5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Finite element analysis of support structures attached to RELAX machine for producing not only reversed-field pinch but also tokamak

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Recently, there is a new field of research in which not only reversed field pinth (RFP) but also tokamak plasmas are formed in RFP devices to study potential problems in future tokamak fusion devices [1,2]. In order to experimentally investigate if such toroidal plasmas are frozen-in the canonical flux tube before and after the sawtooth instability and the conservation of canonical helicity during the event, we are preparing to modify the RELAX device to form tokamak plasmas in addition to RFP plasmas.

The safety factor (q) at the tokamak plasma edge is typically between three and four. Since the current poloidal field at the vacuum vessel edge is few tens of mT, it is necessary to increase the toroidal field (B_t) to 0.2 T ($I_{\mathrm{TFC}} = 21$ kA), which is four times larger than that applied to produce RFP plasma. Therefore, compared to the RFP configuration, the tokamak configuration would have stronger electromagnetic (EM) forces, such as hoop and lateral forces, acting on the entire set of RELAX toroidal field coils (TFCs). To support TFCs mechanically during the tokamak formation, a complete set of three-dimensional electromagnetic forces are numerically calculated by use of a finite element analysis method. The absolute values of the hoop forces on the upper, lower and inner parts of a one-turn coil are 1840 N, 1700 N, and 4500 N, respectively. These are directed outwardly from the center of the TFC. The lateral forces act in the φ direction for the upper and lower coils. These forces act in opposite directions to each other, and the absolute values of them are almost the same, about 1600 N. Also, a force on the feeder acts in the R direction of 2300 N. Based on the obtained results, structural analysis is then performed to investigate how to keep the mechanical strength of the TFCs against the electromagnetic forces. Figure 1 shows the schematics of the conventional support structure (center-stack and TFC-sub support) and the newly designed support structure (TFC-feeder support and TFC-spacer) attached to the RELAX device. Figure 2 shows the distribution of von Mises stress of the TFCs when only the conventional support structure is considered, and when the newly designed support structure is considered in addition to those attached to RELAX device. It is numerically shown that the stress on the TFCs can be suppressed below 60 MPa, the allowable stress of copper, by attaching the newly designed support structure to the TFCs. Moreover, measurements of the strains of the TFCs are carried out to confirm the validity of the simulation results.

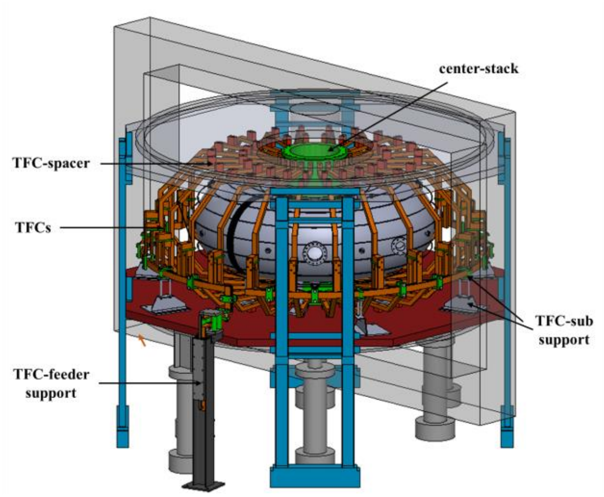

Figure 1. Schematic of coils and support structures attached to RELAX device

References
[1] S. Munaretto, *et al.*, Nucl. Fusion **60** (2020) 046024.
[2] G. Grenfell, *et al.*, Nucl. Fusion **60** (2020) 126006.

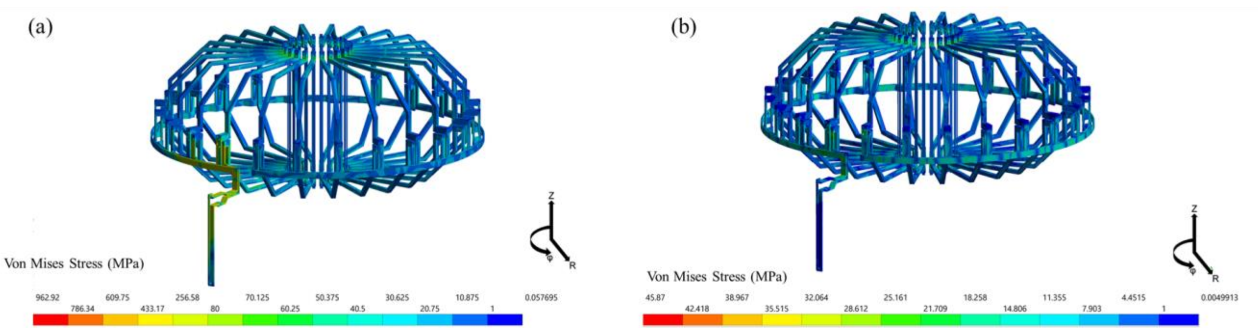

Figure 2. Calculated 3D distribution of von Mises stress of the TFCs for (a) conventional support structure only (b) newly designed support structure included.