180
6-26-81

(2)

Dr. 2777

B-5299

ORNL/TM-7665

ornl

OAK RIDGE NATIONAL LABORATORY

UNION CARBIDE

MASTER

Using Gifts on the Cray-1 for the Large Coil Test Facility Test-Stand Design Analysis

T. V. Baudry
W. H. Gray

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

CONTENTS

ABSTRACT

The GIFTS finite element program has been used extensively throughout the Large Coil Test Facility (LCTF) test stand design analysis. Effective use has been made of GIFTS both as a preprocessor to other finite element programs and as a complete structural analysis package. The LCTF test stand design involved stress analysis ranging from simple textbook-type problems to very complicated three-dimensional structural problems. Two areas of the design analysis are discussed.

1. INTRODUCTION

The Large Coil Program (LCP)[1] at Oak Ridge National Laboratory (ORNL) is a research, development, and demonstration effort specifically for the advancement of the technologies involved in the production of large superconducting magnets. Central to this program is the Large Coil Test Facility (LCTF),[2] which will consist of a test stand that supports up to six test coils, a pair of smaller coils that impose a pulsed field on any selected test coil, a large vacuum tank that provides thermal isolation, and refrigeration, electrical, and data acquisition systems.

The test stand is designed to provide a restraint for a variety of both in-plane and out-of-plane loading conditions while supporting one to six coils from a central bucking post mounted on a spider-shaped base. Two torque rings clamp the outer corners of the test coils and provide a tangential restraint between them.

2. LCTF STRUCTURAL ANALYSIS SCHEME

The six toroidal coil designs to be evaluated in the LCP have different stiffnesses and current densities that reflect various ways of satisfying the LCP design specification.[3] Evolving competitive designs are not necessarily available for free exchange between coil manufacturers. This problem of design/analysis has been solved by establishing a scheme[4] that enables the coil designers to design their coils with a limited knowledge of the LCTF system. This in turn allows ORNL engineers to design the LCTF without detailed characterization of the various coils.

The scheme involves the determination of the LCTF structural behavior at its interface with any selected test coil and its behavior at interfaces between LCTF components. Systems Analysis, Incorporated (SAI) performed the overall structural analysis of the LCTF to support the design sizing calculations. To perform this structural analysis, Johnson et al.[5] used a suite of pre- and postprocessor computer programs based on NASTRAN.

The NASTRAN finite element model was a simple, but large, beam and plate model deemed sufficient to evaluate the overall macroscopic structural behavior of the LCTF. The individual components were not modeled in sufficient detail to determine stress concentrations.

3. LCTF COMPONENT STRUCTURAL ANALYSIS

Like the individual coil manufacturers, ORNL engineers had only a limited knowledge of each manufacturer's coil design while they were making important design decisions for LCTF structural components. This problem was resolved by using the facility side of the SAI LCTF structural model to provide interface forces and deflections for refined finite element models of the individual components in the LCTF. The design and analysis of one of the major components are described in Sect. 4. The design and analysis tasks for the other LCTF components were performed in a similar manner.

The tasks were accomplished primarily using the ORNL version of GIFTS.[6,7] Most of the graphical output displayed here was produced with GIFTS or converted with the program GFTMOV[8] to a format for display with the MOVIE.BYU[9] hidden line removal program.

4. TORQUE RING STRUCTURAL ANALYSIS

First, a GIFTS beam model was generated with very crudely established elastic properties. This initial model provided ORNL design engineers with an understanding of the gross behavior of the torque ring under various loading conditions. A total of 73 nodes and 73 BEAM2 elements was used in this model (see Fig. 1). Interface loads were provided for six coordinates at each of the six coils from the SAI LCTF structural model.

Resulting forces and displacements from the GIFTS model were used directly for sizing individual sections of the LCTF torque ring. This first design became the basis, after numerous iterations, for the current LCTF torque ring design. The final design consists of three identical segments, each of which spans two coils. The three segments bolt together at points midway between coils and form a full 360° ring. Three schedule-80 stainless steel pipes span the chord between adjacent coils and are rigidly attached to a rectangular collar that interfaces with the toroidal field coils. The torque ring collars provide tangential resistance between adjacent coils but allow radial displacement of the individual coils. The torque ring is vertically supported by roller connections to the toroidal field coils.

Two detailed GIFTS models were used to analyze major design considerations. Worst-case loads occur during a two-coil test (a proposed test of just two coils for shakedown of the LCTF) and produce a torsional deflection of the 120° torque ring segment. Symmetry was assumed for this two-coil case that allowed a one-sixth symmetric model. Figure 2 shows an isometric view of the one-sixth torque ring finite element model. A discretization of 180 nodal points with 195 elements adequately represents the section. Figure 3 depicts typical loads applied to a collar section.

A GIFTS model of the full six-coil torque ring was also generated. Approximately 2300 degrees of freedom were involved as defined by 1244 nodes and 1107 elements. The initial run of this model was performed on a DECsystem-10 with the following time statistics:

ORNL-DWG 80-2298 FED

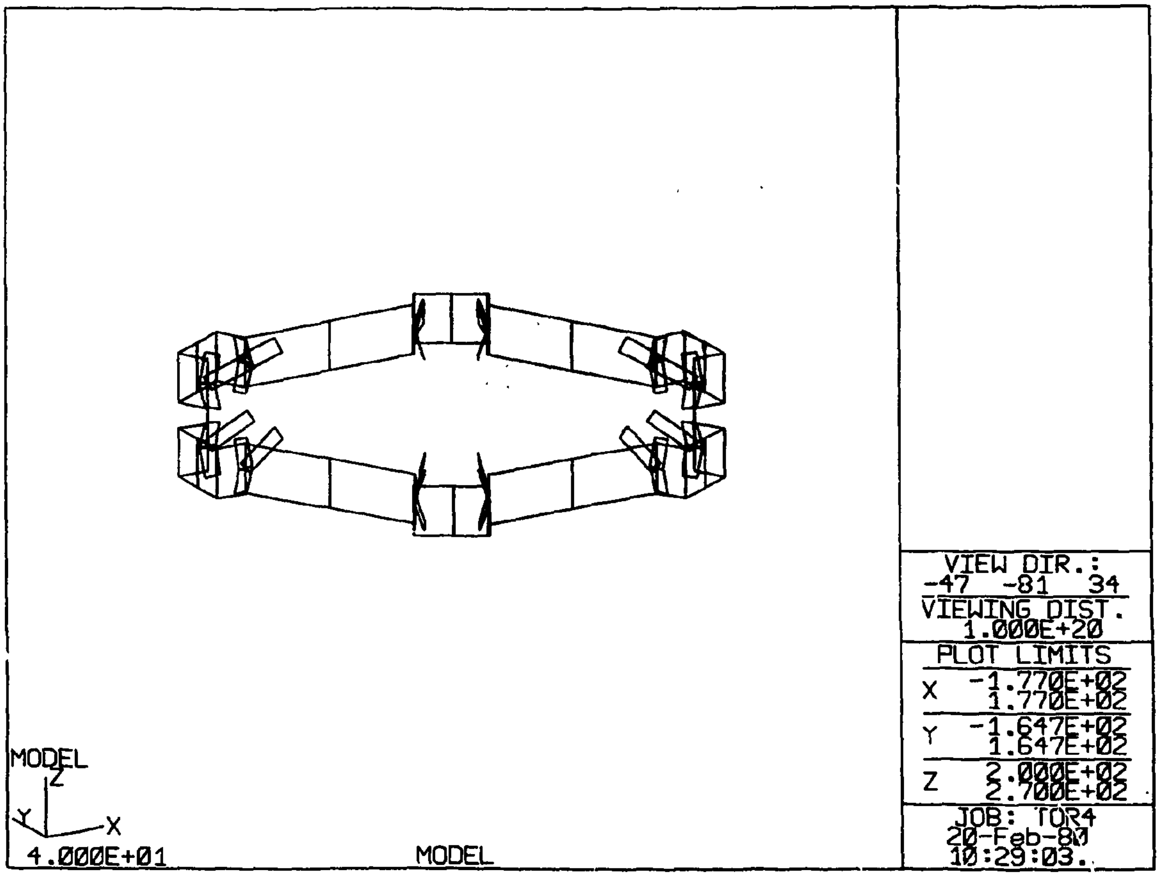

Fig. 1. An isometric view of the first torque ring finite element model, used primarily for determination of gross mechanical behavior.

ORNL-DWG 80-2291 FED

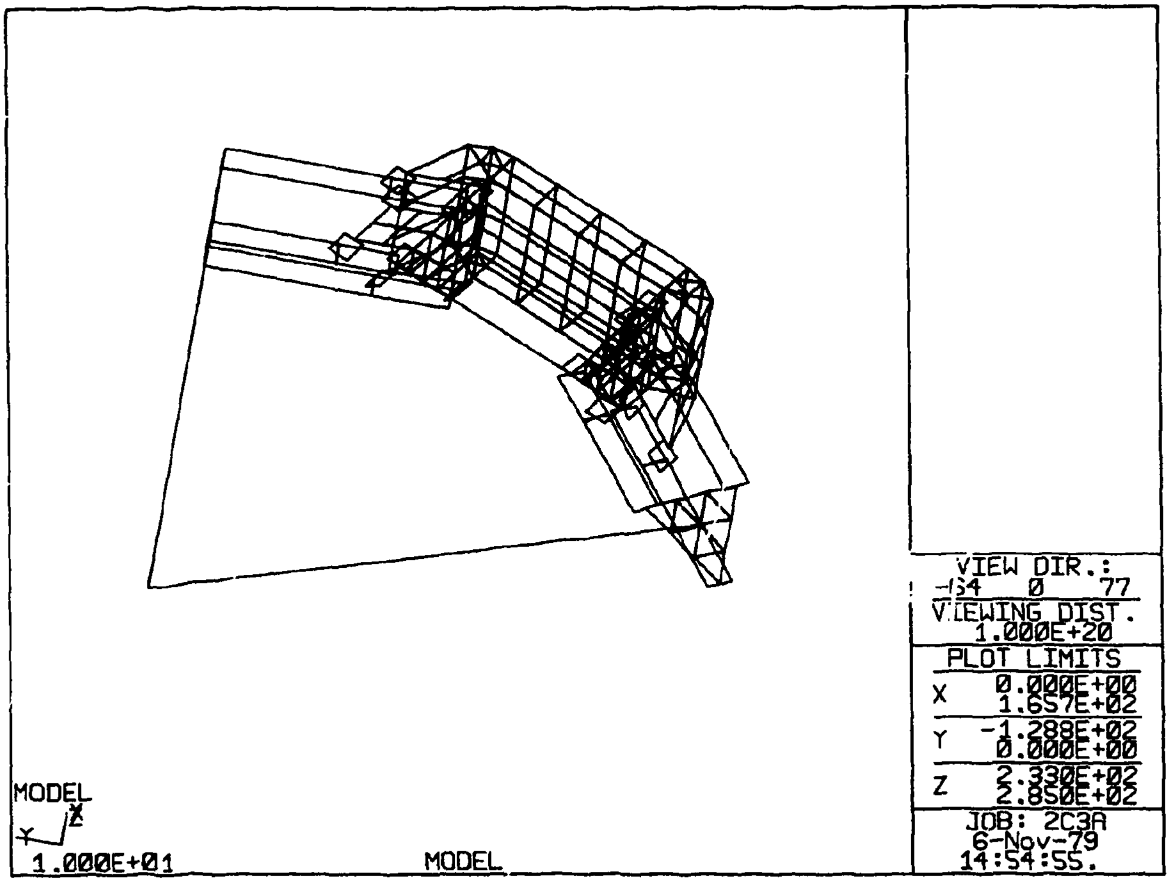

Fig. 2. An isometric view of the LCTF torque ring one-sixth symmetric finite element model. Two tie rods are shown that restrain the radial motion of the torque ring for the two-coil test case.

