Eddy current and Mechanical Support of the Wendelstein 7-X Thermal Shield

S. Y. Shim,[a] M. Nagel,[b] F. Schauer [b]
[a] *KSTAR, Korea Basic Science Institute, Daejeon 305-332, South Korea*
[b] *Max-Planck-Institute for Plasma Physics, Greifswald Branch, Euratom Association*
Wendelsteinstraße 1, D-17491 Greifswald, Germany

1. Introduction

The machine which equipped huge magnet such as fusion reactor must be in need of special care on the emergency process. Rapid drop down magnetic field generate noticeable induced current, eddy current, and it causes strong electromagnetic forces on mechanical structure. The Wendelstein 7-X consists with 5 pentagonal shaped modules, plasma vessel, and each module can be divided into two symmetric half modules. Each half-module is going to be covered by 20 pieces of plasma vessel thermal shield (PVTS). The subject of this calculation is to find appropriate support positions for PVTS which can withstand self-weight of PVTS and electromagnetic force during the emergency case within our design criterion. We report the calculation procedure and results with half-module of PVTS.

2. Model Construction and Calculation Procedure

Before design the finite element model for calculation we should find reasonable boundary conditions. When the time dependent magnetic field radiates on metallic material, the magnitude of penetrated magnetic field is decreased as a function of depth from the surface of the material. We can characterize the decreasing rate of magnetic field with the idea of the skin depth which is similar concept with time constant in RLC circuit. Skin depth is one of important factor to choose appropriate calculation code. And it makes a restriction to handle the code and to build model [1-2]. If we use current conducting material which is thicker than skin depth, we should calculate the magnetic field as a function of depth for reducing the computation errors.

We can easily imagine that skin depth, δ, is a function of material parameters σ, conductivity, μ, permeability, and f, frequency.

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}} \qquad (1)$$

Mitsushi Abe et. al. reported eddy current calculation result at the superconducting tokamak machine [3]. They assumed 10 ms time constant and corresponding frequency was considered to be a quarter of a 25 Hz wave. Our transition time constant is 3 sec and we can assume the corresponding frequency is 8.3×10^{-2} Hz. Electric conductivity of stainless steel at 80 K is 5.3×10^{-7} Ohm·m and $\delta = 2$ mm. The skin depth with our time constant and conductivity is 2.4×10^{6} m. Comparing our model thickness 2 mm , it is much higher value. This means that the magnetic field can fully penetrate inside metallic PVTS with our time constant. Therefore, two layer of finite element for current conducting region is reasonable for our case.

We use commercial finite element code, ANSYS, for eddy current and mechanical calculation. It is implemented various ways to calculate electromagnetic model. We use magnetic vector potential method so called MVP with SOLID97 finite element. The vector potentials on the surface of model were extracted using historical code EFFI [4].

Only maximum eddy current density can be a great help in determining the position of PVTS support.

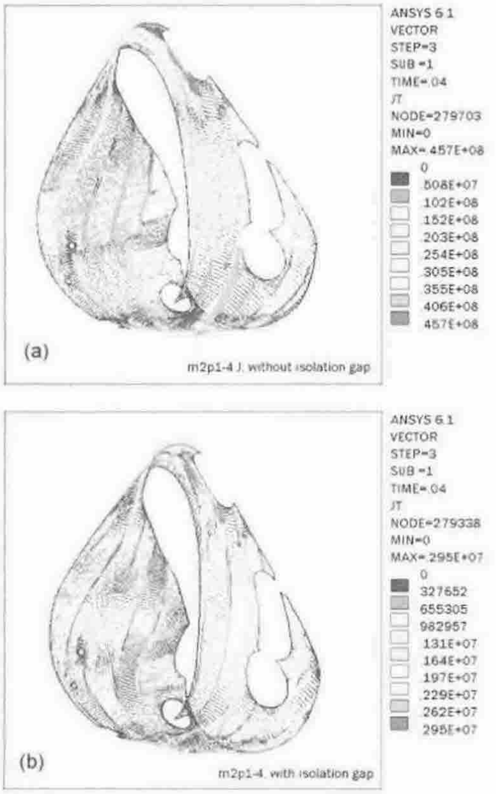

Figure 1. (a) Eddy current density without toloial direction electric isolation gap. Maximum electromagnetic force per unit volume of (a) is 1.4×10^{7}N/m^3 and (b) is 6.13×10^{5}N/m^3.

After calculating the eddy current and electromagnetic forces at each node, we applied those forces to the shell element model, SHELL96, for mechanical calculation.

Only one support position has to be fixed with all directions. The others are fixed only normal direction of the panel and tangential direction is free to move. We also considered the effect of self-weight by gravity.

3. Results

During first iteration of eddy current calculation, we found one important modeling condition. The toroidal direction magnetic field which is passing through the cross section of plasma vessel is one of the highest field compared with another directions, z and radial direction. It generates poloidal direction eddy current on the PVTS. Based on this prediction, we compared the eddy current and electromagnetic force with and without electrical isolation. And the result is shown at Fig. 1. The eddy current density of Fig. 1(a) is almost 15 times higher than that of Fig. 1(b). And the ratio of electromagnetic force per volume between the model without isolation gap and with gap is also 22.8. Therefore it is highly recommended to make a electrical isolation gap on the direction to the toroidal direction. Fortunately, each panel already has thermally, electrical isolation gap except upper region at the port number M1P4. Thus, if we make electrical isolation only on that position, we can remove the effect of toroidal direction magnetic field on thermal shield. This fact enables us to calculate eddy current with each individual panel. And we reduce huge calculation time and computation resource.

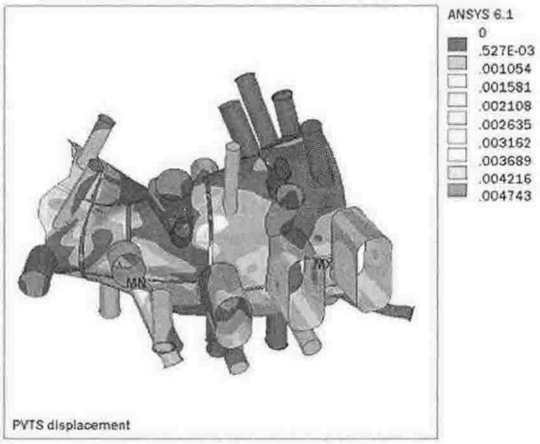

Figure 2. Displacement of whole PVTS. After calculating appropriate support position with individual PVTS, we applied results into whole PVTS for finding appropriate supporting condition.

4. Conclusion

We have found appropriate support positions with and without eddy current effect based on electrical and mechanical finite element calculation. The deformation, stress and reaction forces are close to our criterion during shutdown process. On the other hand, result at the stationary state is well satisfied with our design criterion. The modeling and the calculation procedures are optimized for computational time and accuracy of results. Average number of support per panel is 5.7 for supporting the PVTS.

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