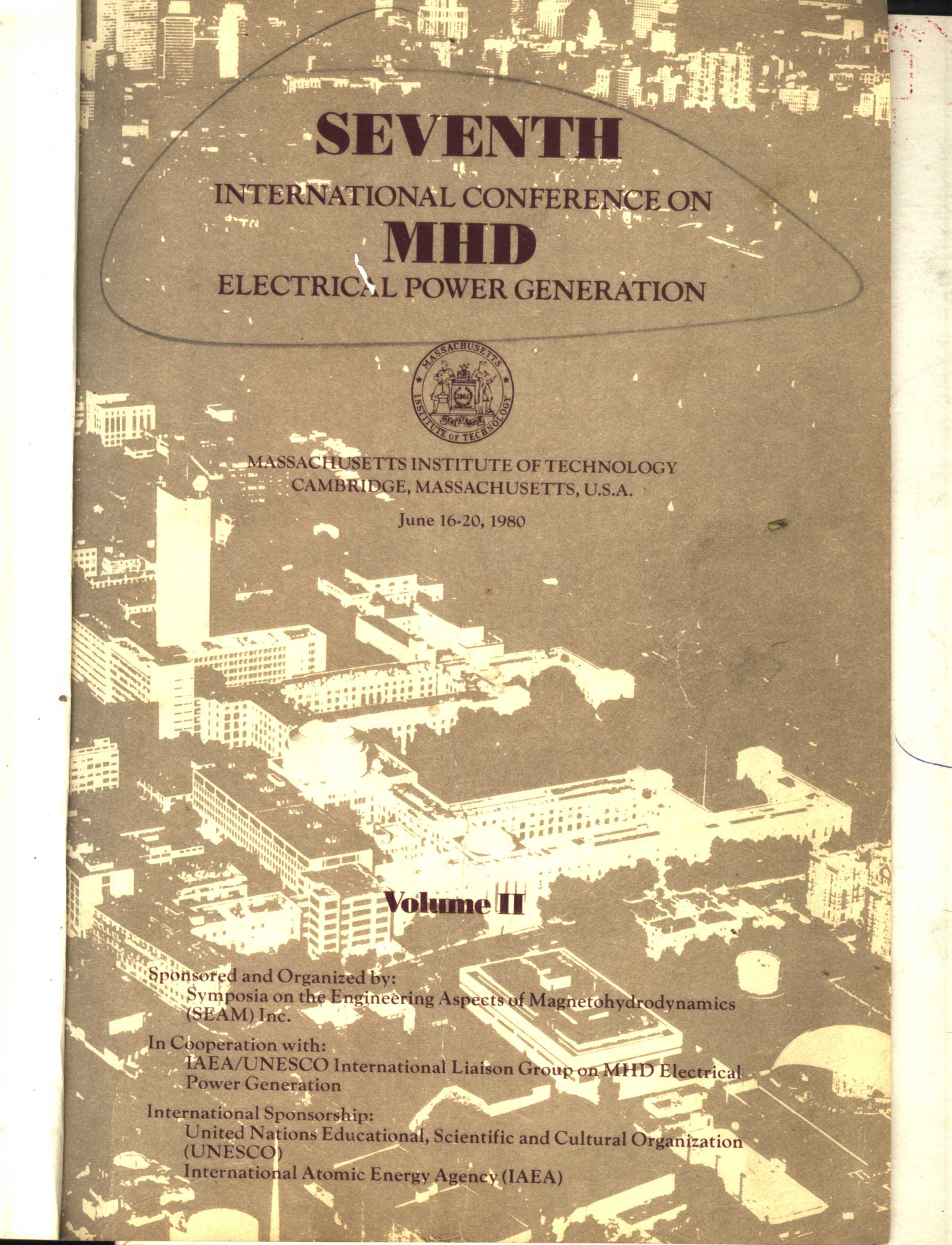


SEVENTH
INTERNATIONAL CONFERENCE
ON
MHD
ELECTRICAL POWER GENERATION

Vol. 2



SEVENTH

INTERNATIONAL CONFERENCE ON

MHD

ELECTRICAL POWER GENERATION



MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS, U.S.A.

June 16-20, 1980

Volume II

Sponsored and Organized by:
Symposia on the Engineering Aspects of Magnetohydrodynamics
(SEAM) Inc.

