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MASTER

18T RESISTIVE INSERT DEVELOPMENT

CONCEPTUAL DESIGN SECOND ANNUAL REPORT

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REPORT GDC-CRAD-85-003

18T RESISTIVE MAGNET

DEVELOPMENT REPORT

CONCEPTUAL DESIGN SECOND ANNUAL REPORT

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FOREWORD

This is the second annual report of the engineering design analysis and test of a normal copper alloy resistive insert coil. The coil is a part of an 18 tesla magnet set to be used in the MFTF-B Upgrade experiment at Lawrence Livermore National Laboratory (LLNL). The work reported herein was performed under LLNL subcontract #4786805 titled "18 Tesla Magnet Development." The report constitutes the Fiscal Year 1985 document.

All of the tasks have been performed under the direction of the General Dynamics Space Systems Division, Energy Programs Department (710-0).

The authors wish to express their appreciation for the assistance of Mr. Edward Dalder of LLNL. He has provided a large amount of information and test data concerning the material properties of the copper alloys and he has been most encouraging with regard to the value and application of the work performed.

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SUMMARY

This report documents the work performed on a normal conducting magnet during fiscal year 1985. Emphasis, during the study, was on refinement of the structural design and optimization of the coil current density distribution for either maximum field generation or minimum power consumption. The results have shown that one can generate a 4.4 tesla field using 6.14 megawatts or 3.1 tesla at 1.43 megawatts. The structural design has been modified to stiffen the outer turn of the conductor. The modification was confirmed to be structurally adequate by both analysis and test.

SECTION 1

INTRODUCTION

1.1 BACKGROUND

A tandem mirror fusion reactor requires magnetic fields great enough to confine the plasma at either end of the central cell. These fields are on the order of 18 to 30 tesla and are produced by solenoids called "choke" coils. The choke coils are generally configured from a combination of a resistive copper inner coil (hereafter called the resistive insert), surrounded by a superconducting background coil. At the present magnet design state of the art for fusion reactor applications, only 12 tesla fields have been made from superconducting magnets. While fields of 16 to 20 tesla are possible from a single superconducting magnet, future choke coils will undoubtedly be comprised of a hybrid combination of normal and superconducting coil. The fiscal year 1984 work focused on the initial conceptual design and fabrication of an engineering model resistive insert double pancake coil. The fiscal year 1985 work, reported herein, concentrated on design and analysis refinement, structural integration and test of some key elements in the design.

1.2 PROJECT OBJECTIVES

During 1985 the primary objectives of the project included study of configuration alternatives, detail design of the conductor coil based on additional analysis, finite element stress analysis, conceptual integration of the resistive insert with the background superconducting coil, and test of some key elements of the design. All of these objectives were achieved. Maximum field and minimum power configurations were generated and analyzed. The outer conductor was strengthened because of the need to react bending moments generated by asymmetric conductor loads. A detail finite element model of the coil was made and analyzed. Drawings of the coil support structure and superconducting coil interface structure were made. The coil conductor was modeled from aluminum, then stress tested and lastly, the electrical isolation hydraulic connector was tested for voltage standoff and flow pressure drop.

1.3 APPLICATIONS

While the primary application of the project work is for Mirror Fusion Reactors, the materials knowledge, design techniques, manufacturing technology and analysis could apply to Tokamak Fusion Reactors as well. At least two Tokamak ignition experiments, MIT's Long Pulse Ignition Test Experiment and PPPL's Ignition Studies Project are considering the use of copper alloy

magnets to generate the toroidal magnetic field. Many of the subjects covered in this and the previous report apply to the copper Tokamaks. Some of these subjects are: current density grading, machining of high strength copper alloy, heat treatment of zirconium copper alloy, radiation resistant electrical insulation, optimum coolant flow, path, area and velocity, and conductor electrical joints.

SECTION 2

REQUIREMENTS

2.1 DESIGN

The primary design objective for the resistive insert is to generate 3.0 to 3.1 tesla magnetic field within a 15 tesla background field so that the total field generated by the hybrid magnet set is at least 18 tesla. The baseline resistive insert coil must be sized to fit within the envelope defined by the inside dimension of the background coil. The coil shall be water cooled so that its temperature does not exceed the annealing temperature for the construction material.

