Abstract

- Motivated by growing interest in Hyperloop system, we have researched on a new mode of transportation that runs inside vacuum tube above 1,000 km/h.
- 2G HTS magnet with detachable cryocoolers has been developed to efficiently thrust and levitate the capsule train as well as reduces its weight. To compensate for performance loss caused by increased operating temperature, HTS coil shape of the on-board superconducting magnet is topologically optimized in view of the cost and performance respectively. With a number of linear constraints converted from nonlinear superconductivity conditions, many linear topology optimization problems are solved, and then most preferred design is determined by considering its shape, cost, and performance.

Main Characteristics of HTX
- Vacuum (0.001 atm) tube infrastructure to minimize air resistance
- Electrodynamic large air gap (100 mm) levitation using on-board superconducting electromagnets with detachable cryocoolers
- Superconducting linear synchronous motor for subsonic (over 1000 km/h) propulsion
- Streamline shaped aircraft material capsule with subsonic driving stabilization device

2G HTS Magnet Design
- To improve performance/cost:
  - Change aspect ratio (radial / axial thickness)
  - Modify coil shape and distribution
  
Optimization Model

Critical Characteristics of 2G HTS Wire
- Multi-layer REBCO coated tape
- Critical current depends on magnetic field magnitude and angle
- Nonlinear superconductivity condition $B_s(I_s) ≤ f(B_s(I_s))$ → linearizing for $I_s ≤ \theta \cdot B_s$
- $B_s ≤ a(I_s) + b(I_s)B_0$

Linear Topology Optimization

Optimization Example

- Design Specification
  - HTS wire (SuNam, SANS94200)
  - Width 4 mm
  - Length 3 km

- Optimization Example 1
  - $10 \% ≤ V_r ≤ 80 \%$
  - $100 \% ≤ I ≤ 180 \%$
  - $V_r$ or (wire length) ↑ → $B_{avg}$ ↑

- Optimization Example 2
  - $V_r = 32.42 \%$ (3 km length)
  - $I_c = 146 \, A$, $B_{avg} = 0.2560 \, T$

Design Example and Conclusion

- Performance Improvement
  - $B_{avg}$ ↑ 15-20% ↑
  - $I_c$ ↑ 14-15% ↑
  - MMF 10-11% ↑
  - Additional ways:
    - Optimize design with other product, enlarge SCM size, or increase wire length

Design Criteria
- MMF ($\mathcal{W}$)
- Magnetic field distribution $B(r) = \sum_{i=1}^{n} \rho_i A_i^{-1} B_i(r)$
- Objective function: $\max \sum w_i d_i$ subjected to $0 ≤ d_i ≤ 1$
- Superconductivity constraint: $b_0(I_s)B_0(I_s) ≤ a(I_s)B_0(I_s)$
- Wire volume (or length) constraint: $V_e = V_{tot} \sum_i V_i$
- Magnetic field relation: $B(r) = \sum_{i=1}^{n} \rho_i A_i^{-1} B_i(r)$

Magnetic Design
- To change aspect ratio
- Changing aspect ratio?

3D CAD Model

Performance Improvement
- $B_{avg}$ ↑
- $I_c$ ↑
- MMF ↑
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Design and Conclusion
- Example 1
  - $10 \% ≤ V_r ≤ 80 \%$
  - $100 \% ≤ I ≤ 180 \%$
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- Example 2
  - $V_r = 32.42 \%$ (3 km length)
  - $I_c = 146 \, A$, $B_{avg} = 0.2560 \, T$