In Cooperation with:
IAEA/UNESCO International Liaison Group on MHD Electrical
Power Generation

International Sponsorship:
United Nations Educational, Scientific and Cultural Organization
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International Atomic Energy Agency (IAEA)

FOREWORD

The Seventh International Conference on MHD Electrical Power Generation, held at the Massachusetts Institute of Technology, Cambridge, Massachusetts and sponsored by the Symposia for the Engineering Aspects of Magnetohydrodynamics (SEAM) Inc., the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Atomic Energy Agency (IAEA) has attempted, in the tradition of the earlier conferences, to present the best work in all aspects of MHD power generation research, both physics and engineering, from around the world and to provide a forum for the presentation and exchange of information and ideas in this field. Papers were selected by the International Paper Selection Committee with the advice of the several area and national paper selection committees. These papers are published in Volumes I and II of these Proceedings and as best possible follow the conference program sessions. Any papers not available at the time of printing are not included but abstracts have been presented wherever possible.

The commercialization of MHD is approaching rapidly and this Conference has made a special effort to highlight this maturation through panels presenting the views of potential MHD users and component manufacturers and has also tried to assess the political and energy balance impacts of this technology by providing a forum for representatives of the nations with active MHD programs. Summaries by the panel chairmen will be published in Volume III of the Proceedings together with the rapporteur reports.

ACKNOWLEDGMENTS

I would like to thank the many people who have contributed to the success of the Conference. In particular, I wish to thank William D. Jackson for soliciting financial support for the Conference; Dianne Overlan for her unrelenting effort in order to put the Conference Program and the Proceedings together; Nora Treimanis for financial record keeping; Mimi Rittman, Patricia Connell and Dollina Borella for assistance in Conference paper coordination and preparation; Joseph O'Sullivan for assistance in typing; Barbara Keesler, Tricia Garritty, Elaine King and Patti Catano for assistance with registration.

Jean F. Louis
U.S. Program Committee Chairman

EDITORS' NOTE

Each Volume of the Preprint Volumes is organized by session/subject. The listing of groups of papers in any Volume follows the order in which they were presented at the Conference.

The papers in the Preprint Volumes have been printed by photo-offset directly from material provided by the authors. The general content of the papers remains the responsibility of the authors and the indulgence of the reader is requested with regard to the inevitable errors and omissions which find their way into a volume of this type.

Alberta M. Dawson and Dianne Overlan

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THE CASK CONCEPT FOR COMMERCIAL DEMONSTRATION PLANT MHD SUPERCONDUCTING MAGNETS*

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Abstract

The overall objective of this engineering study was to develop a conceptual design of a readily producible superconducting MHD (magnetohydrodynamics) magnet system for commercial size power plant installations. The essential design requirements for this magnet system include a 14.5m (47.57 ft) active region length with a 6.0 T peak field. The inlet and outlet bore diameters measure 2.48m (8.14 ft) and 4.50m (14.76 ft), respectively.

An innovative design concept, designated CASK, was selected as the basis for this design study. The CASK concept resulted from MIT's Winding Model Magnet program in which Magnetic Engineering Associates and Supercon, Inc. assisted General Dynamics. The key fundamental concept of CASK is the division of the conical substructure into a number of independently manufactured axial staves. These staves are nested together to form the shells which contain the distributed windings. Minimum welding of the winding support shell is required at the assembly site. Surrounding the assembly of the staves containing the coils are the superstructure hoops. Thus, this concept was designated "CASK" because of its similarity to barrel construction. All components are thus reduced to manageable sizes that may be prefabricated at a central factory site and shipped to the commercial power plant site for final assembly. The staves (substructure) are designed to contain the 276×10^6 newtons (62×10^6 lb) axial forces and tangential magnetic forces. The hoops (superstructure) are designed to contain the 988×10^6 newtons (222×10^6 lb) radial forces.

Conceptual design activities have resulted in a highly efficient, 5,824,300-pound magnet system. Detailed analysis and evaluation of the CASK MHD magnet concept indicates that it can meet all performance requirements and that it can be economically built with today's technology.

Introduction

The primary goal of this study was to develop a technically sound, economically producible design concept of the magnet system for commercial demonstration power plants.

Due to the immense size requirements for this magnet system, this goal proved to be highly challenging. The comparative sizes of existing and planned MHD superconducting magnet systems are shown in Figure 1. The magnet system for a Commercial Demonstration Plant (CDP) has 80% of the active region length of proposed baseload magnets. The essential design requirements for CDP magnet system are presented in Figure 2.