2.2 MATERIALS

The primary material requirement is for the conductor. Ideally it would be a good electrical conductor and have a relatively high yield strength. Because the coil will necessarily dissipate a large quantity of heat, its material should be relatively insensitive to temperature. The electrical insulation between coil turns and pancakes must also withstand high nuclear radiation doses. Ordinary copper conductor and organic insulations will not perform reliably under these conditions, therefore a high strength zirconium copper alloy (Amzirc) has been used for the conductor and a General Dynamics proprietary metal oxide material has been used as the insulation. These materials are described more completely in Section 5.

SECTION 3

DESIGN

3.1 MAGNET DESIGN

The resistive insert coil conductor has been redesigned. Analysis showed the conductor having excessive bending stress in the second turn because of the spiral conductor form. Stress reduction has been accomplished by increasing the conductor's height. This has resulted in an overall increase in magnet pancake diameter. The original dimension of 46.70 cm. has changed to 51.50 cm. diameter. The number of pancakes in the magnet is 24 and the overall magnet length is 51.10 cm., unchanged from the design of a year ago. Figure 3-1 shows the overall magnet dimensioned in section.

The pancake is machined from Amzirc Cl5000 copper alloy, which has been cold worked and aged to produce an alloy having a room temperature yield stress of 60,000 psi.

3.1.1 CONDUCTOR. The conductor dimensions have been tailored to react both tension and bending as it spirals out from the magnet hub. The former design neglected bending because of an assumption that the bending would be reacted by friction between pancakes. A more conservative approach is incorporated into the present design. The conductor is stiffened in the second turn region by increasing the conductor section modulus and we no longer depend upon friction to carry load.

Outer Conductor. A new set of conductor shape equations have been created for the improved design. The new equations generate a larger second turn. They define the radius to the inner edge of the conductor as a function of the angular position from the start.

For $\theta =$ zero degrees to 360 degrees

$$R = 12.89 + 1.605(\theta/180) + 0.055(\theta/180)**2$$

For $\theta =$ 360 degrees to 540 degrees

$$R = 11.62 + 2.24(\theta/180) + 0.055(\theta/180)**2$$

For $\theta =$ 540 degrees to 720 degrees

$$R = 9.715 + 2.875(\theta/180) + 0.055(\theta/180)**2$$

Figure 3-2 shows the redesigned machined pancake with its larger outer (second) turn. Note that there are still two conductors per pancake and the conductors start at $\theta =$ zero near the hub, as indicated in the figure.

Figure 3-1. Resistive Coil Cross-Section

Figure 3-2. Revised Machined Conductor Pancake

The length of each conductor is 226.5 cm. from its start out to the mid point of the pancake-to-pancake joint bolt pattern. The selected configuration results in a conductor capable of maximum current density and minimum size for the materials used and the magnetic field produced. This would not be possible with a conventional, constant cross section, wound, conductor.

Hub Configuration. The new pancake starts the insulation slot 45 degrees from the conductor start point. This has resulted in an additional inside 1/8 turn for each pancake conductor. Because this additional turn is at the inside radius, it is in the most efficient field generation location possible. The increased conductor length also reduces the hub pancake-to-pancake overlap in proportion.

Tubing. The water coolant tube is a 0.73 cm. O.D. copper pipe with a 0.0305 cm. wall thickness. The tube material is "Cupronickel" (CDA C71500 Cu + 30% nickel). This alloy is appropriate because of its erosion, corrosion, cavitation and pitting resistance to high pressure, high velocity, flow conditions. The coolant water design velocity is 45 ft/s. at a 428 psi pressure. Two coolant tubes are used for each double pancake. Each tube joggles from one pancake to its adjacent mate at the inner hub. The tubes are soldered (with 63Sn/37Pb eutectic paste) into grooves machined into the conductors for that purpose. The tube extends beyond the outer turn by 15.2 cm. A non-corrosive rosin mildly activated solder flux is used in the soldering process. It is removed from the conductor after processing by a hot water bath.