ORNL-DWG 80-2296 FED

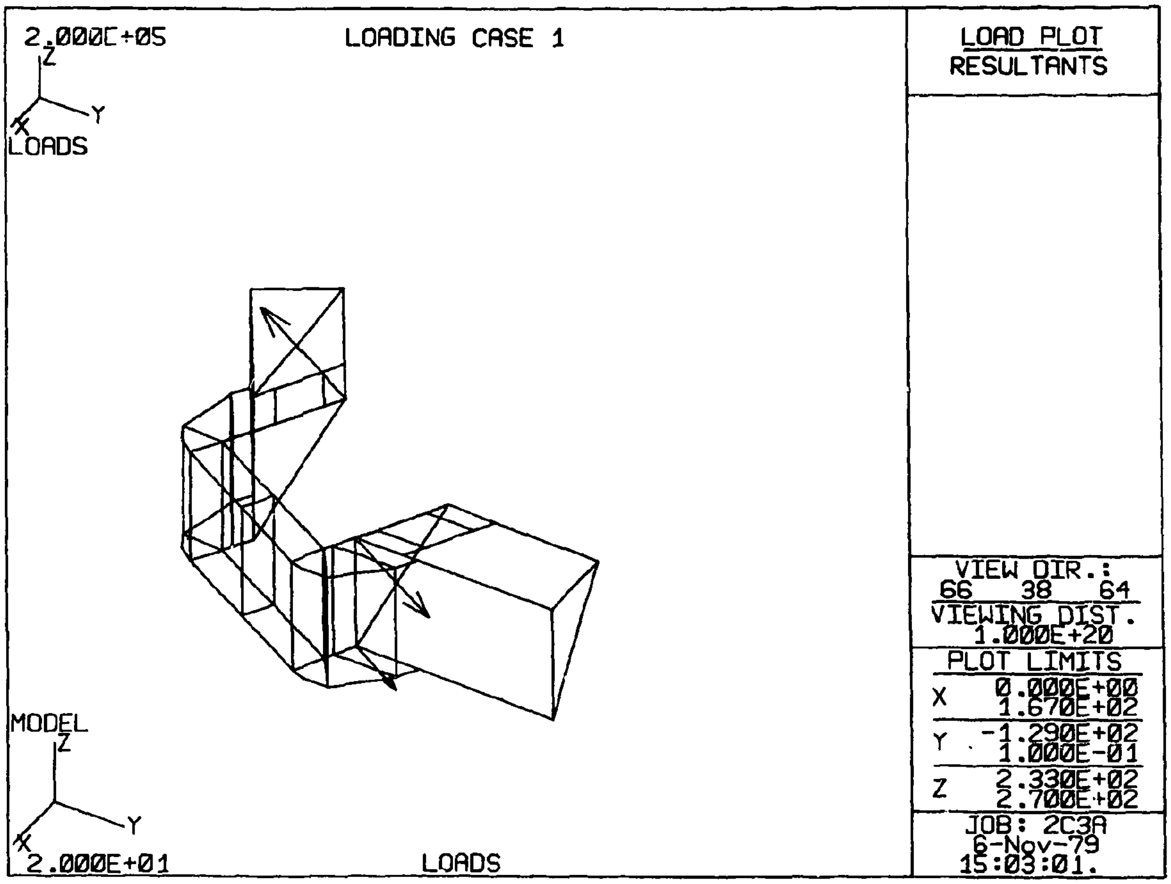

Fig. 3. An isometric view of the LCTF torque ring one-sixth symmetric finite element model. On this plot all interior lines have been deleted for clarity. The vectors represent the applied loads.

Module	CPU (min)
OPTIM	1:4.30
STIFF	21:1.01
DECOM	2:5:25.53
DEFL	15:50.82
STRESS	3:19.69

This analysis was performed during a nonprime computer shift and consumed about nine hours of wall-clock time. An identical model was executed with the CRAY-1 version of GIFTS.[10] Precise statistics are unavailable, but the total CPU time was about 9 min. for the entire run. Figure 4 is an isometric view of the full six-coil torque coil model. Figure 5 shows the deflected shape of the entire upper torque ring for the six-coil cluster, worst-case loading condition (one coil faulted, the rest are energized to design current). Warping of the torque ring is clearly visible in this figure.

It has been learned from this analysis that the torque ring design is extremely sensitive to changes in interface loads. Because of this and at the suggestion of the other LCP design participants, a new LCTF finite element model has been created.

