Summary of findings, conclusions, and recommendations

Title: Mechanical and Thermal Analysis of Multi -Metallic Cryogenic Vessel for Superconducting Clinical Diagnostics

Methodology: The preliminary design of components in Solidworks and FEA simulations had been done. The experimental tools and techniques had been employed in the studies. The work shall be jointly executed with IUAC and MED, JMI. The methods as well as their specific application in the research are briefly given in this section.

1. Vacuum vessel/Helium vessel Development

Vacuum vessel will be design and developed essentially to maintain the insulating vacuum and provide the structural integrity to the entire cold mass of the MRI magnet. The vacuum vessel will provide the support the thermal shield. Helium Vessel, Superconducting magnet through axial and radial composite support links. The vacuum vessel will be designed as per ASME Pressure Vessel Code, Sec. VIII, Div.1 and subjected to qualification pressure test under 1.43 times the allowable pressure. The helium vessel will be designed to provide the bath cooling of the superconducting magnet along with providing all safety aspects of the magnet operation. Mechanical and thermal performance (stress, deformation etc) of the helium vessel is very crucial as it would provide the positional accuracy to the magnet. During quench of magnet, all the liquid helium turns out to be cold gas and there is sudden pressure rise inside the helium vessel. The vessel should withstand the quench pressure and also designed with the relief systems and safety factor. We have done the FEA analysis for different internal pressure, to analyse the vessel strength and deformation. The vacuum load and the higher value of internal pressure load were considered in the structural analysis of the LHe vessel. The analysis was done with 3 bara internal pressure yielding a peak stress of 312 MPa.

2. Thermal radiation shield Dvelopment

To reduce radiation heat flow, a dedicated cryogenic circuit actively cools the intermediate shield. Thermal shield maintained ate 40-60K will be developed using high strength and high thermal conductivity Aluminium alloys. Thermal heat shield will be designed and developed to maintain uniform temperature profile while maintain mechanical strength. Copper-Aluminium thermal intercepts would play a crucial role in determining the performance of the thermal shield. During design, the performance of the thermal shield will analytically be studied for different alloys of high strength and high conductive Aluminium. The performance will be validated by experimental measurement.

3. Composite support system development

The composite support system or support link is one of the critical components of any MRI cryostat. The support link will be designed and developed for providing the structural support (static and dynamic) to entire cold mass of the cryostat through the metal-composite mechanical joint. For the support system, the stresses due to cool down, transportation load of the system, self-centring mechanism shall also be considered. The composite link will have intermediate thermal intercepts at will be developed considering the mechanical strength, heat flow and maximum pretension force etc.

4. Thermal Intercepts

Thermal intercepts play a crucial role in determining the thermal behaviour of the heat radiation shield and the composite support links. The metallic intercepts will be designed and developed to provide desired thermal profile on the radiation shield and composite support system through metal-metal or metal-composite mechanical joints. The performance will be validated by experimental measurement.

Findings: During the design of MRI cryostat, we had done extensive simulation and experimental test. We have found lots of effective results which are as follow.

- The thermal, mechanical and electrical behavior of the thermal shield made of various aluminium alloys(AA110,AA5083-O,AA6061-T6) are compared extensively to achieve an optimum performance of the thermal shield in presence of any time varying field. The material combination aluminium alloys (AA110,AA6061-T6) gives the best results.
- The best material for the support rod is HS carbon fibre, which has higher strength and less thermal conductivity below 50K.
- Material for the Axial rod has better thermal performance, but the Machining and welding of rod is complex.
- Re-condenser performance is good for given fin size details.

Conclusion: The thermal shield made up of aluminium alloys AA110 (for cylindrical shell) and AA6061-T6(for Side plate) give positive impact on thermal, electrical and mechanical performances. The recondensing capacity of recondenser along with cryocooler is a positive news. The self-centring support rod performs well under assembly and Pre-Tensioning condition.

Recommendations for Future Research:

Considering the experience and finding of the present work, the future direction of research can be forecasted to reveal some new paths for surface modification with some novel approaches. The current work explored the ZBO based MRI cryostat. The future work can explore it more to further explore the new horizon for the upcoming researchers. Following areas can be touched in the upcoming days:

- Low liquid helium-based MRI has been developed already. One can try to reduce the liquid helium capacity of MRI cryostat further.
- Liquid helium free (Cryo free) MRI cryostat can be made by using GM cryocooler.
- Support system can be design based on the higher load capacity by using band/strap.
- Automated Jigs and fixture can designed for large production purpose.