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PLT TOROIDAL FIELD COIL POWER TESTS

R. Marino, J. Citrolo, J. Frankenberg
Plasma Physics Laboratory, Princeton University
Princeton, New Jersey 08540

Summary

The PLT toroidal field coil power tests were initiated in October, 1974 to gain information in several areas. The most important objectives during the tests were the verification of deflections and stresses as predicted by Frankenberg[1] and Smith.[2] Also, the stability of the toroidal field coils against radial self-field loading was to be determined. Lastly, the predicted thermal characteristics of the coils were to be verified.

During testing the measured horizontal and vertical bore deflections were found to be larger than predicted. Stresses, however, measured in the inner bore of the coils, were very close to the predicted values. The net centering forces on the coils were successfully resisted by the wedging action of the coil noses. A stable relative radial position of the coils was achieved with the help of a restraining device. The predicted coil thermal properties proved to be accurate.

Tests were conducted in phases. Phase I began in late October, 1974, and lasted for approximately four weeks. The test was temporarily terminated to allow for vacuum vessel installation.[3] Phase II testing began in early January, 1975 and lasted for three weeks. The interrupted schedule allowed time to plan more detailed testing in areas of particular interest.

Unfortunately, an integral part of the mechanical support structure, the center column, was not available for the tests.[4] This necessitated setting a force limit (50% full magnetic force, 35 kilogauss).

Bore Deflections

The primary function of the center column is to provide a support point for the toroidal field coils in an area of high bending and shear stress.[1] Support points are shown on Figure 1, 45 degrees above and below the horizontal centerline of the coil. The unavailability of the center column support structure required that the field limit for the test be set at 35 kilogauss, which corresponds to one-half the net centering force per coil. The full design value for the toroidal field is 50 kilogauss. A temporary center column, whose function was to provide shaping field and ohmic heating winding preload, was installed prior to Phase II testing. This center column did not contact the coils in the previously mentioned high stress area, and did not provide any additional stiffening. During testing a new replacement center column was being designed.[4] To provide data for this design attention was paid to the motion of the center column support points: The best correlation between experimental vs calculated values was achieved here. Measured deflections ranged between 1.5 and 4.6 times the predicted values. Support point deflections for two coils, at 50% full force, are summarized in Table I.[5]

Both Frankenberg and Smith carried out deflection analysis for a coil without center column support. These calculations were used as a basis for theoretical vs experimental comparisons of bore deflections. Vertical and horizontal bore deflections were measured with diametral extensometers on several different coils at varying force levels. The positioning of these devices is illustrated in Figure 1. Experimental repeatability for these measurements was excellent and results are summarized in Table II.[5]

Force vs bore deflection curves were linear at forces greater than 10% full force. Figure 2 shows a typical force-deflection curve. A comparison of predicted vs measured bore deflections is tabulated in Table II. Slopes of the force-deflection curves are also described in Table II. Predicted deflections and slopes are from a finite element model of homogeneous material, exhibiting perfect elasticity.[2] No center column support reactions are used in this analysis. As is shown in Table II, the measured bore deflections vary between 2.0 and 9.4 times the predicted values. Slopes are between 2.0 and 8.0 times greater than expected.

A non-linear excursion of vertical bore deflection at approximately 43% full force was experienced on two coils simultaneously. Figure 3 is a deflection-load curve for one of the coils experiencing this phenomenon. After the event, lower level pulses caused deflections larger than had been experienced before the non-linear run. Subsequent series of pulses remained on this return curve up to and beyond the nonlinearity. The excursion was never repeated on any later run.

Strain Measurements

Stresses were calculated from strain measurements taken at locations shown in Figure 1. At each location a rossette configuration was used so that principal strain directio. could be determined.

Two strain-inducing effects were distinguished from true strain during these measurements. One was thermal strain, which is due to thermal growth of the coil from resistive heating. This strain component was evident at the end of the pulse with zero current in the coil. Magnetic field effects on the strain gages were compensated for by superimposing an inactive gage directly over the active one. By including both in the half-bridge circuitry, magnetic strain components were automatically compensated for.

Resulting net strains yielded stresses in the order of 12,000 psi on the inner bore in the meridonal direction. This was found to be the largest component of stress, and compares favorably with predictions of 15,000 psi by Frankenberg.[1]

TF Coil Radial Positioning

Each toroidal field coil experiences a net centering load of approximately 3,000,000 lbs.[1] This load is resisted by a normal force on the coil's wedged faces from its neighbors. Equilibrium of the entire coil system is dependent on: 1) each coil's radial position relative to the center of the machine and 2) wedge surface area in contact with neighboring wedges.

Small imbalances in centering force reactions on the wedge faces resulted in net motion in a radial direction. Figure 4 shows the toroidal field coils changing positions after a finite number of pulses. Careful realignment of the displaced coils improved the situation, but did not solve the problem completely.

By providing a horizontal support point for the coil, the center column also limits radial motion. Because this device was not available for the first power tests, a similar mechanism was fabricated in time for Phase II testing. It was used to exert a small reaction on the nose of each coil at the horizontal midplane. By careful use of this device coil radial motion virtually ceased. This is illustrated in Figure 5 which shows very little radial coil motion after a large number of pulses.

Thermal Properties

Thermal properties of the toroidal field coils were recorded in two modes. In the first mode, the steady state condition, coils were powered at various currents ranging from one to ten kiloamperes. Temperature data was taken at cooling water outlet after coils had come to thermal equilibrium for the various current levels. Figure 5 summarizes the recorded data and gives predicted values at ten kiloamperes.

Coil thermal properties were also examined in the pulsed mode. Figure 6 shows rates for cooling paths through various portions of the coil. Time zero denotes the end of a 18 kilo ampere peak pulse. The single pulse RMS current was 6.5 kiloamperes.

Conclusion

With the exception of horizontal and vertical bore deflection data, all measured mechanical and thermal characteristics of the toroidal field coils were as predicted. It is important to note, however, that no permanent coil bore deformation was observed. Repeated pulses to 35 kilogauss yielded consistently repeatable bore deflection data.

Stresses measured in the inner bore area of the coils support values calculated by Frankenberg.[1] Coil relative radial motion was successfully controlled by the use of temporary center column adjustments. Copper cooling proved to be adequate.

Acknowledgement

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References

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