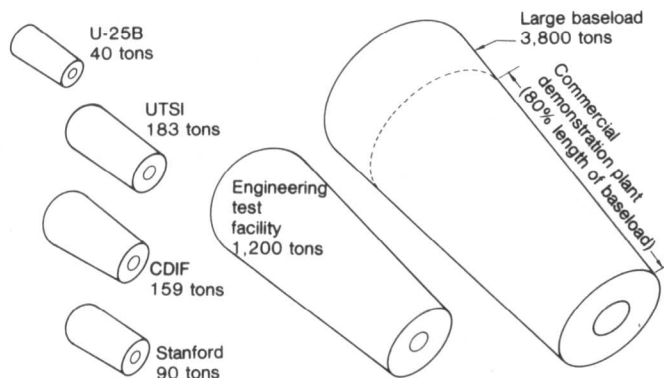


Figure 1. Comparative sizes of existing and planned MHD superconducting magnet systems.

*Work sponsored by the Department of Energy and Massachusetts Institute of Technology — Francis Bitter National Magnet Laboratory (MIT-FBNML) under contract ML-67466 (Subcontract OSP-83998).

- Inlet bore (beginning of winding) = 2.48m (8.14 ft)
- Outlet bore (end of active length) = 4.50m (14.76 ft)
- Field homogeneity in transverse plane = 5%
- Field profile on axis meets requirements shown below:

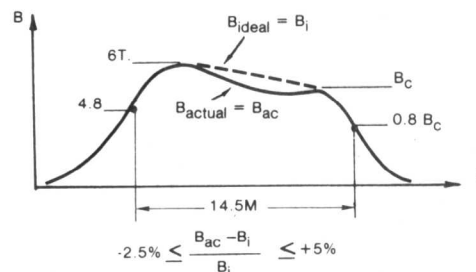


Figure 2. Commercial demonstration plant (CDP) MHD magnet system design requirements.

CASK was originally envisioned during the performance of MIT's Winding Model Magnet (WMM) program. The intent of the WMM program was to design a small-scale (less than one meter outside diameter) MHD magnet to simulate producibility aspects of a baseload-size superconducting magnet. The WMM (CASK) design concept is shown in Figure 3. The shaded elements depict the stave and hoop components of the CASK configuration. Because of the anticipated technical and producibility advantages of this concept, the follow-on phase of the WMM design program was devoted to the conceptual design of a CDP-size CASK magnet.

This conceptual design study was conducted under the direction of Massachusetts Institute of Technology — Francis Bitter National Magnet Laboratory (MIT-FBNML) by the team of General Dynamics Convair (GDC), Magnetic Engineering Associates (MEA), and Supercon, Inc. General Dynamics Convair was the prime contractor performing overall design and analysis integration plus discrete tasks in:

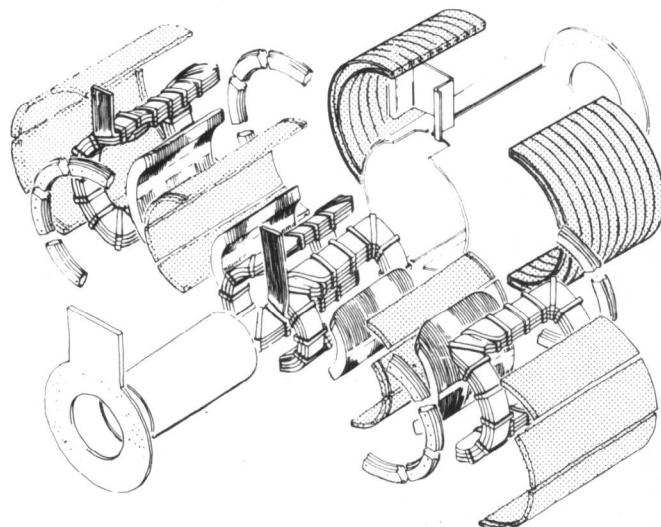


Figure 3. Winding model magnet (CASK) simulates baseload magnet producibility aspects.

- Magnet system design
- Thermodynamic analysis
- Design standards
- Structural analysis
- Material selections
- Manufacturing producibility
- Quality assurance.

