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Design of large vacuum chamber for VEC superconducting cyclotron beam line switching magnet

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Abstract. VEC K500 superconducting cyclotron will be used to accelerate heavy ion. The accelerated beam will be transported to different beam halls by using large switching magnets. The vacuum chamber for the switching magnet is around 1000 mm long. It has a height of 85 mm and width varying from 100 mm to 360 mm. The material for the chamber has been chosen as SS304.The material for the vacuum chamber for the switching magnet has been chosen as SS304. Design of the vessel was done as per ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. It was observed that primary stress values exceed the allowable limit. Since, the magnet was already designed with a fixed pole gap; increase of the vacuum chamber plate thickness restricts the space for beam transport. Design was optimized using stress analysis software ANSYS. Analysis was started using plate thickness of 4 mm. The stress was found higher than the allowable level. The analysis was repeated by increasing plate thickness to 6 mm, resulting in the reduction of stress level below the allowable level. In order to reduce the stress concentration due to sharp bend, chamfering was done at the corner, where the stress level was higher. The thickness of the plate at the corner was increased from 6 mm to 10 mm. These measures resulted in reduction of localized stress.

1. Introduction

VEC K500 superconducting cyclotron will be used to accelerate heavy ion beams of energy up to 80 MeV/A for light heavy ions and about 10 MeV/A for medium mass heavy ions. The accelerated beam will be transported to different beam halls by using large switching magnets. The vacuum chamber for the switching magnet is around 1000 mm long. It has a height of 85 mm and width varying from 100 mm to 360 mm. The material for the chamber has been chosen as SS304.

2. Selection of Material

The vacuum chamber is to be operated at a pressure of $1X10^{-7}$ mbar inside and atmospheric pressure outside. Hence, all the joints must have helium leak tightness @ $1X10^{-9}$ Std. cc/sec. Under this circumstance, metal gasket only to be used to connect the chamber in the beam line. The use of metal gaskets using the conflate flanges rules out the possibility of the using aluminum as material for the vacuum chamber. The material should be weldable to facilitate the fabrication. So, SS 304 is chosen as it has both the qualities, non-magnetic as well as weldable.

3. Design procedure

Design of the vacuum chamber was done as per ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. A uniform cross section equal to the largest cross section was considered for the design and the rules of Appendix 13 were applied. The material property values from ASME Boiler and Pressure Vessel Code, Section II, part D. The allowable stress limit for SS 304 was found to be 126 MPa. It was observed that primary stress values varied from 370 MPa to 166 MPa for plate thickness variation from 4 mm to 6 mm. as the primary stress values exceeds the allowable limit, the thickness of the plates needed to be increased. Since, the magnet was already designed with a pole gap of 90 mm; increase of the vacuum chamber plate thickness restricts the space for beam transport. So, the plate thickness more than 6mm was not practically feasible. Hence, design needed to be optimized.

4. Optimization of design

Design of the vacuum vessel was optimized using stress analysis software ANSYS. Modeling of the vacuum vessel was done with CATIA and the model was used in ANSYS for analysis. Solid element SOLID95, a 20 node structural element was chosen. This element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. It can tolerate irregular shapes without as much loss of accuracy. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. Smart meshing has been chosen. Smart element sizing is a meshing feature that creates initial element sizes for free meshing operations. The Smart Sizing algorithm first computes estimated element edge lengths for all lines in the areas or volumes being meshed. The edge lengths on these lines are then refined for curvature and proximity of features in the geometry. Since all lines and areas are sized before meshing begins, the quality of the generated mesh is not dependent on the order in which the areas or volumes are meshed. This feature, provides a range of settings (from coarse to fine mesh) for meshing the models.

Analysis was started using plate thickness of 4 mm for all the sides. The degrees of freedom for all the directions for the end plates have been put zero, as the chamber will placed in the beam line, and all the other areas are put under atmospheric pressure. The result of the analysis is shown in figure 1.

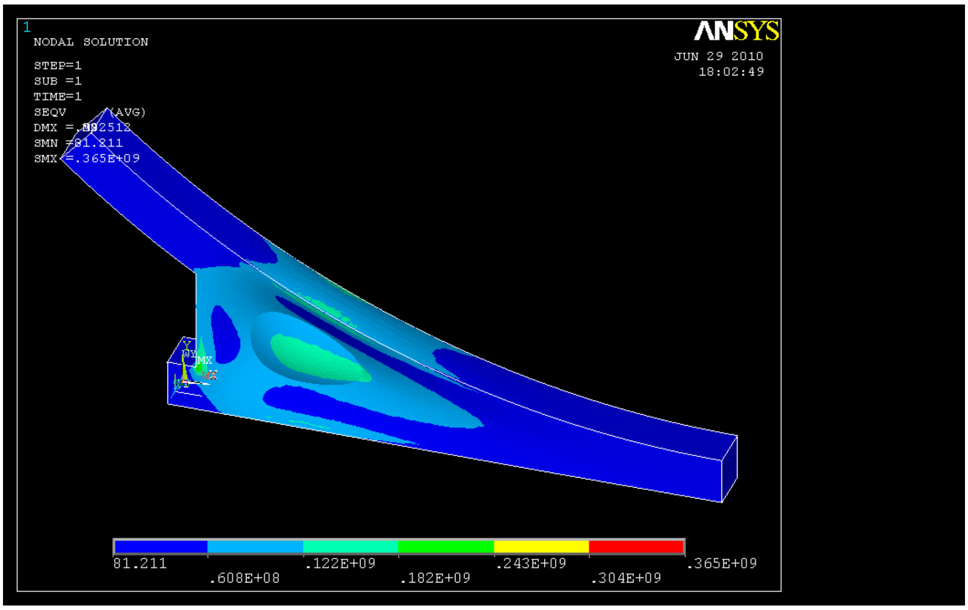

Fig.: 1. Stress Analysis of the Vacuum Chamber with 4 mm wall thickness.