3.1. INSULATION.

Proprietary Metal Oxide. The nuclear radiation environment in which the resistive insert coil must operate renders conventional organic electrical insulation inadequate. General Dynamics has invented and tested a proprietary nuclear radiation resistant electrical insulation with their own internal research and development funds. The insulation consists of multilayer .003 mil. Titanium alloy strip, coated with a proprietary oxide of metal. Five layers of this material are inserted between each conductor turn and between each pancake. Five ply provides 10 separate insulation surfaces for increased reliability.

Layer-to-Layer. The total built-up thickness of insulation is 0.10 cm., which is the same as the interstitial conductor space. Figure 3-3 shows the turn-to-turn insulation. It is a 0.0203 cm. thick by 1.537 cm. wide by 226 cm. long. It runs from the start of the conductor turn-to-turn slot in the hub to the outer end of the conductor.

Pancake-to-Pancake. Figure 3-4 shows the pancake-to-pancake insulation. As in the turn-to-turn insulation, five plys are used. Each ply is cut into two pieces to facilitate installation around the hub connection and permit the seams to be staggered so

that only one joint occurs at any given location. Between double pancake assemblies the same insulation is used, but it is not cut because there is no hub connection to contend with.

Figure 3-3. Double Pancake Assembly

Figure 3-4. Pancake-to-Pancake Metallic Insulation for a Double Pancake

3.2 MAGNET INTERFACES

The resistive coil has two interfaces; coolant and power. One of the design problems is the requirement to connect the pancake coils in series while the coolant path is in parallel with the pancake coils. The problem is solved by the use of ceramic insulator in line with the coolant flow.

3.2.1 CERAMIC SEALS/INSULATORS. The water coolant lines for the coil pancakes are equipped with in-line ceramic insulators. Both inlet and outlet of each conductor are also equipped. A total of 48 insulators is required. The insulators prevent coil-to-coil shorting via the copper coolant tubes. Their installation location is shown in Figure 3-5. Figure 3-6 shows their construction details.

The insulating material is a high alumina (95%) ceramic having an external glaze which contributes to cleanliness, appearance and surface electrical resistivity. The tubing material in contact with the ceramic is 316L stainless steel. The tubing dimensions are 1.588 cm. O.D. by 0.0711 cm. wall. The steel is brazed to the ceramic with a silver-copper 779 Centegrate eutectic. The resultant seal is good to 10^{-9} torr. liters per second.

3.2.2 PIPING ROUTES AND COOLANT HEADERS. The water coolant lines entering and leaving the coil are also shown in Figure 3-5. The lines are seamless 316L stainless steel of the same size as the insulator tubing. A total of 48 coolant lines service the resistive insert coil. A tubing reducer is used to connect to the CuproNickel coil tubing. The interface joint is brazed while any steel-to-steel joint is welded. Two manifolds are used; one for coolant in and the other for coolant out. As a result of the manifolding, only two external water supply lines are required for the insert magnet.

3.2.3 CURRENT LEADS. The water-cooled power buss is made from CDA C10100 Oxygen Free Electrolytic copper, temper H-00 per ASTM B-152. The buss lead connector is soldered and bolted to the pancake at the three 1.219 cm. bolt holes provided. Attachment from the connector to the main buss is by a soldered and bolted joint that uses twelve 0.635 cm. bolt holes. The buss connector detail is shown in Figure 3-7. The main buss will also be water cooled. The connector itself will be cooled by conduction to both the coil conductor and the buss cooling water.

Figure 3-5A. Resistive Coil Installation

Figure 3-5B. Resistive Coil Installation

Figure 3-6. Coolant Line Tube-to-Tube Insulator

Figure 3-7. Coil Current Lead Bus

3.3 MAGNET SUPPORT STRUCTURE

The 18 Tesla resistive insert coil installation and support structure is shown in Figure 3-5. Coil support tubes are attached to spider fittings at the ends of the tubes. The Spider incorporates a central ring frame with a 5.08 cm. by 5.08 cm. cross section attached to the tube. The spider's six radial arms bolt to the case of the superconducting background coil. There is one spider at each end of the coil but each has a different cross section. The one at the power buss and coolant fitting end is made very stiff (5.08 cm. by 5.08 cm.) to react all loads and keep the service fittings firmly held. At the other end, the spider is 0.2 cm. by 5.08 cm. This thinner spider allows the support to flex in the axial direction so that thermal expansion and magnetic compression are accommodated with the coil is activated.