ORNL-DWG 80-2300 FED

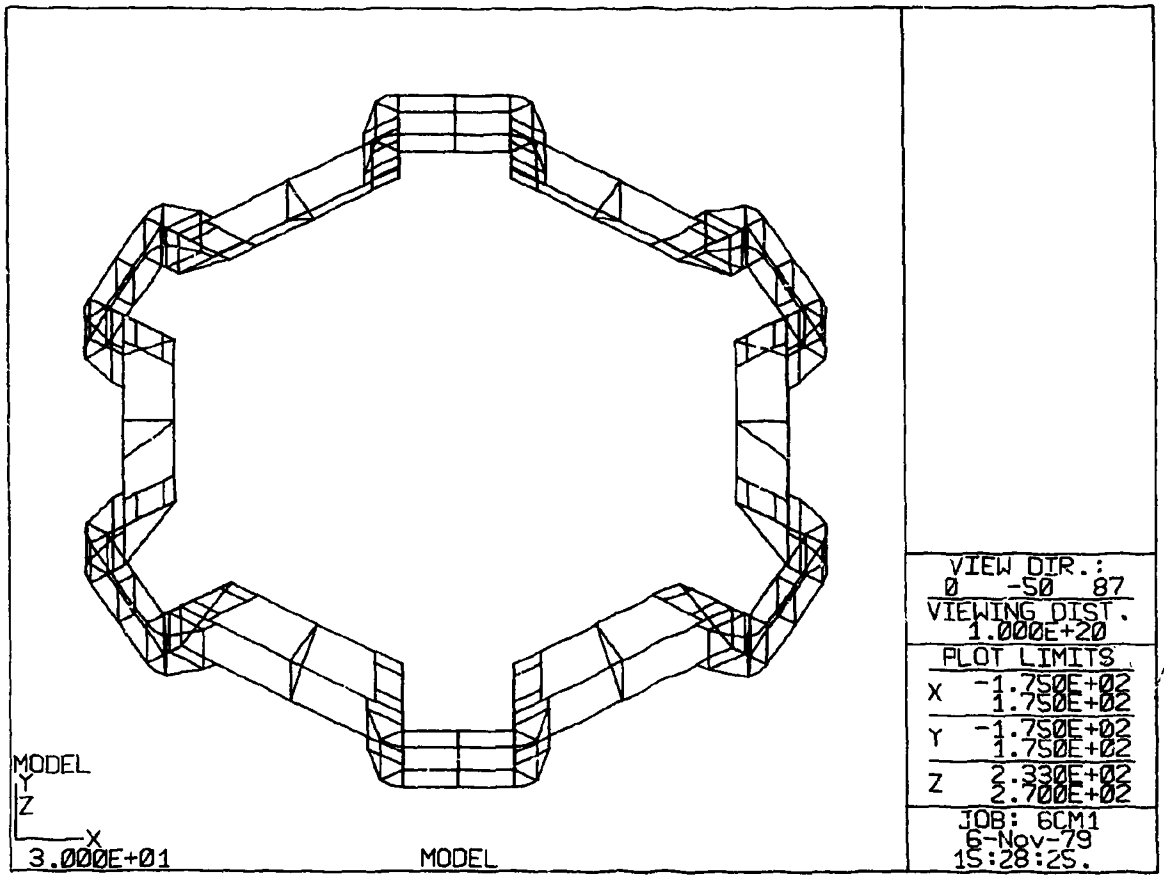

Fig. 4. An isometric view of the LCTF torque ring full finite element model. The torque ring is approximately 9 m wide and 1.2 m high. On this plot all interior lines have been deleted for clarity.

ORNL-DWG 80-2299 FED

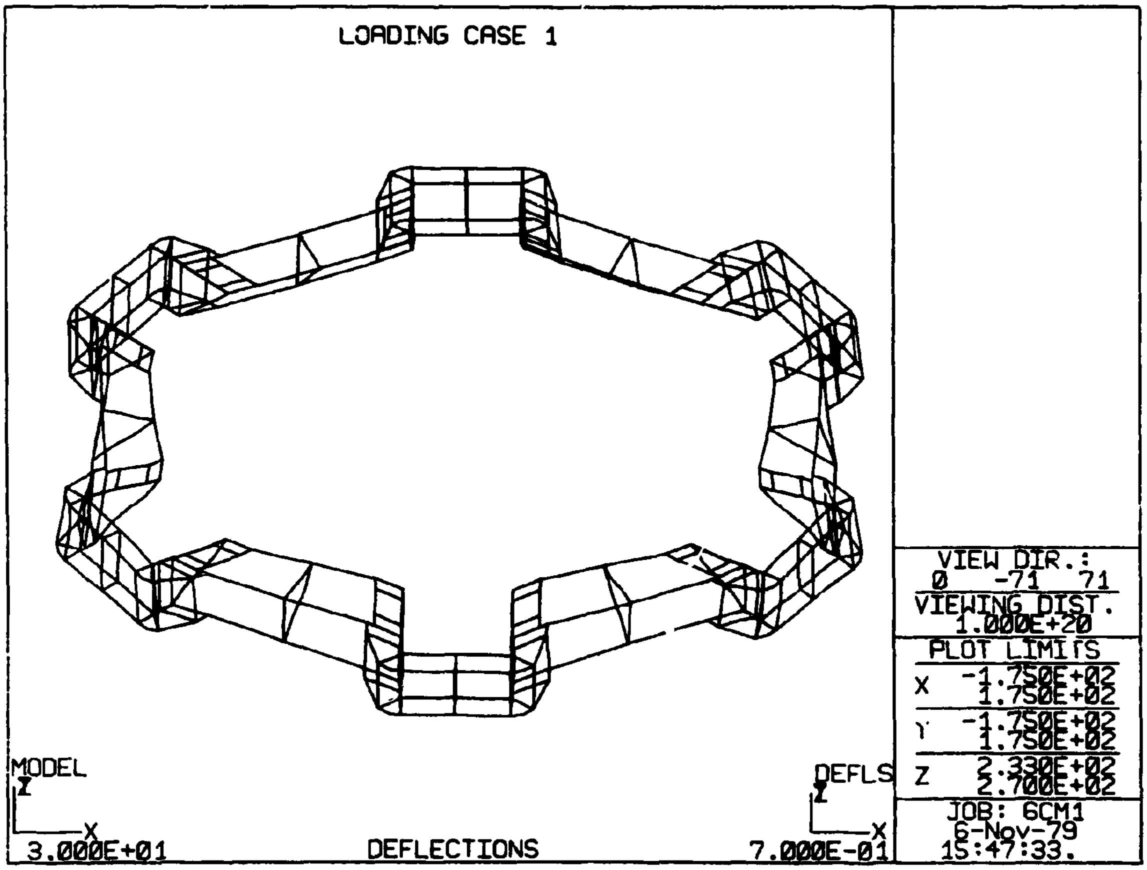

Fig. 5. An isometric view of the LCTF torque ring model showing exaggerated deflections (a deflection magnification of 10 was used). This model clearly shows that significant warping of the torque ring will occur under the worst-case condition.

5. THE NEW LCTF STRUCTURAL MODEL

With the experience gained from the orderly progression of structural analysis of the individual components of the LCTF, a new structural model of the LCTF is being created. Contained within this model are the four major components of the LCTF: the spider base, the torque rings, the bucking post, and the coils. Because of several unresolved concerns about the behavior of the torque ring, a simulation of the two-coil test has been selected for the first phase of the new structural analysis task. Therefore, only two coils and a 120° segment of the upper and lower torque rings are modeled, along with a complete spider frame and bucking post.

The upper and lower torque rings are discretized with plate, beam, and rod elements. Figure 6 shows an isometric view of the elements in the upper torque ring structure. The spider base is modeled with plate and beam elements. Since the mechanical response of the spider base closely resembles that of a beam, a simplistic model (see Fig. 7) can be used to capture the correct behavior.

At present two coils are modeled for the beginning shakedown of the model. They are identical and reflect the current General Dynamics (GD) toroidal field coil design. (GD was the first contractor to finish the Phase II design task.) As shown in Fig. 8, a single rod is used to model the conductor winding pack, and this rod is connected to the coil case via two radial and two axial rods. The coil case is modeled with plate elements of the appropriate thicknesses and is shown in Fig. 9.