After the analysis the stress level was found higher than the allowable level of 126 MPa. The localized stress at a corner was 365 MPa and the stress at the middle of the plate is also high between

122 MPa to 182 MPa which is also higher than the allowable stress limits. Hence the thickness of the plates is needed to be increased.

The analysis was repeated by increasing plate thickness to 6 mm. The result is depicted in the figure 2.

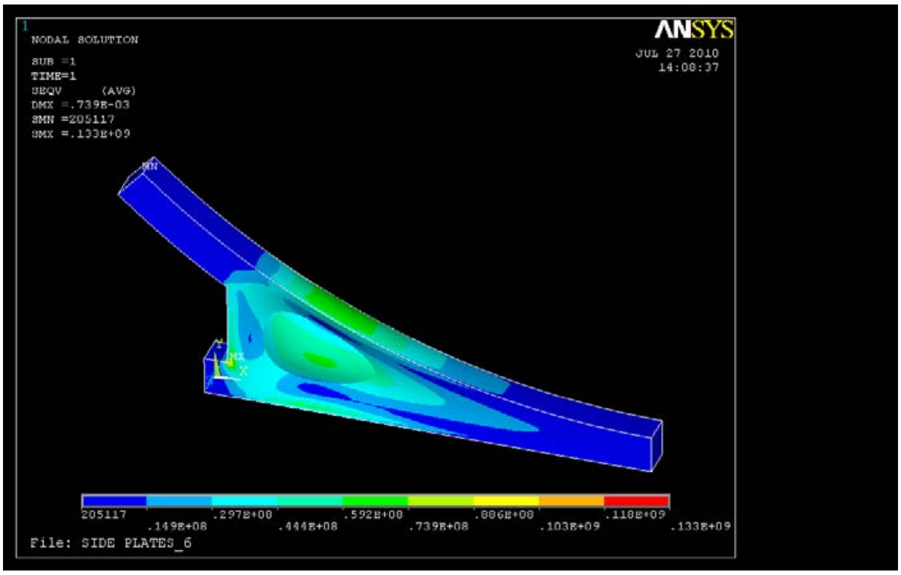

Fig. 2. Stress Analysis of the Vacuum Chamber with 6 mm wall thickness.

Figure 2 shows, the increase of thickness of the plates from 4 mm to 6 mm, resulting in the reduction of overall stress level below the allowable level. But the localized stress at a corner is still higher than the permissible limit.

In order to reduce the stress concentration at the corner due to sharp bend, chamfering was done at the corner, where the stress level was higher. The thickness of the plate at the corner was increased from 6 mm to 10 mm. The same analysis was repeated with this configuration. These measures resulted in reduction of localized stress. It was observed that the stress was 122 MPa, which is within acceptable limits of 126 MPa. The final shape of the vacuum chamber is shown in figure 3.

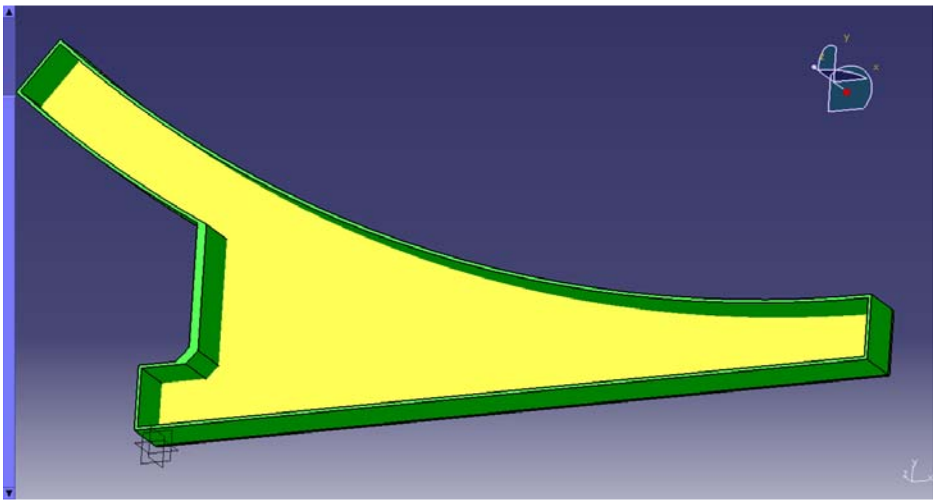

Fig. 3. The vacuum chamber for the switching magnet

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