Design of dewar supports through topology optimization

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Introduction

- Large dewars employ support systems to hold the inner and outer vessels
- Supports should be mechanically strong and allow minimal heat inleak through them
- Design of supports become an optimization problem

Objectives

- To design an optimized dewar support system
- To study the stress distribution in, and heat inleak through a dewar support member

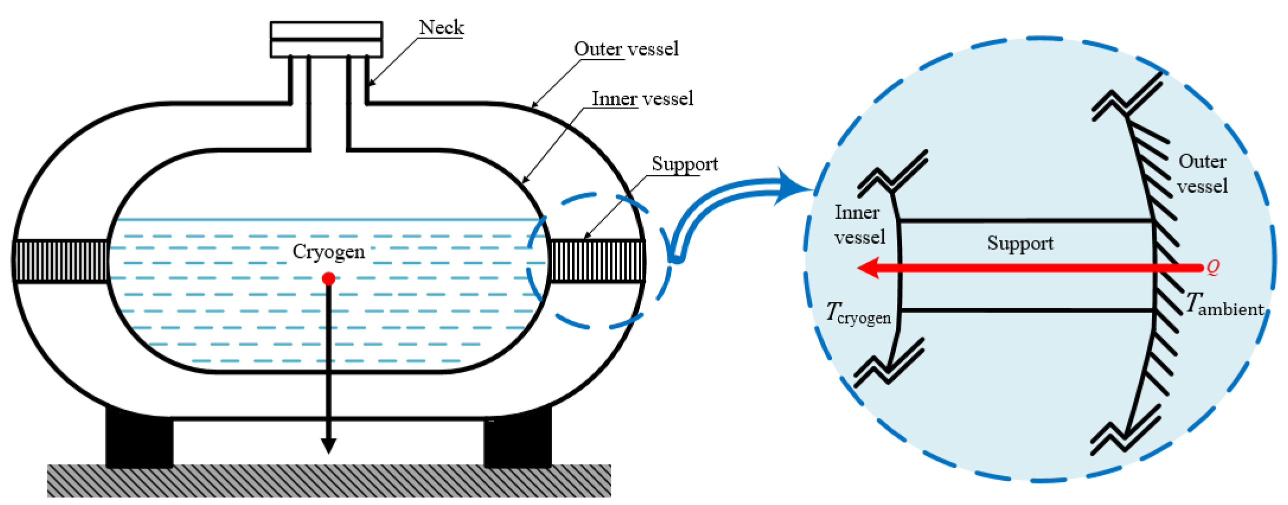

Figure 1: Typical support system in a dewar

Model Assumptions

- Steady state
- Material of construction of the support is isotropic and homogeneous
- Heat inleak to the inner vessel is due to only conductive heat transfer through the support member
- Weight of the support member is negligible compared to the loads acting on it

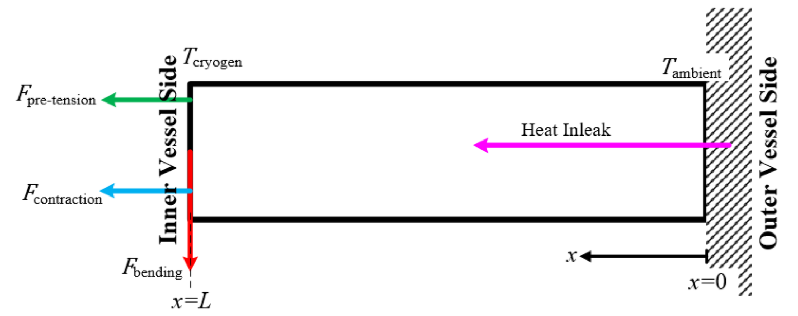

Figure 2: Forces acting on, and heat inleak through a support member

Model Equations

Stress Distribution

$$\sigma_{\text{bending}} = \frac{My}{I} \quad (1)$$

$$\sigma_{\text{pre-tension}} = \frac{F_{\text{pre-tension}}}{A} \quad (2)$$

$$\sigma_{\text{contraction}} = E\alpha\,(\Delta T) \quad (3)$$

$$\sigma = \sigma_{\text{bending}} + \sigma_{\text{pre - tension}} + \sigma_{\text{contraction}} = \frac{My}{I} + \frac{F_{\text{pre - tension}}}{A} + E\alpha\,(\Delta T) \quad (4)$$