The bucking post is modeled with beams and membrane elements (see Fig. 10) and is the least satisfactory discretization in the model, since solid elements cannot be used for an analysis with CIFTS. Therefore, the response of the bucking post discretization will be very carefully scrutinized for possible modeling problems.

The assembled two-coil LCTF structural model includes 1451 nodes with 1780 elements and is shown in Fig. 11. Of the 1780 elements, 375 are ROD2, 211 are BEAM2, 88 are TM3, 282 are TB3, and 824 are QB4. This results in 5682 degrees of freedom with an unoptimized half-bandwidth of 2567.5. The optimized half-bandwidth is 467.7. Generation and

ORNL-DWG 80-2292 FED

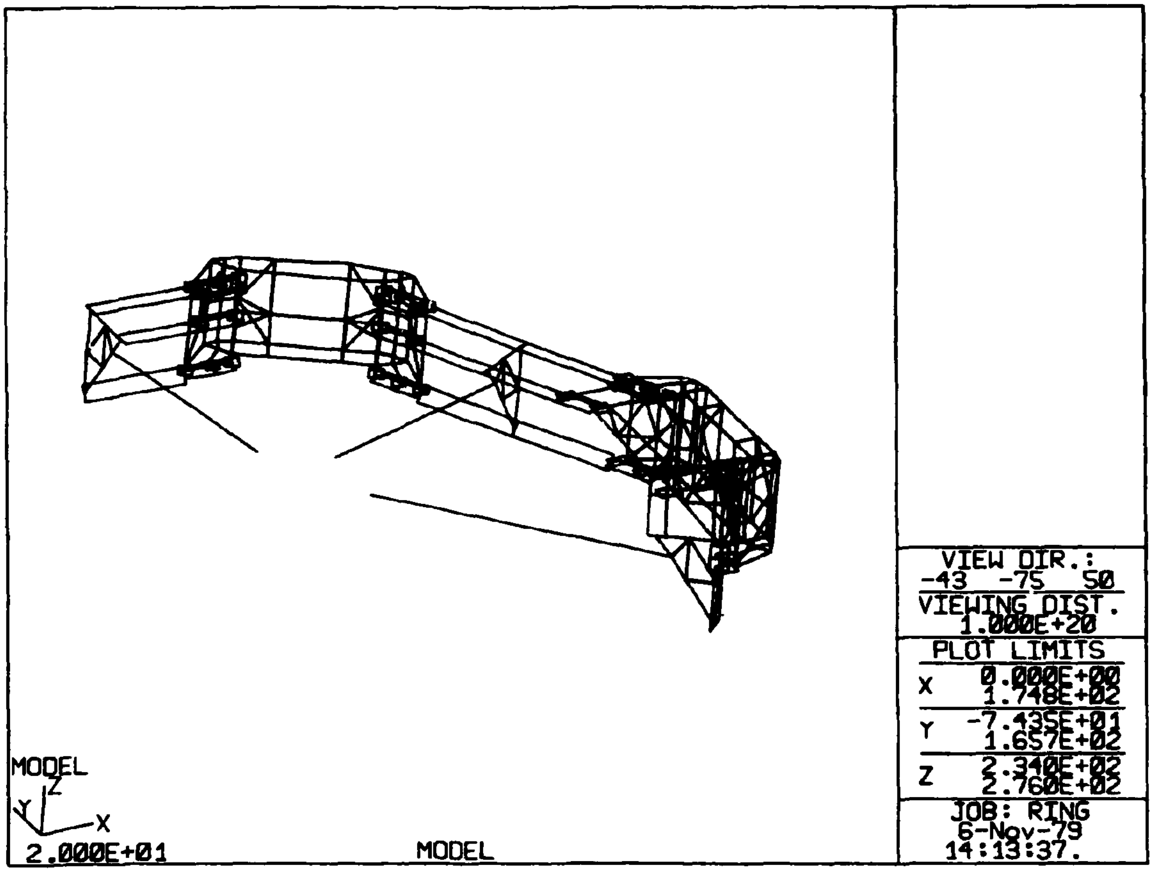

Fig. 6. An isometric view of the upper torque ring finite element model for the new LCTF structural model. All elements are shown. (The observer's eye is located under the torque ring.)

