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FAILURE OF A LARGE CRYOGENIC MHD MAGNET*

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Résumé — En décembre 1982, l’aimant MHD (conçu pour atteindre 6 Tesla dans un volume utile d’environ 1 m² sur 7 m de long) construit pour l’expérience de démonstration de haute performance (HPDE) a subi un échec de structure catastrophique, qui a déclenché une fracture massive et friable. Les auteurs en ont terminé l’autopsie et l’analyse et ont établi la cause de l’échec.

Abstract — In December of 1982 the MHD magnet (designed to achieve 6 T over an active bore approximately 1 m square x 7 m long) for the High Performance Demonstration Experiment (HPDE) suffered a catastrophic structural failure, which induced massive brittle fracture. The authors have completed an autopsy and analysis, and have determined the cause of failure.

SUMMARY

The magnet was designed to operate in either of two modes: (1) as a 3.7 T (continuous) water cooled magnet, or (2) as a 6 T (long pulse) nitrogen precooled, cryogenic magnet. In either mode, coolant would flow through conventional hollow copper conductor windings. A unique force containment structure of 2219 aluminum alloy was selected on the basis of thermal considerations (77 to 350 K operating temperature range; coefficient of thermal expansion permitting dimensional matching to the coil) and cost. Figures 1 through 3 show, respectively, a photograph of the completed magnet including the outer thermal enclosure, the general distribution of Lorentz forces on the coil windings at 6 T, and the force containment structure (FCS). Components of the FCS were fastened together with high strength keys and bolts.

The FCS design analyses identified multiple load paths for support of the total longitudinal force. The effects of tolerances on the interactions among FCS components increased the complexity of the structural analysis. Although the design was conservative with respect to support of the longitudinal loads, the effects of deflections due to the (comparatively small) transverse loads (in the saddle region) on the longitudinal force support elements were overlooked.

Figures 4 and 5 graphically depict the effects of the transverse saddle loads on the longitudinal tension members (LTM) and on the collars. As a result of these transverse loadings, combined stresses in the fingers of the LTM (where they are notched to penetrate the faceplate) were on the order of twice the measured ultimate strength of the 2219 aluminum alloy (at 77 K) at a field level of 4 T, which is approximately half the design load. Stresses in the collar fingers were on the same order.

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The magnet failed as a result of design defects that were not detected during the FCS design analyses. For a more detailed discussion of the design and analysis of the failure, including a discussion of failure scenarios, see Reference 1.

COMMENTS

This failure is distressing not only because of its magnitude, cost, and impact on a critical test program, but also because of the care with which the design and construction was managed and the technical work performed. Two independent stress analyses were completed, work was regularly reviewed by panels of experts, and more than the usual attention was given to instrumenting the magnet due to concerns over stresses in the FCS. After two years of operation at field strengths up to 4 T, a review of strain gauge data concluded that the FCS was conservatively safe for 6 T operation. For those of us who have seen the destruction of this magnet, the event is a powerful reminder of the potential for catastrophic failure, even in well managed, competently staffed programs.

REFERENCES


Fig. 1. MHD High Performance Demonstration Experiment Installation

Fig. 2. 6 T Forces on HPDE Magnet Coils
Fig. 4. Exaggerated Depiction of the LTM-Related Deflections at the Magnet Midplane

Fig. 5. Collar Corner Behavior