MEA provided electromagnetic field and force analysis and developed several design trade study concepts. Supercon, Inc. provided design details and preliminary manufacturing plans for the conductor. MIT-FBNML, in addition to providing overall direction, provided significant contributions in the baseline conductor selection and electromagnetic field and force analysis.

The CASK CDP design program, which is fully documented in Reference 1, resulted in the design concept shown in Figure 4. The primary producibility advantage of the CASK approach is the division of major structural components into economically-sized subcomponents. Figure 5 shows an exploded view of the CASK CDP magnet. As shown, the substructure consists of 16 stave elements per subshell. Each stave member can be individually prefabricated using existing spar or skin mills. The superstructure elements have been sized such that they can be readily prefabricated using existing technology.

Configuration

The philosophy of the General Dynamics team is to design a magnet that (1) meets all specifications through proven techniques that

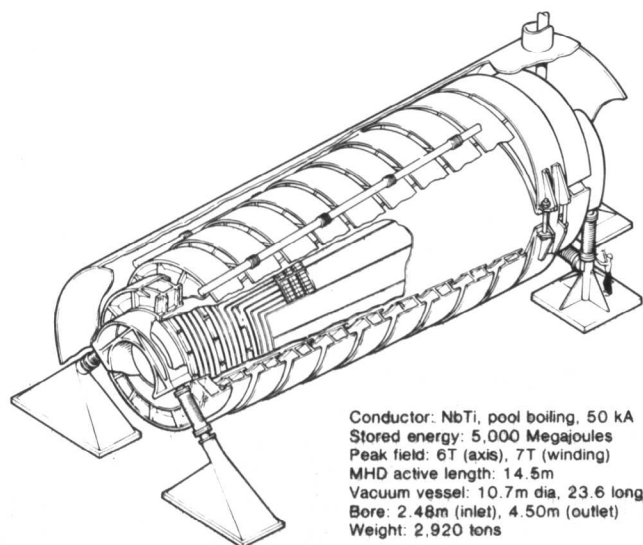


Figure 4. CASK conceptual design for commercial demonstration plant MHD magnet systems.

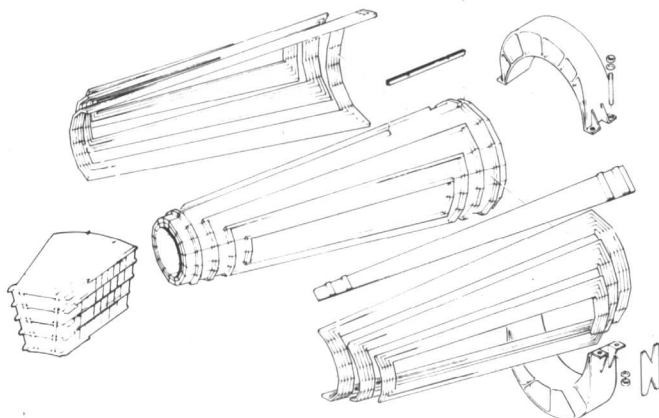


Figure 5. CASK structural elements are economically producible.

minimize risk, (2) is scalable to larger or smaller magnets, and (3) minimizes fabrication complexity with maximum inspectability. During the conceptual design phase for CASK CDP, emphasis was placed upon ensuring structural integrity, cryostability, design simplicity, and low cost fabrication. Table 1 summarizes the key technical features for the CASK CDP magnet system.

Table 1. Key features of CASK CDP MHD magnet system.

Conductor

- Amperage rating — 50KA
- NbTi, pool boiling

Field

- Peak field on axis — 6.0T
- Peak field in winding — 7.0T (approx)
- MHD active length — 14.5m (47.6 ft)

Overall dimensions

- Vacuum vessel — 10.7m (35.0 ft) OD
23.62m (77.50 ft) long
- Inlet bore — 2.48m (8.14 ft)
- Outlet bore — 4.50m (14.76 ft)

Materials

- Structure & vessels — 304L(N) stainless steel
- Conductor substrate — OFHC copper
- Radiation shield — 6061-T6 aluminum
- Insulation (elect & thermal) — G-10CR fiberglass epoxy

Weight

- Cold mass (including superstructure) — 2,226,942 Kg (4,905,158 lb)
- Vacuum vessel, radiation shield & supports — 417,290 Kg (919,142 lb)
- Total magnet — 2,644,232 Kg (5,824,300 lb)

Conductor/Winding. A prototype of the CASK 50KA conductor is shown in Figure 6. This configuration resulted from the trade studies which are documented in Reference 2. Key features of the baseline conductor are presented in Table 2. The conductor is oriented circumferentially (i.e., wide dimension is parallel rather than perpendicular with respect to the substructure shells). Saddle windings are oriented such that the coil halves are split on a vertical plan. The winding is electrically center tapped grounded at the coil halves to the grounded substructure.