ORNL-DWG 80-2294 FED

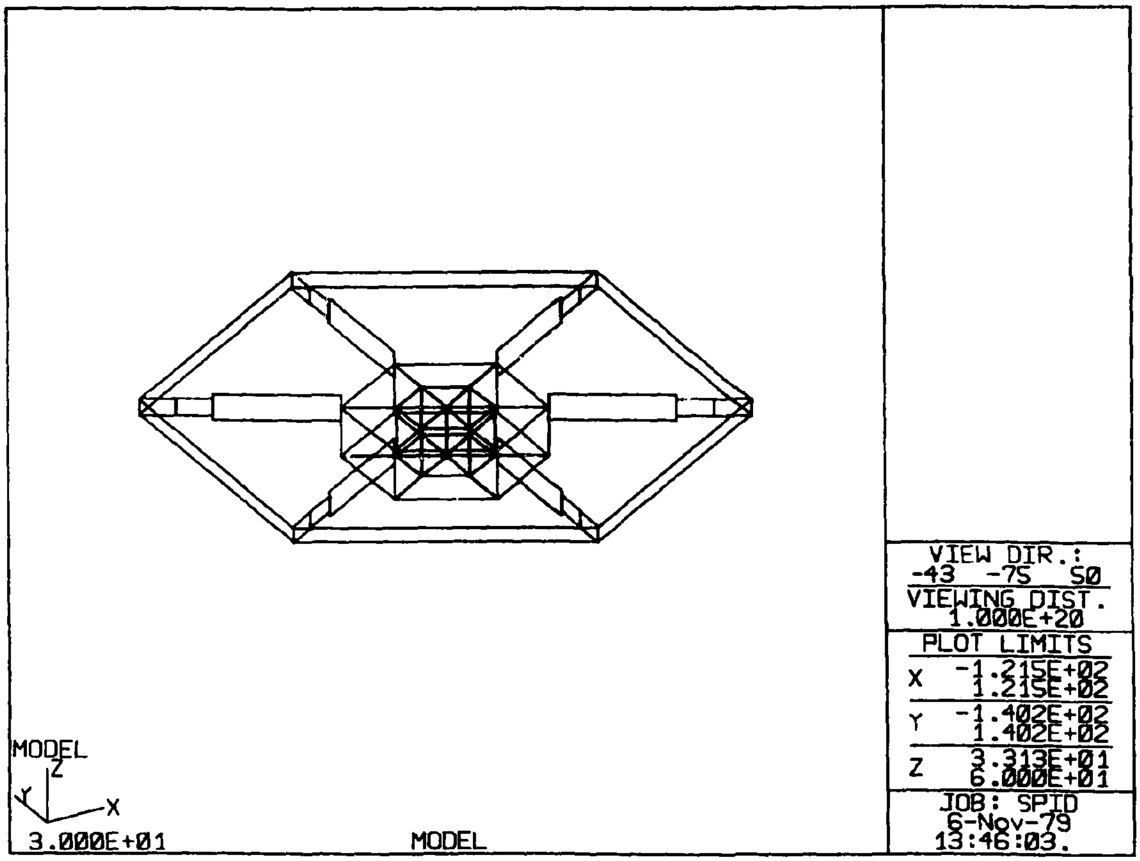

Fig. 7. An isometric view of the spider base finite element model for the new LCTF structural model. All elements are shown. (The observer's eye is located above the top surface of the spider base.)

ORNL-DWG 80-2297 FED

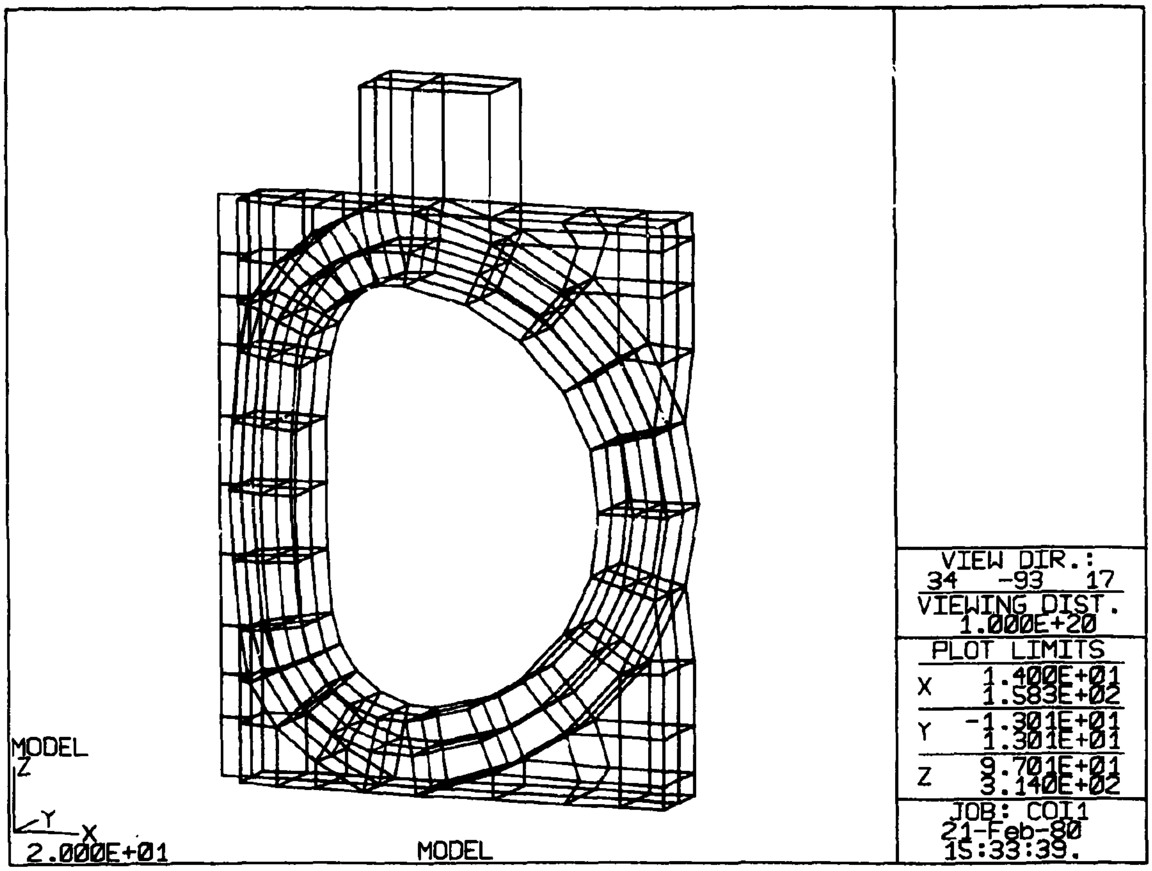

Fig. 8. An isometric view of the GD toroidal field coil finite element model for the new LCTF structural model. All elements are shown. (The observer's eye is located to the left of the coil.) Rod elements are used to capture the mechanical response of the winding pack. These elements resist the hoop tensile force. The bending forces are assumed to be resisted by the coil case plate elements.

