

## §9. Analysis for Mechanical Rigidity of Coil Pack Simulated the Helical Coil in LHD

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The electromagnetic force loaded to helical coil in the LHD is about 10 MN/m and pressure to the insulator reached up to 100 MPa in maximum. To investigate the rigidity of the helical coils, finite element method and mixture law were applied to calculate apparent rigidity of coil pack that simulated the section of actual helical coil. Since the structure in the LHD designed to minimize the deformation, the coils must have the enough rigidity to bear this electromagnetic force. It is not easy to perform the deformation of helical coil because it has a complex 3-dimensional shape and is used in the liquid helium. Furthermore, coil is the composite structure of the conductors, insulators and coil can, and each of them is also composite material. For this reason, it is important to grasp the mechanical behavior and deformation of the coil under electromagnetic force and at cryogenic temperature.

To investigate the compressive rigidity of the helical coils, the mechanical tests for the coil pack simulating the actual helical coils were carried out at 4.2 K in NIFS. The finite element analysis was used to evaluate the detail of experimental results. The properties used in this analysis were obtained by mixture law. Here assumed the 2-dimensional plain strain, two cross section models were prepared. One was the side view cross section (Model A), and the other was transverse cross section (Model B). Considered the symmetry, half area of cross section was used in the modeling. Faithful 3-dimensional finite element models (Model C) were also calculated. Rigidity of conductor and insulator were apparently changed according to increase or decrease of compressive load.

We assumed not to change the rigidity of conductor. The longitudinal elastic modulus of each material in KISO-4B conductor that used to calculate the mixed apparent rigidity of it was 85

GPa for NbTi/Cu, 81 GPa for Aluminum and 120 GPa for copper. The apparent rigidity of KISO-4B of longitudinal and its vertical direction was 107.5 GPa and 97.5 GPa, respectively. Poisson's ratio of longitudinal direction respect to its normal direction was assumed to be 0.3. Opposite value of this poisson's ratio were calculated according to Maxwell's reciprocal theorem.

In the case of the rigidity of GFRP set to 5 GPa to its compressed direction, calculated apparent rigidity of compressive direction used mixture law was 23.6 GPa. This shows a good agreement with the maximum rigidity obtained by experiments. This result is understand the case of GFRP is completely fixed to the conductor and the effect of its bending can be ignored.

Property of GFRP assumed to change by the loading in analysis. Further more, assumed to have half rigidity considering the exposure ratio of 50 % in Model A, B. The fifth cycle data avoid the permanent sets are plotted with the results of finite element analysis in Figure 1. The value of GFRP was assumed to be 5 GPa for compressed direction and 15 GPa for longitudinal direction at 1.0 MN loading, and in the same way, 2.5 GPa and 7.5 GPa at 0.5 MN loading. The value of poisson's ratio was assumed to be 0.3 for each load case. The representative results by this assumption were good agreement with the experiment.

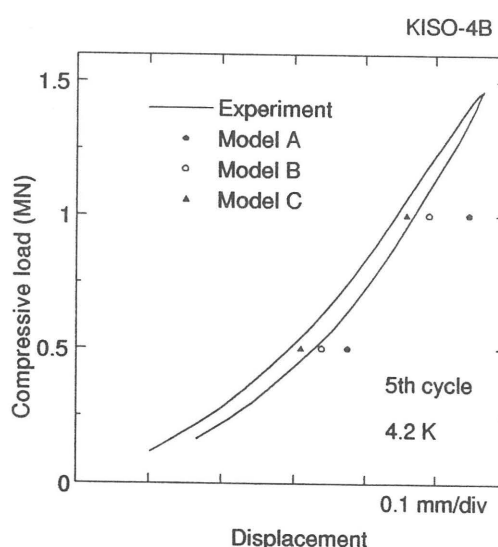


Fig. 1. Results of finite element analysis for KISO-4B coil pack of 5th cycle.