Stresses & Deformations in Vessel Containing Copper Magnet & Shielding

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Model: Vessel (bore tube, flanges & cylindrical shell) are of steel; specific gravity $\gamma = 7.85$; $E = 200$ GPa.

Shielding, of $\gamma = 9.88$ (60% WC of $\gamma = 15.8 + 40\%$ H$_2$O), exerts pressure proportional to depth.

Overall dimensions: outer radius $r_2 = 1.15$ m; upstream end $z_1 = -2.35$ m; downstream end $z_2 = 3.00$ m.

Thickness of: 1) Flange: $t_f = 0.05$ m; 2) Bore tube: $0.04$ m; 3) Outer cylindrical shell: $0.03$ m.

I.R. of bore tube = $0.08$ m for $-2.35 < z < 0$, flaring elliptically thereafter as in blue curve of Fig 1.

To reduce number of mesh elements, model effect of bore tube by its axial force on flanges.

**Inner Radius of Bore Tube that Flares Elliptically with Axial Distance**

Fig. 1: Inner radius of bore tube that flares elliptically from $r = 0.08$ m at $z = 0$ to $r = 0.30$ m at $3$ m (gray curve), $4$ m (green), $5$ m (turquoise), $6$ m (blue), $7.5$ m (magenta); $10$ m (red) or $15$ m (black).
Fig. 2: Isometric view of vessel, with cylindrical shell, flanges, and bore tube of constant inner radius of 0.08 m from \( z = -2.35 \) m to 0, flaring elliptically thereafter to 0.262 m at \( z = 2.95 \) m.

Fig. 3a-c: Von Mises stress \( \sigma_{VM} \) and deformation \( \delta \) (magnified 400 times) with weight supported by line contact of flanges with ground (boundary condition \( \delta_y = 0 \) along line segments \( [x=0, y=-r_2, (z_1-t_f) < z < z_1 \) & \( z_2 < z < (z_2+t_f)] \)). Bore-tube axial force \( \equiv 120 \) kN; maximum axial stress \( \sigma_z \approx 4.8 \) MPa; maximum axial strain \( \varepsilon_z \approx 2.4 \times 10^{-5} \); bore-tube elongation \( \Delta z < 0.12 \) mm. Left: Maximum localized \( \sigma_{VM} \approx 450 \) MPa; typical \( \sigma_{VM} \approx 10-20 \) MPa. Center: Isometric view of deformation; maximum \( \delta \approx 0.66 \) mm. Right: View from x axis, with y rightwards and z upwards.