ORNL-DWG 80-2290 FED

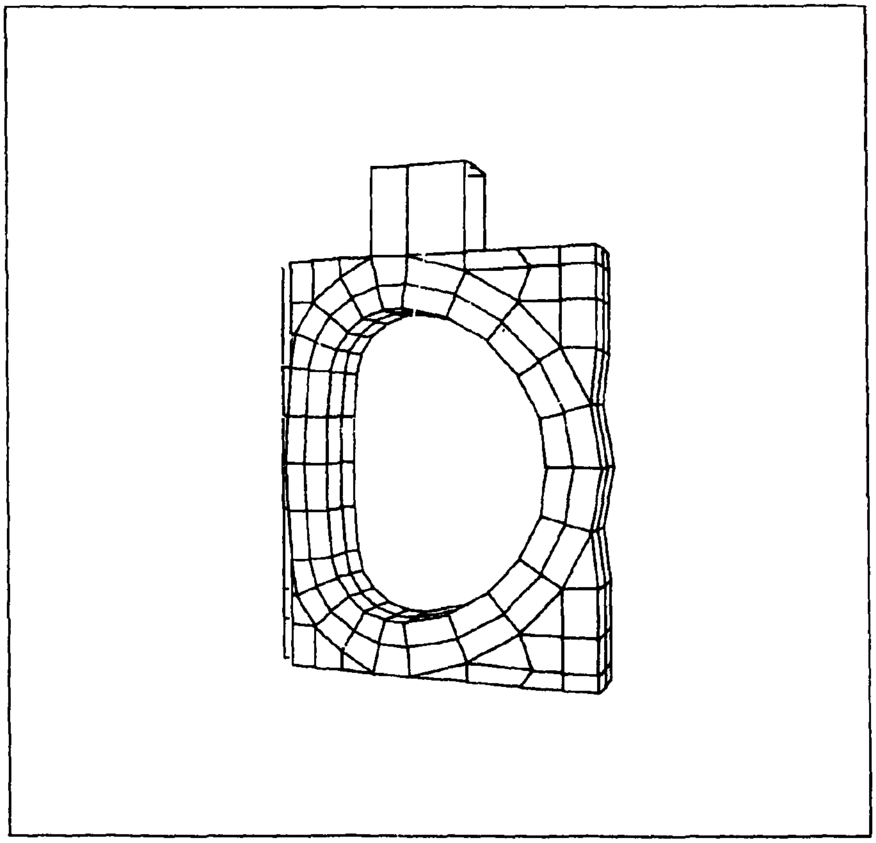

Fig. 9. A perspective view of the GD toroidal field coil finite element model for the new LCTF structural model. This view is of the left surface of the coil. (The hidden lines have been removed for clarity.)

ORNL-DWG 80-2293 FED

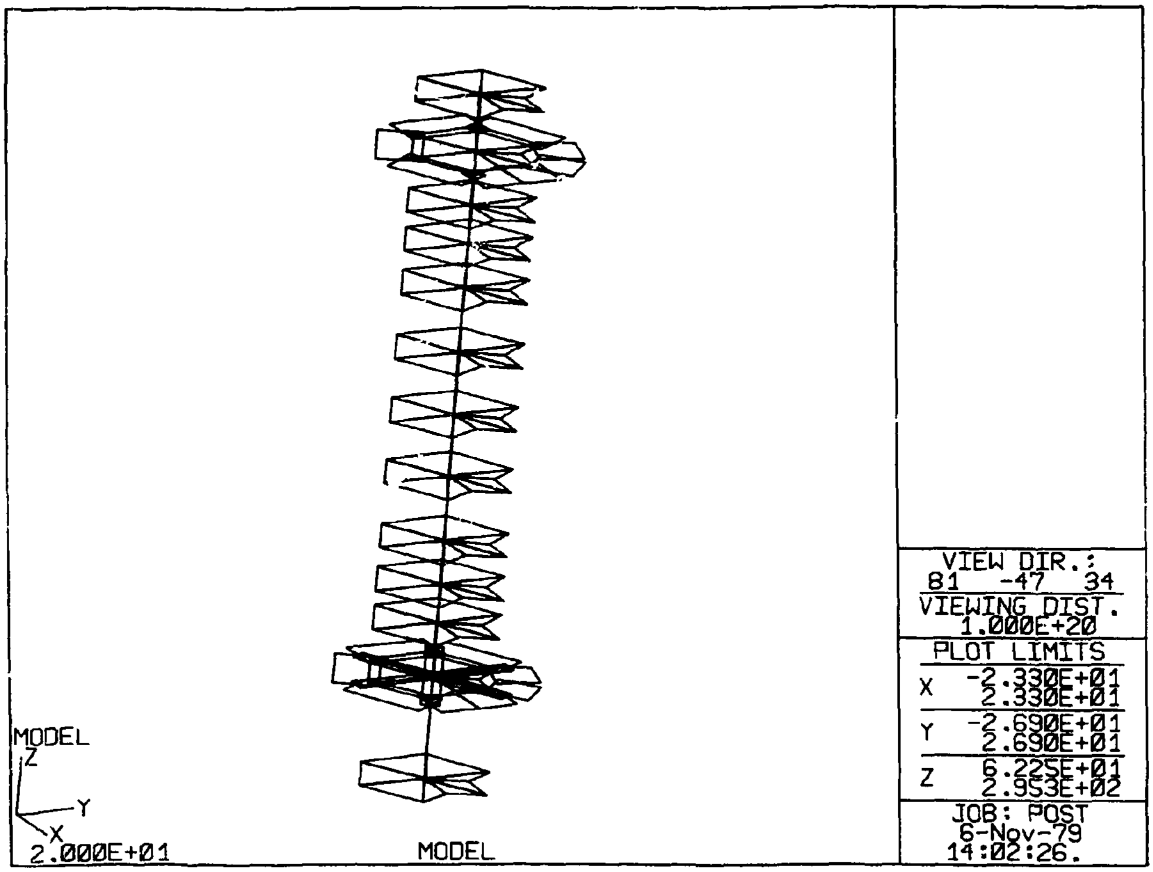

Fig. 10. An isometric view of the bucking post finite element model for the new LCTF structural model. A central beam runs the length of the bucking post. Membrane elements are used to transmit the toroidal field coil centering force to the beam elements. The upper and lower toroidal coil restraining collars are modeled with beams.

