MQXFA Welding Shim
FE Analysis

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LBNL
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We want to evaluate the effect of the welding shim on the magnet. Main questions:

- Can this shim allow to better control the coil peak stress variation as a function of the magnet/vessel interference?
- Thanks to the shim, can friction can prevent relative displacements of the magnet w.r.t the ss vessel?
2D Model Description

- Full 2D, variable welding shim size and shell/vessel interference
- Welding shim introduced as shell/vessel interference
Circ. interf. computed on the ‘loaded’ magnet
The welding shim allows for a lower sensitivity to the circumferential interference especially in the regions with low vessel stress
Allowed stress increase on the coil: ~4 MPa at R.T.
What is the expected tolerance?
Radial contact force can be used to estimate the frictional force
- Total force in cross-section
- Can be used to prevent motion during transportation and during test at cold temperature
- This would easily work, but is not the critical case – same force required as during a quench, with higher interference.

The relationship between vessel/pole/force is linear – not affected by shim thickness
- From the required force, we can easily compute the minimum vessel and pole stress
- 3D and 2D models give similar results, also close to analytic estimate
- Increase in circular interference to get back to the same stresses: 1.2 mm
  - Integral contraction of the magnet: 3.54 mm/m
  - Stainless steel contraction: 2.95 mm/m
- In the range below 10 MPa, shims < 1 mm might be too sensitive to the interference
  - Easy to ‘loose’ contact with small errors
  - Need to estimate the real ‘control range’
- Non-linear relationship between R.T. pole stress and radial force at cold
- This is expected as we are in the ‘non-linear’ region of the shim
How much force do we need at cold?
- 123 kN long, with 0.1 friction: 1230 kN, or 307 kN/m
- 154 kN/m with 0.2, 51 kN/m with 0.6

Stress increase required is below 3 MPa with a shim of at least 1 mm

However, the available ‘error band’ is significantly reduced
- Using a 0.2 friction coefficient, this is equal to ~0.5 mm on the R.T. interference
- With higher friction coefficients it increases (~doubles at 0.6)
- We would need to evaluate the friction coefficient experimentally, possibly as a function of the normal load
3D Model – Description and validation

- Simplified 3D model to check effects during thermal cycles
  - Octant model would not be sufficient
  - Loading as interference between the collar and the yoke
- Main results compared with the usual octant model
  - Average vertical pole and shell stress on the mid-plane, radius variation after loading and after cooldown
  - Surprisingly close, no?

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Step</th>
<th>Model</th>
<th>Value</th>
<th>Unit</th>
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<td>MPa</td>
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Checking, during a thermal cycle, the impact on:

- Coil stress → Negligible
- Shell stress → Negligible
- Shell longitudinal displacement (at z=0) → 20 µm reduction
- Vessel contact force → ~10% reduction after the first t.c.
- More thermal cycles in the additional slides
Conclusion

- The welding shim allows for a better control on the coil stress
  - For the same magnet/vessel interference variation, the coil stress variation is reduced
  - We can allow for larger ‘errors’ in the interference
    - E.g. magnet size, vessel circumferential length

- With the welding shim, it might be possible to hold the magnet by friction with no significant impact on the coil stress
  - However, this possibility is strongly dependent on the friction coefficient considered

- We built a simplified 3D model to check the impact of thermal cycles on the magnet
  - Negligible effects on the coil and the shell stresses
  - Slight reduction of the longitudinal displacement of the shell
  - Vessel contact force reduced after the first thermal cycle ~ 10%

- Further checks, in progress:
  - 2D: Sensitivity analysis to vessel t.c. (2.8 to 3.2 mm/m)
  - 3D: Thermal cycle in standard model
  - 3D: More thermal cycles with the vessel shim
The relationship between the vessel stress and the pole stress does not depend on the shim thickness.
### Vessel stress / Pole Stress

<table>
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<tr>
<th>Step</th>
<th>scoil</th>
<th>sshell</th>
<th>svessel</th>
<th>fx_cont</th>
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- Results, 3D, no vessel
If want to keep the pole stress below 5 MPa at warm (2 mm shim), very roughly:

- With 0.1 friction coefficient it does not work
- With 0.2 it can work. Range of acceptable circular interference ~ 0.5 mm.
- With 0.6 close to 2 mm
- We would need to prove that the friction coefficient is so high!

<table>
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<th>cinterf [mm]</th>
<th>spole_rt [MPa]</th>
<th>spole_cd [MPa]</th>
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<th>svessel_cd [MPa]</th>
<th>fcont_rt [kN/m]</th>
<th>fcont_cd [kN/m]</th>
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