$$\Delta T = T\,(x,t) - T\,(x,0) \quad (5)$$

Energy Balance

$$\frac{d}{dx}\left(k\,(T)\,\frac{dT}{dx}\right) = 0; \text{B.C.}: T|_{x=0} = T_{\text{ambient}} \text{and} T|_{x=L} = T_{\text{cryogen}} \quad (6)$$

Heat inleak

$$\dot{q} = -k\frac{dT}{dx}\bigg|_{x=L} \quad (7)$$

Solution Methodology

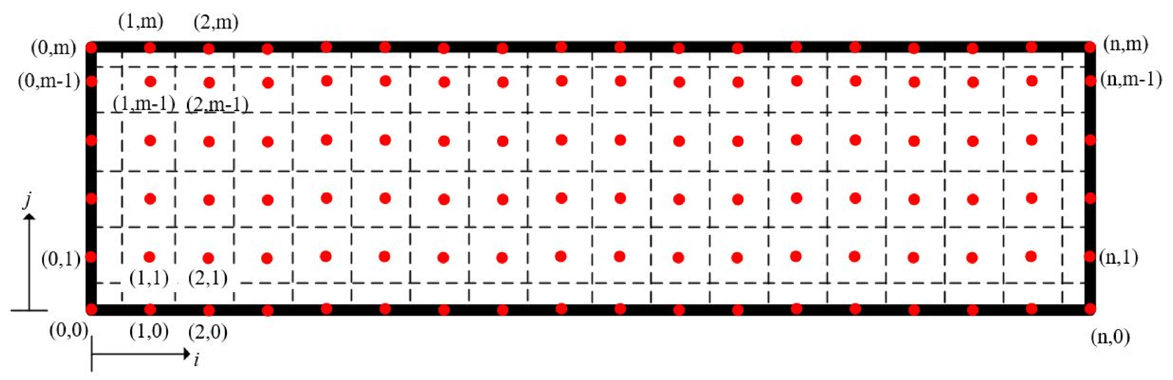

Figure 3: Meshing of the support member

- Determine stress distribution using Equation 4
- Determine temperature distribution using Equation 6
- Topology optimization (TO)
  - Initialize removal rate, RR
  - Specify evolution rate, ER
  - Compute stress ratio, SR= $\frac{\sigma}{\sigma_{\max}}$ at all mesh points
  - For $\sigma_{\max} < \sigma_{\text{ultimate}}$, compare SR and RR at each discretized control volume. Remove material if SR $<$ RR
  - If $\sigma_{\max} = \sigma_{\min}$ then update RR as $\text{RR}^{(I)} = \text{RR}^{(I-1)} + \text{ER}$
  - Continue until $\sigma_{\max} > \sigma_{\text{ultimate}}$
- Determine heat inleak and mass of support member initially and after topology optimization

Results and Discussion

Operating Conditions

Length of the support (mm)	300	Pre-tension load (N)	10000
Diameter of the support (mm)	54	Bending load (N)	10000
Ambient temperature (K)	300	Material of construction	SS 304
Temperature of the cryogen (K)	70	Density of SS 304 (kg/m^3)	8000