3.4 MAGNET ASSEMBLY

The following parts are required for a double pancake assembly:

- Two machined pancakes
- One hub spacer
- Two CuproNickel tubes
- 40 NAS1200 M6 flush head monel rivets
- 63Sn/37Pb eutectic solder

The two pancakes are aligned at the ten bolt holes and at the hub with the hub spacer in place. The 40 hub rivet holes are match drilled, 0.478 cm. diameter, through both pancakes and the hub spacer. The pancakes are then disassembled, swept clean of chips, and all machined edges deburred. The pancakes are then reassembled with set-up bolts, and solder paste on the faying surfaces. After heating, to complete the soldering process, the setup bolts are removed and replaced by the monel rivets. The rivets are fixed double flush by a rivet squeezer. The traditional rivet gun and bucking bar is not used because the associated vibration might break the solder bond. After the rivets are in place the CuproNickel tubes are set in their grooves, pasted with solder and heated to bond in place.

SECTION 4

ANALYSIS

4.1 FIELDS

In this section, two different, additional magnet configurations are compared to the baseline. One is a maximum field configuration, the other is a minimum power configuration. The objectives of this analysis work were to:

- 1) Define a current density distribution that will generate the maximum possible field from a given coil geometry and,
- 2) Define a coil geometry and current density distribution that will minimize the coil power consumption given the coil's maximum allowable dimensions and minimum inside radius.

4.1.1 BASELINE CONFIGURATION. The parameters for the baseline configuration are given in Table 4-1. The target central field is 3.1 tesla. Baseline power consumption is 1.9 MW and the magnet material (Amzirc) is operating below both stress and temperature limits.

Table 4-1. SPIRAL Code Results for the Baseline
Coil Geometry Producing 3.1 Tesla

INPUT DATA:

TITLE: MAX FIELD

CONDUCTOR WIDTH, CM.	1.6
COOLANT TUBE OUTSIDE DIAMETER, INCHES	.288
COOLANT TUBE WALL THICKNESS, INCHES	.012
THE COOLANT TUBE MATERIAL IS:	COPPER
CONDUCTOR ALLOWABLE STRESS, PSI	18472
PANCAKE-TO-PANCAKE INSULATION THICKNESS, CM	.1
TURN-TO-TURN INSULATION THICKNESS, CM	.1
THE NUMBER OF PANCAKES IS	24
VALUE OF FIELD AT INNER RADIUS IS, IN TESLA	18.2
VALUE OF FIELD AT OUTER RADIUS IS, IN TESLA	15.2
THE NUMBER OF CONDUCTORS PER PANCAKE	2
COOLANT VELOCITY, FT/S	45
COOLANT DENSITY, LB/FT**3	60.1
COOLANT SPECIFIC HEAT, BTU/LB-F	1
PRANDTL NUMBER	1.45
WATER THERMAL CONDUCTIVITY, BTU/HR-FT-F	.386
CONDUCTOR THERMAL CONDUCTIVITY, BTU/HR-FT-F	200
TUBE THERMAL CONDUCTIVITY, BTU/HR-FT-F	17
SOLDER THERMAL CONDUCTIVITY, BTU/HR-FT-F	19
CONDUCTOR RESISTIVITY, INITIAL GUESS, MICRO OHM-CM	2.8E-06
COOLANT WATER INLET TEMPERATURE, F	105
NEUTRON WALL LOADING, W/M**2	0

OUTPUT DATA:

THE CONDUCTOR CURRENT IS, AMPS	14381
THE CENTRAL FIELD ON AXIS, TESLA	3.1
MAXIMUM CONDUCTOR TEMPERATURE,C	117.8
CONDUCTOR AVERAGE TEMPERATURE,C	97.7
CONDUCTOR AVERAGE RESISTIVITY, OHM-CM	2.83E-06
COOLANT OUTLET TEMPERATURE,C	80.6
TOTAL POWER CONSUMPTION, MEGAWATTS	1.91
TUBING INLET PRESSURE, PSI	437.5
COIL OVERALL WIDTH, CM	40.8
COIL INSIDE DIAMETER, CM	24.2
COIL OUTSIDE DIAMETER, CM	51.78
COIL VOLUME, M**3	.0671
COOLANT VOLUMETRIC FLOW, M**3/S	9.65E-04
TUBING STRESS, PSI	4803

<u>LAYER</u>	<u>R1(cm)</u>	<u>R2(cm)</u>	<u>J(A/cm**2)</u>
1	12.9	14.94	5425
2	15.04	17.32	4783
3	17.42	19.94	4264
4	20.04	22.80	3840
5	22.90	25.89	3500

4.1.2 MAXIMUM FIELD CONFIGURATION. For a given coil envelope, the maximum field is obtained by operating at the limits of stress and temperature. The maximum allowable operating temperature of the coil's Amzirc alloy is 160°C. The maximum allowable stress is 37 ksi. The General Dynamics proprietary code SPIRAL was used to iteratively vary current density and coolant flow (adjust temperature) to search for the maximum field.

SPIRAL results are given in Table 4-2. A maximum field of 4.4 tesla (4.6 tesla less 4% due to hub current sharing) was obtained. For convenience, uncorrected values of field are quoted in the remainder of this section.

Table 4-2. SPIRAL Results for the Baseline Coil
Geometry Producing the Maximum Field

INPUT DATA:

TITLE: MAX FIELD

CONDUCTOR WIDTH, CM.	1.6
COOLANT TUBE OUTSIDE DIAMETER, INCHES	.47
COOLANT TUBE WALL THICKNESS, INCHES	.012
THE COOLANT TUBE MATERIAL IS:	COPPER
CONDUCTOR ALLOWABLE STRESS, PSI	37000
PANCAKE-TO-PANCAKE INSULATION THICKNESS, CM	.1
TURN-TO-TURN INSULATION THICKNESS, CM	.1
THE NUMBER OF PANCAKES IS	24
VALUE OF FIELD AT INNER RADIUS IS, IN TESLA	18.2
VALUE OF FIELD AT OUTER RADIUS IS, IN TESLA	15.2
THE NUMBER OF CONDUCTORS PER PANCAKE	2
COOLANT VELOCITY, FT/S	45
COOLANT DENSITY, LB/FT**3	60.1
COOLANT SPECIFIC HEAT, BTU/LB-F	1
PRANDTL NUMBER	1.45
WATER THERMAL CONDUCTIVITY, BTU/HR-FT-F	.386
CONDUCTOR THERMAL CONDUCTIVITY, BTU/HR-FT-F	17
TUBE THERMAL CONDUCTIVITY, BTU/HR-FT-F	19
SOLDER THERMAL CONDUCTIVITY, BTU/HR-FT-F	3.11E-06
CONDUCTOR RESISTIVITY, INITIAL GUESS, MICRO OHM-CM	105
COOLANT WATER INLET TEMPERATURE, F	0
NEUTRON WALL LOADING, W/M**2	

OUTPUT DATA:

THE CONDUCTOR CURRENT IS, AMPS	21231
THE CENTRAL FIELD ON AXIS, TESLA	4.61
MAXIMUM CONDUCTOR TEMPERATURE, C	161.1
CONDUCTOR AVERAGE TEMPERATURE, C	138.4
CONDUCTOR AVERAGE RESISTIVITY, OHM-CM	3.11E-06
COOLANT OUTLET TEMPERATURE, C	86
TOTAL POWER CONSUMPTION, MEGAWATTS	6.14
TUBING INLET PRESSURE, PSI	257.9
COIL OVERALL WIDTH, CM	40.8
COIL INSIDE DIAMETER, CM	24.2
COIL OUTSIDE DIAMETER, CM	50.32
COIL VOLUME, M**3	.0624
COOLANT VOLUMETRIC FLOW, M**3/S	2.77E-03
TUBING STRESS, PSI	4793