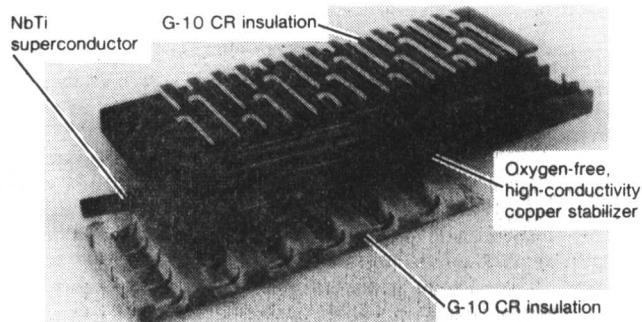
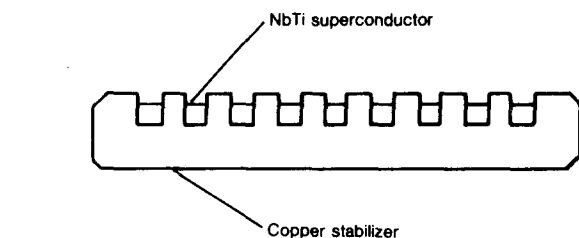


Figure 6. CASK CDP 50,000-ampere prototype conductor.

Substructure. The substructure, which supports the windings, consists of five shells with 16 full-length "stave" members in each shell. The staves are independently fabricated from approximately 25mm (1.00 in.) thick 304LN stainless steel. Since the substructure is electrically at ground potential, conductor bundles are fully electrically insulated from the staves.

A composite cross-section showing the arrangement of the conductor bundles and staves at three different axial positions near the inlet end of the magnet is shown in Figure 7. A more detailed cross-section showing the corner blocks is shown in Figure 8. The corner blocks intersect the staves at each corner of the polygon-shaped substructure. These blocks accumulate conductor forces and transmit the forces into the stave members. In this manner, the circumferential forces and deflections, which are generated by the conductor, are regionalized into the stave sectors. The corner blocks also provide a means of securing and clamping the stave members through bolts during assembly.

Table 2. Key features of CASK CDP 50,000-ampere conductor.



Substrate: Copper (CDA alloy 101)
 ¼ hard, RRR at (H = 0) 110
 Approx 100mm × 24mm

Insert: Composite; NbTi filaments in copper
 (CDA alloy 101), matrix
 5.13mm square
 600 filaments, 0.13mm diameter
 100mm twist pitch
 Cu:SC = 2.0:1 (insert)
 = 32.0:1 (overall)

J_c (filament) at 7 T = $6.0 \times 10^4 \text{ A/cm}^2$
 J_c (insert) = $2.0 \times 10^4 \text{ A/cm}^2$
 J_c (conductor) = $2.0 \times 10^3 \text{ A/cm}^2$
 Up to 10 inserts in substrate

Conductor: Average cross-section area 23cm²
 Average weight/meter 20.5kg/m
 Substrate length/piece 10m or greater
 Insert length piece 650m

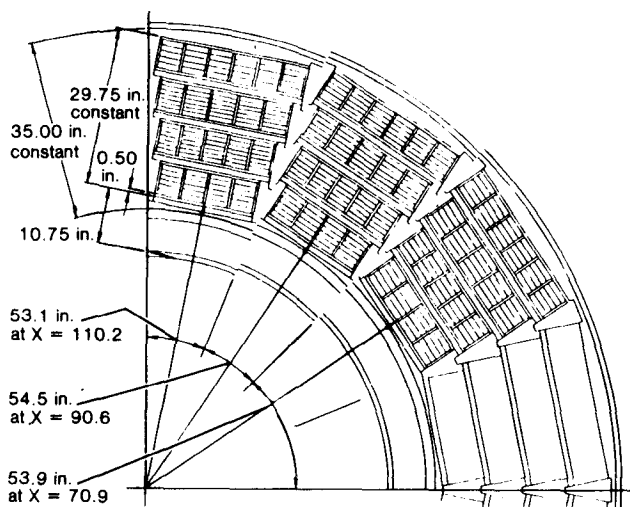


Figure 7. Conductor configuration is optimized to fully utilize space at the magnet inlet end.

