§11. Mechanical Characteristics in the Excitation Tests of a Single Vertical Coil

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Cooldown and excitation tests of an Inner Vertical (IV) coil were performed using test facilities at the cryogenics and superconductivity laboratories at the National Institute for Fusion Science. The main purpose of this experiment was to confirm the coil's performance before installing it in the LHD cryostat. The coil was successfully energized up to the LHD nominal current, 20.8 kA on December 8, 1995. Here the mechanical characteristics are discussed on the excitation tests.

During excitations #2401, #2402 and #2701, the coil was discharged by the protection system because magnetic field leakage affected a valve control system. In #3301, the protection system was operated again when the current just reached 20.8 kA because the magnetic field affected a water cooling system of the power supply. After shielding the sensitive equipment from the magnetic field, the target operation was first achieved in #3302.

The results of displacement measurements are shown in Fig. 1. The figure indicates the total outward radial force versus displacement curves. The total force is the integration of every force inside the coil divided by the average coil circumference ($\pi \times$average diameter). The displacement is the average of four sensors, which cancels the rigid displacement due to magnetic attraction to a building wall. From the results, the maximum displacement was found to be 0.7 mm at 20.8 kA. Allowable motion at the maximum current was specified to be less than 2 mm because the motion affects field error of the coil. The measured displacements were confirmed to be less than the allowable motion. After #3301, a permanent displacement of 0.1 mm remained. This may be caused by compaction of an insulator. Hysteresis of the curves may be due to sliding friction between the coil and supporting posts.

A model of a thick cylinder with inner pressure (p) was applied to estimate the coil rigidity. The outward displacement of the coil outside (d) can be calculated by the following equation:

$$d = [2r_i^2 r_o / (r_o^2 - r_i^2)](p/E), \qquad (1)$$

where r_i and r_o are the inner and outer radii, respectively. The total force was converted into the inner pressure by dividing by the coil height. The equivalent rigidity in the winding direction (E) was estimated about 100 GPa by a mixture law including strands. The rigidity of strands contributes one third to the equivalent rigidity. The displacement at 20.8 kA was then calculated as 0.77 mm, which shows good agreement with the experimental value.

Figure 2 shows the cumulative acoustic emission (AE) counts during the excitations. It should be noted that AE was not observed below the maximum experienced current from the previous cycle. This is clearly an irreversible effect, which is known as the Kaiser effect. The reason of the AE behavior is, therefore, considered to be the compaction of epoxy as described before. After #3302, only a few signals were observed. This confirms that the force did not damage the coil.

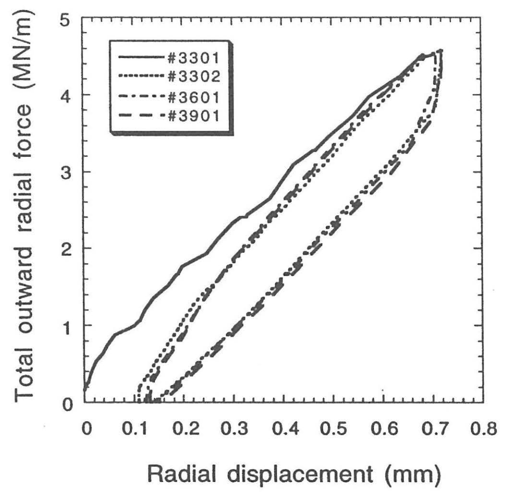

Fig. 1. Outward radial force versus displacement curves.

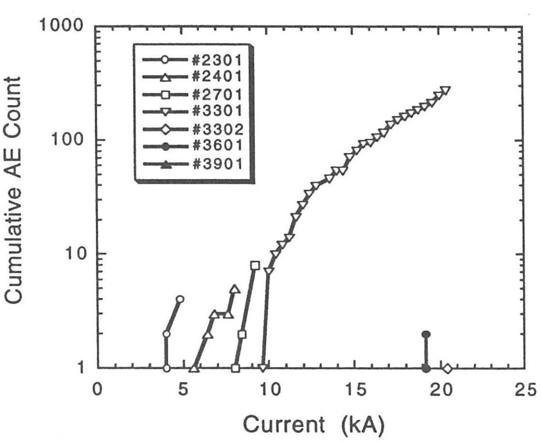

Fig. 2. Cumulative AE counts.