<u>LAYER</u>	<u>R1(cm)</u>	<u>R2(cm)</u>	<u>J(A/cm**2)</u>
1	12.90	14.94	10866
2	15.04	17.25	9596
3	17.35	19.73	8593
4	19.83	22.37	7795
5	22.47	25.16	7159

4.1.3 MINIMUM POWER CONFIGURATION. Another coil configuration was considered in addition to the baseline. It is a constant current density coil, having dimensions selected to minimize the magnet's power consumption. It has been shown, (2) that for a constant current density coil, the power is minimized when $\alpha = 3$ and $\beta = 2$, where α is the ratio of coil outer to inner radius, and β is the ratio of the coil axial length to twice the inner radius. The results are shown in Table 4-3.

Table 4-3. SPIRAL Run For and Alpha = 2,
Beta = 3 Coil That Produces 3.1 Tesla

INPUT DATA:

TITLE: MAX FIELD

CONDUCTOR WIDTH, CM.	1.6
COOLANT TUBE OUTSIDE DIAMETER, INCHES	.288
COOLANT TUBE WALL THICKNESS, INCHES	.012
THE COOLANT TUBE MATERIAL IS:	COPPER
CONDUCTOR ALLOWABLE STRESS, PSI	37000
PANCAKE-TO-PANCAKE INSULATION THICKNESS, CM	.1
TURN-TO-TURN INSULATION THICKNESS, CM	.1
THE NUMBER OF PANCAKES IS	30
VALUE OF FIELD AT INNER RADIUS IS, IN TESLA	18.2
VALUE OF FIELD AT OUTER RADIUS IS, IN TESLA	15.2
THE NUMBER OF CONDUCTORS PER PANCAKE	2
COOLANT VELOCITY, FT/S	45
COOLANT DENSITY, LB/FT**E	60.1
COOLANT SPECIFIC HEAT, BTU/LB-F	1
PRANDTL NUMBER	1.45
WATER THERMAL CONDUCTIVITY, BTU/HR-FT-F	.386
CONDUCTOR THERMAL CONDUCTIVITY, BTU/HR-FT-F	200
TUBE THERMAL CONDUCTIVITY, BTU/HR-FT-F	17
SOLDER THERMAL CONDUCTIVITY, BTU/HR-FT-F	19
CONDUCTOR RESISTIVITY, INITIAL GUESS, MICRO OHM-CM	2.8E-06
COOLANT WATER INLET TEMPERATURE, F	105
NEUTRON WALL LOADING, W/M**2	0

OUTPUT DATA:

THE CONDUCTOR CURRENT IS, AMPS	14464
THE CENTRAL FIELD ON AXIS, TESLA	3.1
MAXIMUM CONDUCTOR TEMPERATURE,C	84.1
CONDUCTOR AVERAGE TEMPERATURE,C	72.3
CONDUCTOR AVERAGE RESISTIVITY, OHM-CM	2.66E-06
COOLANT OUTLET TEMPERATURE,C	64
TOTAL POWER CONSUMPTION, MEGAWATTS	1.43
TUBING INLET PRESSURE, PSI	539.1
COIL OVERALL WIDTH, CM	51
COIL INSIDE DIAMETER, CM	24.2
COIL OUTSIDE DIAMETER, CM	75.32
COIL VOLUME, M**3	.2038
COOLANT VOLUMETRIC FLOW, M**3/S	9.65E-04
TUBING STRESS, PSI	5918

<u>LAYER</u>	<u>R1(cm)</u>	<u>R2(cm)</u>	<u>J(A/cm**2)</u>
1	12.9	16.2	3334
2	16.3	20.3	2700
3	20.4	25.2	2219
4	25.3	30.97	1853
5	31.07	37.66	1575

The optimized constant current density coil shows about a 25% reduction in power consumption compared to the baseline at the same 3.1 tesla field. Its overall volume is larger than the baseline having an outer radius of 38.7 cm. and a width of 51.6 cm.

The power saving that results from the axial current density grading of the baseline was also considered. Because the radial variation of the current density is proportional to $1/r$, an optimum current density distribution given by Gaume (2), has been used. This distribution was used to axially grade the current density within the boundary of the baseline geometry. The power consumption of the baseline coil is reduced by 10% when the Gaume distribution is used.

