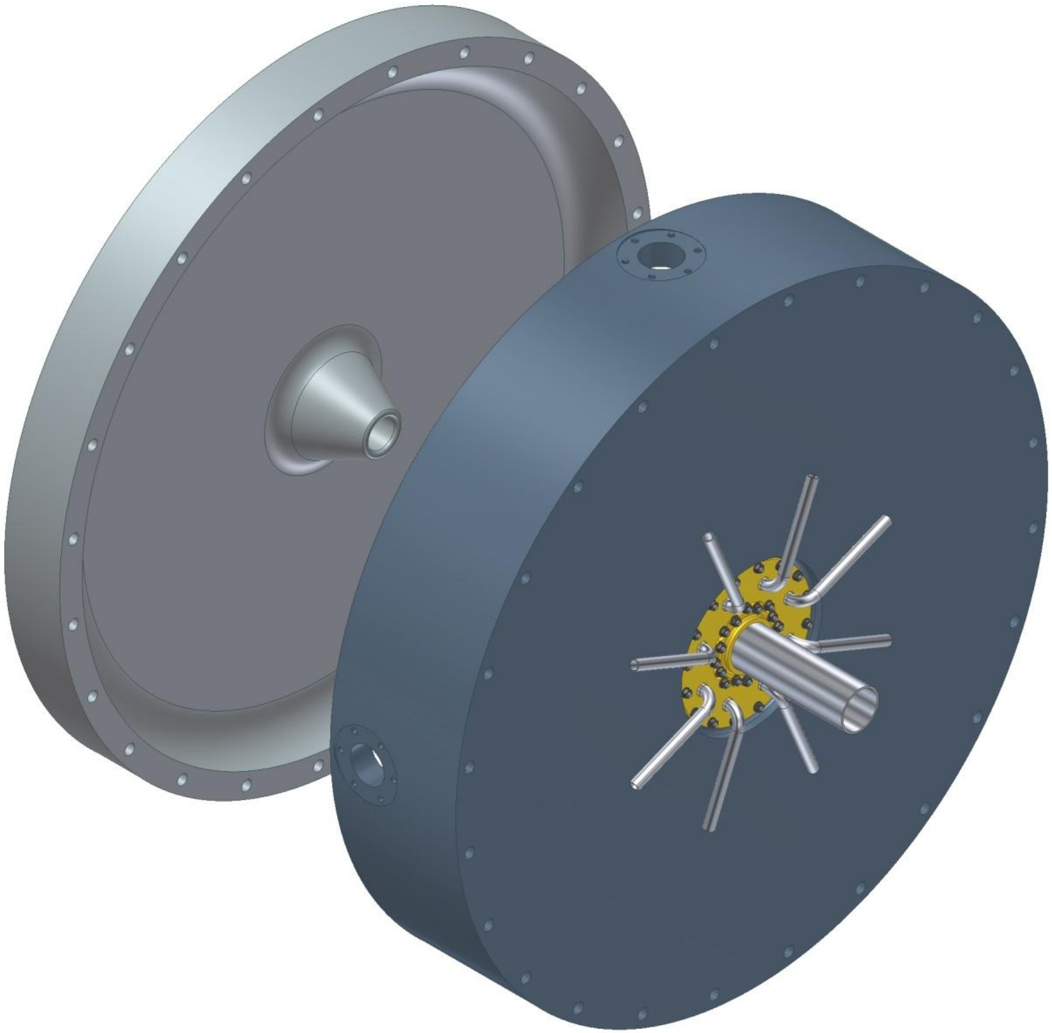
Table 3: Computed Figures of Merit for the Optimized *A30W126T45v1*. Results for the CERN and FETS cavities are also presented.

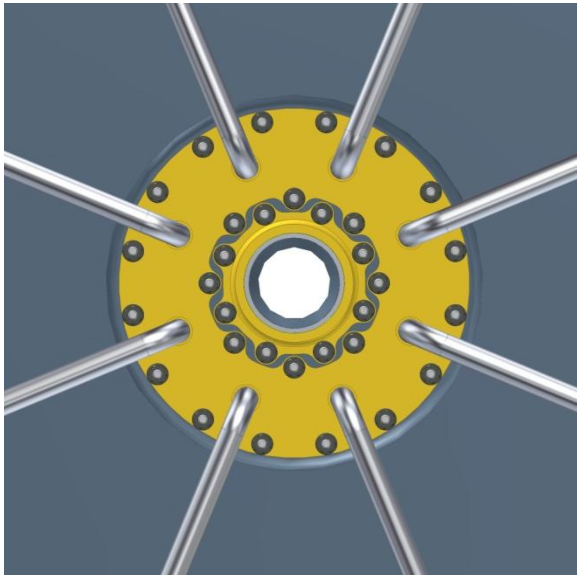
Model	ESS	CERN B30	FETS
Freq, [MHz]	352.20	357.22	315.86
Q_0	23477	24129	27222
T	0.593	0.56	0.636
V_0T, [kV]	140	140	160
P, [kW]	14.02	15.38	11.82
r, [MΩ]	1.4	1.27	2.35
ZT^2, [MΩ/m]	11.1	10.11	15.67
$E_{s,max}$, [MV/m]	27.2	24.25	27.56
Kilpatrick (b)	1.47	1.3	1.49