Helium Vessel. The entire substructure is encapsulated in a helium-tight conical vessel. It is constructed from 25mm (1.00 in.) thick 304L welded stainless steel.

Superstructure. The superstructure surrounds the helium vessel/substructure assembly. A structurally efficient chain-link style superstructure with box beam cross-section was selected as the preferred configuration for CASK. It is fabricated from welded 304LN stainless steel. Structural component plate thickness ranges from 50 mm (2.00 in.) to 125mm (5.00 in.) thick. Figure 9 shows an assembled box beam superstructure component with an associated detail breakdown.

Supports. The total cold-mass weighs 2,226,942 kg (4,905,158 lb). It is supported by a set of six low-heat leak fiberglass/epoxy struts. A unique arrangement of the struts provides dead weight support plus

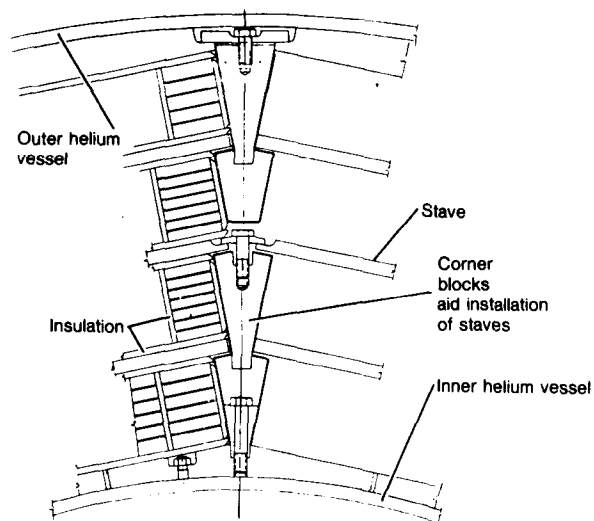


Figure 8. Corner blocks regionalized conductor bundles and air stave installation.

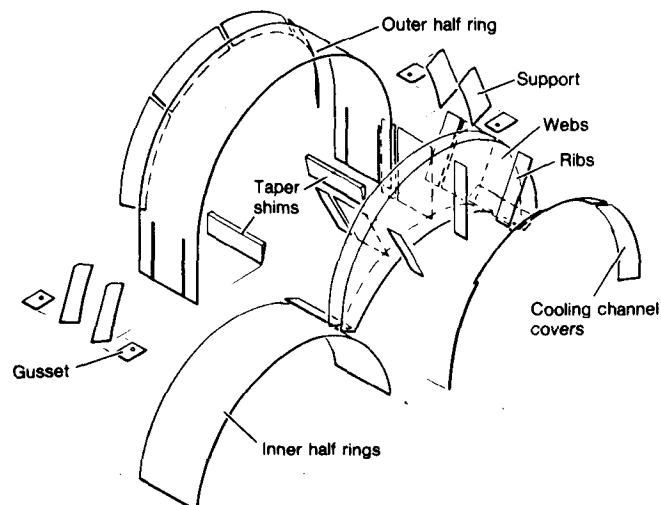
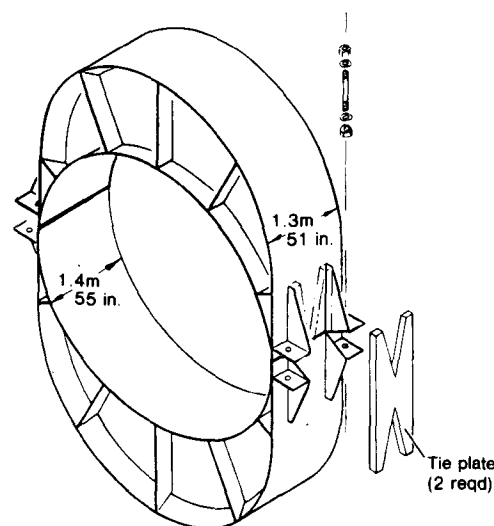


Figure 9. Box beam superstructure is economically producible.

seismic protection while accommodating electromagnetic force and thermal contraction deflections. All services for the magnet (i.e., helium inlet/outlet, power leads, instrumentation, vacuum, nitrogen