4.1.4 REFERENCES.

1. "Hybrid, High Field Magnets," GENERAL DYNAMICS REPORT GSD-ERR-84-904, December 1984.
2. Montgomery, D. B. and R. J. Weggel, Solenoid Magnet Design Boston, R. E. Krieger Publishing Co., 1980.

4.2 LOADS

In this section, the axial and radial magnetic loads are presented. The loads considered include both normal and off normal conditions. They are needed in the stress analysis and detailed design phase of the coil definition. The magnet system surrounding the resistive insert coil is assumed to be the MFTF-B Upgrade coil set as shown in Figure 4-1. This magnet system generates the axial field profile shown in Figure 4-2. The location $z = 10m$ corresponds to the choke coil position where the peak axial field is 18 tesla. These figures were generated by use of the Lawrence Livermore National Laboratory "EIG" computer file "U06" which was specifically made for the MFTF-B Upgrade machine. Detailed choke coil insert parameters were incorporated into this file to accurately portray the load behavior of the resistive insert.

Five different scenarios were considered for load calculations. These were:

1. Nominal operation with all coils on at $\theta = 0$ degrees.
2. Nominal operation with all coils on at $\theta = 90$ degrees.
3. Cu resistive insert coil operating, all other coils off.
4. End-cell coils off with the choke and central cell coils on.
5. Central cell coils off with the choke and end-cell coils on.

These operational scenarios were simulated using the Lorenz force calculational capability of the LNL "EFFI" computer code, the U06 data file, and the baseline choke coil resistive insert current densities. Five nested solenoids were used to model the baseline current density distribution. Figure 4-3 shows the conductor current density and packing factor used in each of the five solenoids used to make the coil. The current density in the model is related to the spiral configuration by the formula:

$$\frac{J_{sol}}{J_{sp}} = \frac{2 \ln(R_o/R_i)}{N} \quad (1)$$

Where:

- Ro = Spiral outer radius
- Ri = Spiral inner radius
- = radial increment per turn
- N = number of turns per conductor
- Rj = average radial position of jth layer

Using Ro = 21.2 cm., Ri = 13.7 cm., N = 2, M = 5, and the average radius values from Figure 4-3, equation (1) yields a ratio of 80%. Therefore, the current density in the model should be 80% of the spiral current density to produce the same central field. The adjusted current density was then used in the calculation of loads.

The model's layers were divided into 5 axial segments and 72 circumferential segments. A typical segment is shown in Figure 4-4. The results of the magnetic load calculations for each of the scenarios are shown in Figure 4-5 through 4-8. The EFFI output includes the radial force Fr, and the axial force Fz. These can be used to calculate hoop stress, axial stress or as input to detail stress analysis codes. The numbers shown in the figures are the radial and axial pound forces for each 25 cross section segments. No significant difference was found between 0 degree and 90 degree planes. The loads tabulated in Figures 4-5 through 4-8 generate the axial and hoop stresses shown in Figures 4-9 and 4-10. Additional bending moments are discussed in section 4.5. The loading analysis conclusions are as follows:

- 1) The radial and axial loads are distributed uniformly in polar angle 0. This is due to the fact that the superconducting background choke field dominates any field variance caused by the end cell coils.
- 2) Radial loads are about five times greater than the axial loads.

- 3) Off-normal operation does not produce any load distributions that would not be accommodated by the design for normal operating loads.
- 4) Low radial loads at the ends of the coil might permit greater current densities at these locations which could be used to optimize the magnet field contribution per unit volume.

Figure 4-1. Schematic of the MFTF-B Upgrade Magnet Set Showing the Location of the Choke Coil

Figure 4-2. Axial Field Profile to be Generated by the Magnet Set of Figure 4-2.1 Has Its Greatest Magnitude of 18 Tesla at the Location of the Choke Coil

Figure 4-3. The Coil Set Used in the Force Model is Designed to Simulate the Equivalent SPIRAL Resistive Insert

l_i = thickness of ith layer

W = segment width

ϕ = angular increment

Figure 4-4. The Model is Divided into Segments That Are Used for Magnetic Load Calculations. For This Calculation $W = 8.16$ cm., and $\phi = 5$ deg.