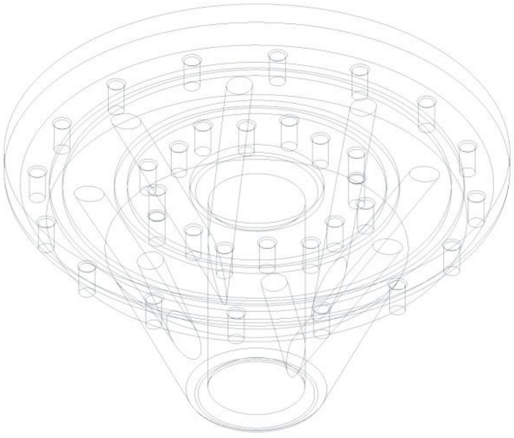


- Diam 47 ports
- Diam 20mm internal radius

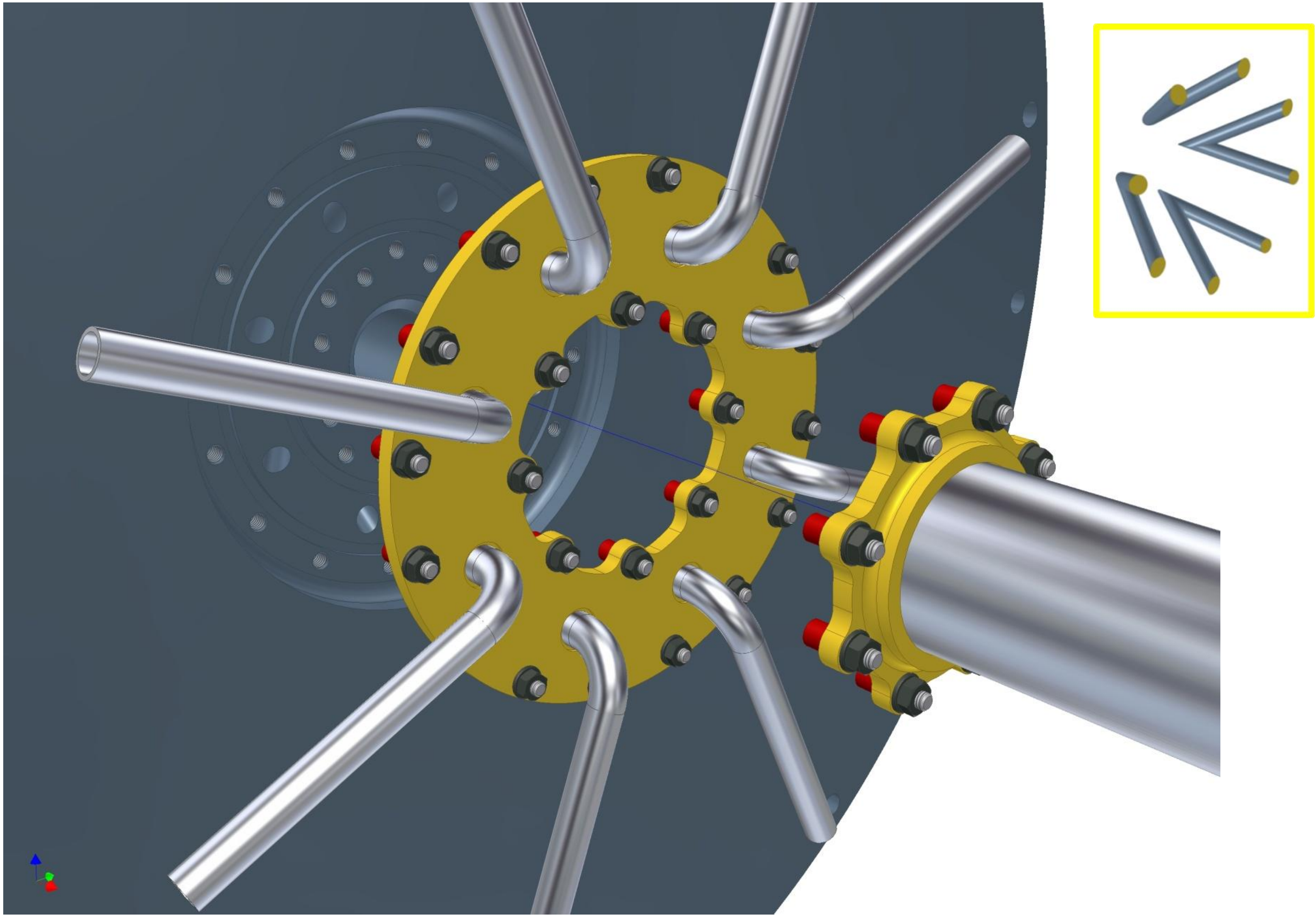
FETS cavity cooling – nose region only







FETS cavity cooling – nose region only



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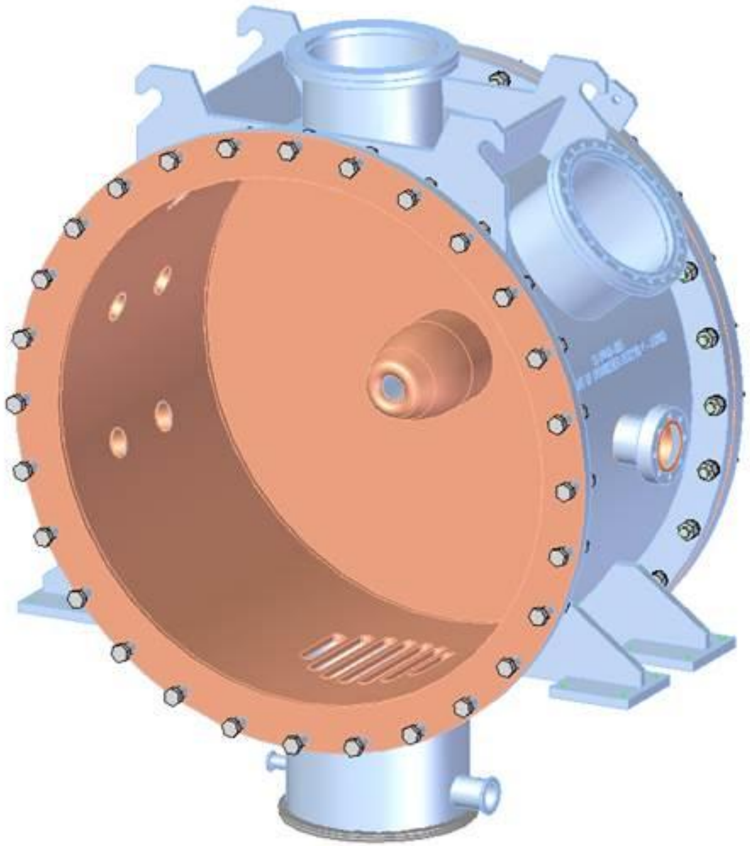
Copper plating about to be done for RAL



- RF powered debunching cavity
- Designed by Ben Drumm @ RAL
- Contact recommendation from Alan
- 1m diameter x 0,5m long
- Stainless steel 304L
- (L = low carbon - for improved weldability)
- Copper plated
- Company: NiTEC UK Ltd (Derbyshire)
- Minimum plating thickness = 200 microns

[A second plating job @ RAL – Linac tank components by Bradley Kirk, material is mild steel, 25 micron thick nickel plate layer applied first]

Copper plating - general

Step 1: **Electroless** nickel plating

Described as an autocatalytic process

"Autocatalytic reactions are chemical reactions in which at least one of the reactants is also a product" - Wikipedia

- Nickel is suspended in a salt solution.
- Nickel will not bind to an oxide layer.
- In the case of aluminium, which oxidises very rapidly, even taking from one solution bath to another – they first plate with a very thin layer of zinc.
- Then the cavity goes into the nickel solution which first removes the zinc and then deposits the nickel on the unoxidised metal surface.