ORNL-DWG 80-2295 FED

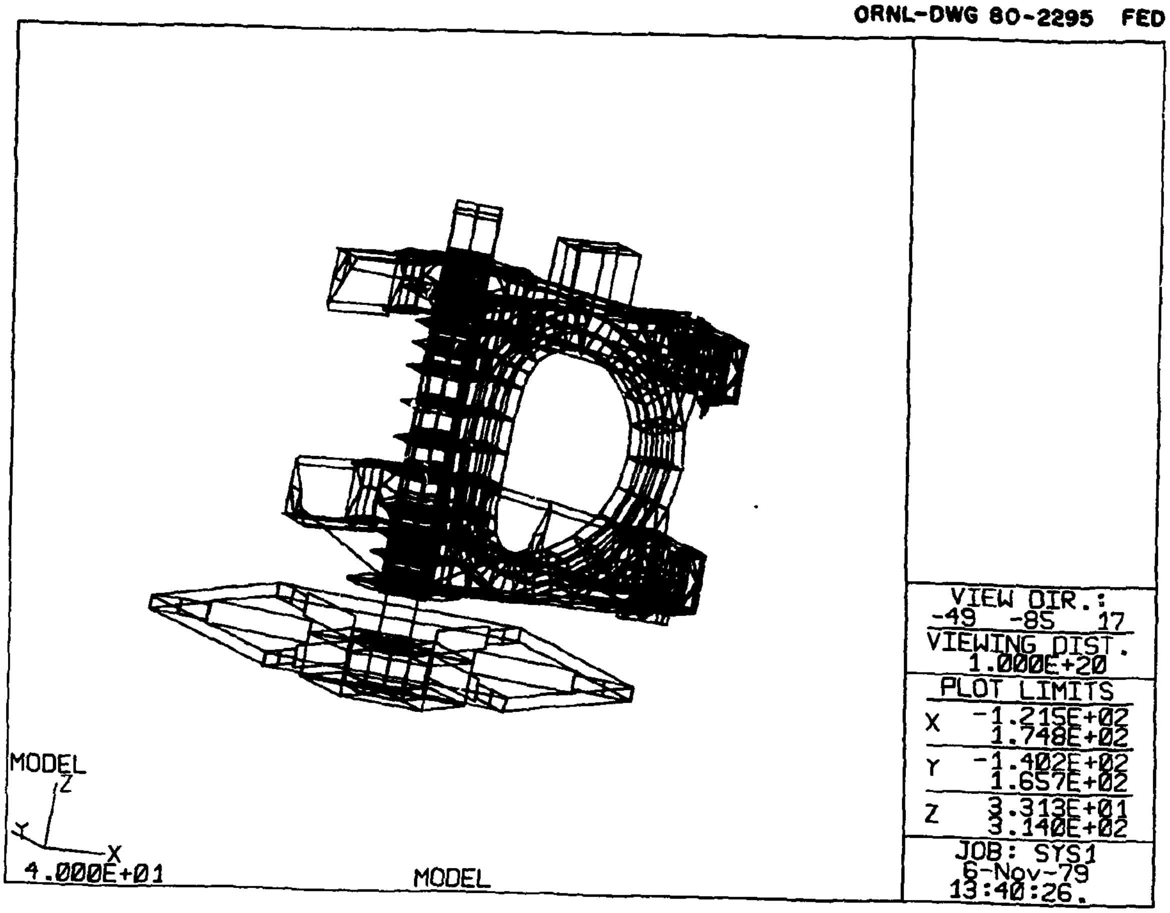

Fig. 11. An isometric view of the assembled LCTF structural model. All elements are shown. (The observer's eye is located directly in front of toroidal coil 2.)

execution of the complete model on the CRAY-1 took 23.03 min of CPU time with 135.88 min of input/output (I/O). Almost 70% of the total time was required by the DECOM module, with DEFL using about 15% and STIFF requiring 10%. The remaining 5% was accounted for among EDITM, EDITLB, and BULKF.

Run times, primarily wall clock, were unacceptable for the LCTF structural analysis. The large I/O counts forced low priority runs which were difficult, if not impossible, to complete. Another complication was the size of the stiffness file — for this model it was in excess of 14 million octal words. At one point during the analysis a one-week wait for a large enough hole on the disks was required before STIFF could be executed.

A combined system time (CPU plus I/O) of about 19 min was required for STIFF on the CRAY-1. DECOM required over 100 min of combined system time, and had a wall-clock time of about five hours. These times necessitated consideration of a revised approach.

As an alternative to scrapping the model and starting over, it was determined that the GIFTS LCTF structural model could be converted to a NASTRAN data base with a minimal time loss. Data dumps using GFTDMP[11] were generated for each of the four major LCTF structural components. The conversion to the NASTRAN data base has been accomplished with a reasonable amount of effort on the DECsystem-10.

6. CONCLUSION

GIFTS has been used extensively in the LCTF test stand analysis. A variety of models, ranging from the simple to the large and complex, have been generated and successfully executed, providing the basis for much of the LCTF test stand design. GIFTS was also implemented on the CRAY-1 system at Lawrence Livermore Laboratory, which is specifically for the execution of very large finite element models. Practical limits on the size of models that can be run with GIFTS have been recognized.

REFERENCES

1. P. N. Haubenreich, W. C. Anderson, J. N. Luton, and P. B. Thompson, Plan for the Large Coil Program, ORNL/TM-5824, Oak Ridge, Tennessee (February 1977).
2. L. W. Nelms, P. B. Thompson, and T. L. Mann, Large Coil Test Facility Conceptual Design Report, ORNL/TM-6032, Oak Ridge, Tennessee (February 1978).
3. UCC-ND Technical Specification No. TS 14700-01 Rev. B, Union Carbide Corporation, Oak Ridge, Tennessee (February 1979).
4. S. D. Moses and N. E. Johnson, "Analysis Techniques for Evaluating the Structural Response of the Large Coil Test Facility," in Computer Technology in Fusion Research, ed. by J. E. Akin and W. H. Gray, American Society of Mechanical Engineers special publication PVP-PB-031, New York, 1978.
5. N. E. Johnson, M. K. Singhal, J. C. Walls, and W. H. Gray, Proc. 8th Symp. on Engineering Problems of Fusion Research, to be published.
6. H. A. Kamel and M. W. McCabe, The GIFTS System: Version 4B User's Manual, University of Arizona, Tucson, Arizona, July 1978.
7. W. H. Gray, System Software for the ORNL Version of GIFTS 4B, ORNL/TM-7009, Oak Ridge, Tennessee (November 1979).
8. W. H. Gray, A User's Guide to Program GFTMOV: A Computer Program to Access and Format a GIFTS 4B UDB into a Data Base for the MOVIE.BYU Program, ORNL/TM-7021, Oak Ridge, Tennessee (January 1980).
9. H. Christianssen and M. Stephenson, MOVIE.BYU: A General Purpose Computer Graphics Display System, Brigham Young University, Provo, Utah, 1978.
10. W. H. Gray, "System Software for the NMFECC Version of GIFTS 4B," to be published.
11. W. H. Gray, "Program GFTDMP: A Computer Program to List the Contents of a GIFTS 4B UDB," to be published.