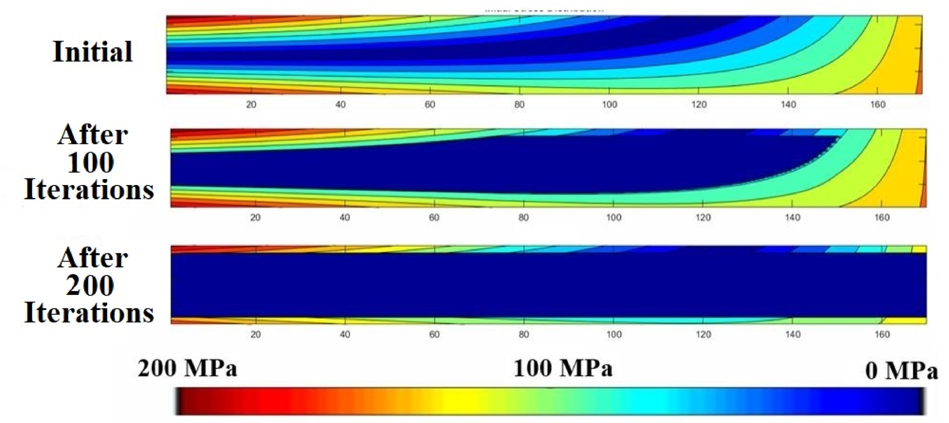

Figure 4: Development of stress field in the support member

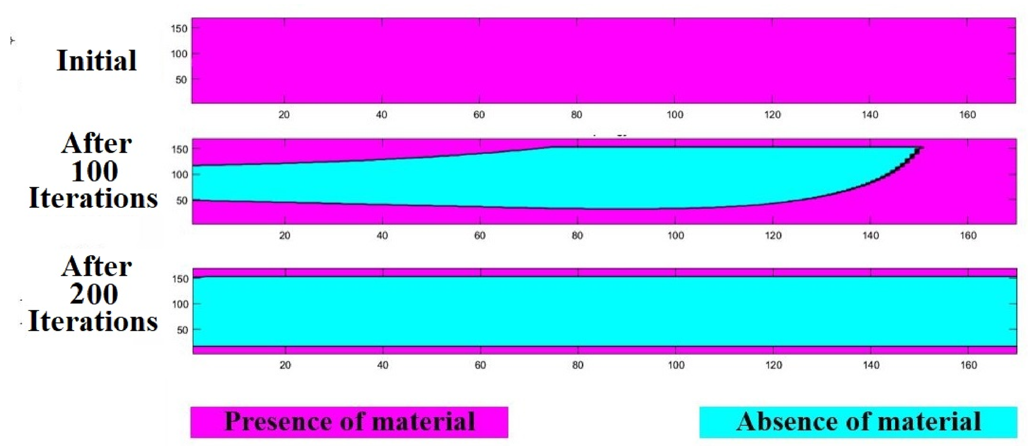

Figure 5: Evolution of topology of the support member

Optimized values

	Mass	Heat inleak
Before TO	5.49 kg	6.532 mW
After TO	1.92 kg	2.353 mW

Conclusions

- Topology optimization has been used to arrive at an optimized geometry for a dewar support system
- A reduction of 65% in mass and 64% in heat inleak in the optimized shape has been obtained

Selected References

[1] B Nitin and Pavitra Sandilya. Structural and thermal analysis of dewar supports for low boil-off long duration storage of cryogenic liquids. *Indian Journal of Cryogenics*, 43(1):33–39, 2018.

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Nomenclature

σ_{bending}	Stress due to bending	M	Moment	I	Moment of Inertia	x, y	Directions
$\sigma_{\text{pre-tension}}$	Stress due to pre-tension	A	Area of cross section	E	Young's Modulus	α	Thermal expansion coefficient
$\sigma_{\text{contraction}}$	Stress due to thermal contraction	σ	Total Stress	ΔT	Temperature difference	k	Thermal conductivity
σ_{ultimate}	Ultimate strength of the material	$\sigma_{\max}$	Maximum stres	$\sigma_{\min}$	Minimum Stress	I	Iteration count

Acknowledgement

The authors would like to acknowledge **Mr. Pritam Saha**, Research Scholar, Process Intensification Laboratory, Cryogenic Engineering Centre, Indian Institute of Technology Kharagpur, for his help and insights during the course of this work.