- The process is very controllable and uniform.
- Plating deep holes is not a problem.

Step 2: **Electrolytic** copper plating

- The nickel plated cavity is copper plated using an electrolytic process.
- The process is not very controllable or even, e.g. A requested minimum thickness of 200 microns could yield 250 to 280 microns thick in places.
- Variation is exaggerated by thicker layers i.e. If we specify a 25 microns layer the variation may only be 5 to 8 microns.

How thick should our Copper plating be?

The AC current density J in a conductor decreases exponentially from its value at the surface J_S according to the depth d from the surface, as follows:

$$J = J_S\, e^{-d/\delta}$$

where δ is called the *skin depth*. The skin depth is thus defined as the depth below the surface of the conductor at which the current density has fallen to $1/e$ (about 0.37) of J_S. In normal cases it is well approximated as:

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}.$$

where

- ρ = resistivity of the conductor
- ω = angular frequency of current = 2π × frequency
- μ = absolute magnetic permeability of the conductor[1]

Source:
http://en.wikipedia.org/wiki/Skin_effect

ρ (Copper) at 20 °C =	1.68×10^{-8} Ω·m
ω =	$2\pi(324\times10^{6})$ Hz
μ =	1.2566290×10^{-6} H/m

Current density falls to 0.37 of the surface value at....

...skin depth $\delta = 3.624\times10^{-6}$ m = 3.6 microns

Lets apply a safety factor of 3 giving 11 microns minimum Copper thickness.

Plating procedure

1. Both cavity pieces are machined to the final shape will all internal and external features – internal shape should be correct after vacuum is applied.
2. The tapped holes on the outside for the cooling and vacuum stainless steel closure plates would be fitted with nylon screws to prevent plating. If aluminium or copper are chosen then the holes may be pre-fitted with thread inserts.
3. Nickel is then plated onto the pieces.
4. Next the nickel plated cooling holes are bunged or taped to prevent plating and then the copper is plated on.
5. Now we have nickel lined cooling holes which will not get eroded by the de-mineralised water flow.

Cavity materials comparison

Material	Material price £	Scrap recovery £	Copper Plating £	Total £	Difference £	Machining time	Thermal expansion microns.m /K	Thermal cond. W/m.Kv	Thread s inserts? Yield / Ultimate (MPa)	Weight kg
Copper	30,000	-7,500	0	22,500	0	Slow	16	400	70 / 220	246
Al 6082 T6	4,500	n/a	9,000	13,500	9,000	Medium / Fast	24	180	340 / 310	74 (6061)
Al 7075	7,000	n/a	9,000	16,000	6,500	Medium / Fast	24	155	450 / 500	-
Mild steel	4,800	n/a	7,200	12,000	10,500	Medium	17	45	250 / 800	216
Stainless steel	?	-	9,000	-	-	Slow	17	18	500 / 800	222

Conclusions:

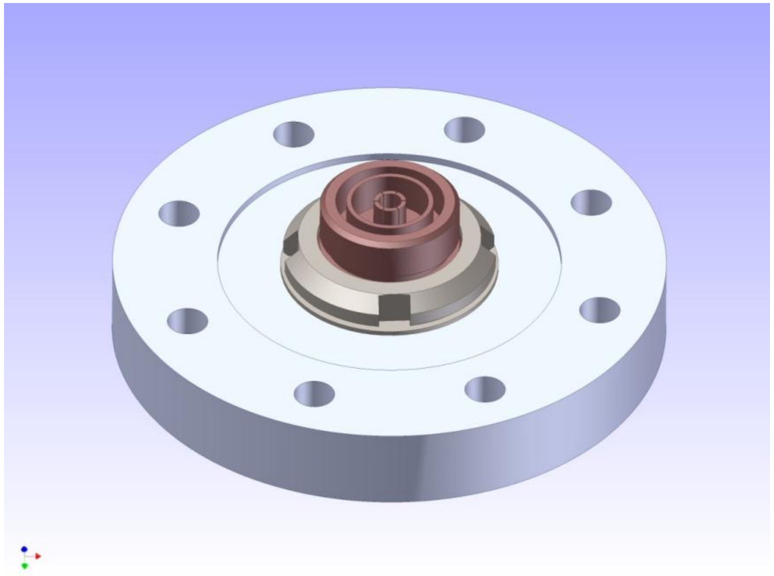
Electrical performance :	plated should in theory perform the same as solid
Platability: Best to worst:	mild steel, stainless steel, aluminium 7xxx, aluminium 6xxxx
Cooling: Best to worst:	copper, aluminium, mild steel, stainless steel
Cost: Low to high:	aluminium 6xxx, mild steel, stainless steel, aluminium 7xxx, copper
Machinability: Best to worst:	aluminium, mild steel, stainless steel, copper
Weight: Low to high:	aluminium, steel, copper (handling, alignment, support deflection)

Cavity – to do list

1. Meet with Jim Loughrey & Co to discus installation – 14th Aug T.B.C.
2. FETS team to choose cavity material.
3. Simulate cooling scheme – power density internal current flow.
4. Check stresses and deflection with cooling channels included.
5. Model frequency shift due to vacuum loading deformation and temperature rise. Is the tuning range sufficient?
6. Get representative shaped test piece plated and measure plating thicknesses (or can we learn from Ben / Bradley?)
7. Extrapolate to determine plating thicknesses on real cavity.
8. Re-model CAD model interior volume oversize (if to be plated) to account for:
    1. 25 microns nickel
    2. ~25 microns copper
    3. Vacuum deformation
9. Consult with Helicoflex manufacturers for seal specification and sealing face geometry.
10. Detail engineering drawings (could be contractor)
11. Pass to OM to handle manufacture.
12. Inspect delivered cavities
13. Vacuum test and bead-pull test.
14. Install on beam line

Any questions?

CF63 N-type feedthrough



Allectra
£300 - £400