CENTRAL CELL

END CELL

$f_r = -28$ $f_z = 220$	$f_r = -40$ $f_z = 79$	$f_r = -34$ $f_z = 0$	$f_r = -40$ $f_z = -79$	$f_r = -28$ $f_z = -220$
$f_r = 134$ $f_z = 226$	$f_r = 158$ $f_z = 76$	$f_r = 168$ $f_z = 0$	$f_r = 158$ $f_z = -76$	$f_r = 134$ $f_z = -226$
$f_r = 259$ $f_z = 212$	$f_r = 315$ $f_z = 69$	$f_r = 331$ $f_z = 0$	$f_r = 315$ $f_z = -69$	$f_r = 259$ $f_z = -212$
$f_r = 357$ $f_z = 186$	$f_r = 438$ $f_z = 61$	$f_r = 457$ $f_z = 0$	$f_r = 438$ $f_z = -61$	$f_r = 357$ $f_z = -186$
$f_r = 432$ $f_z = 153$	$f_r = 528$ $f_z = 52$	$f_r = 549 \text{ lbf}$ $f_z = 0 \text{ lbf}$	$f_r = 258$ $f_z = -52$	$f_r = 432$ $f_z = -153$

Figure 4-5. Copper Resistive Insert Coil on All Others Off Case,
Segment Axial and Radial Load Distribution in the
Insert Coil

CENTRAL CELL

$f_R = 3658$ $f_Z = 456$	$f_R = 3779$ $f_Z = 197$	$f_R = 3831$ $f_Z = \approx 0$	$f_R = 3788$ $f_Z = -186$	$f_R = 3676$ $f_Z = -445$
$f_R = 3440$ $f_Z = 419$	$f_R = 3586$ $f_Z = 173$	$f_R = 3637$ $f_Z = \approx 0$	$f_R = 3592$ $f_Z = -164$	$f_R = 3456$ $f_Z = -410$
$f_R = 3215$ $f_Z = 368$	$f_R = 3370$ $f_Z = 147$	$f_R = 3440$ $f_Z = \approx 0$	$f_R = 3379$ $f_Z = -140$	$f_R = 3219$ $f_Z = -361$
$f_R = 2981$ $f_Z = 313$	$f_R = 3164$ $f_Z = 125$	$f_R = 3234$ $f_Z = \approx 0$	$f_R = 3169$ $f_Z = -118$	$f_R = 2994$ $f_Z = -306$
$f_R = 2743$ $f_Z = 251$	$f_R = 2925$ $f_Z = 101$	$f_R = 2977$ $f_Z = \approx 0 \text{ lbf}$	$f_R = 2930$ $f_Z = -96$	$f_R = 2745$ $f_Z = -245$

END CELL

Figure 4-6. Central Cell Coils Off, All Others On Case

CENTRAL CELL		END CELL	
$f_r = 3706$	$f_r = 3820$	$f_r = 3863$	$f_r = 3813$
$f_z = 446$	$f_z = 187$	$f_z = \approx 0$	$f_z = -197$
$f_r = 3487$	$f_r = 3623$	$f_r = 3669$	$f_r = 3617$
$f_z = 411$	$f_z = 165$	$f_z = \approx 0$	$f_z = -147$
$f_r = 3245$	$f_r = 3405$	$f_r = 3452$	$f_r = 3399$
$f_z = 362$	$f_z = 141$	$f_z = \approx 0$	$f_z = -147$
$f_r = 3019$	$f_r = 3192$	$f_r = 3240$	$f_r = 3186$
$f_z = 307$	$f_z = 119$	$f_z = \approx 0$	$f_z = -124$
$f_r = 2773$	$f_r = 2967$	$f_r = 2999$	$f_r = 2947$
$f_z = 247$	$f_z = 97$	$f_z = \approx 0$ lbf	$f_z = -101$
			$f_r = 3692$
			$f_z = -455$
			$f_r = 3472$
			$f_z = -418$
			$f_z = -368$
			$f_r = 3234$
			$f_z = -368$
			$f_r = 3008$
			$f_z = -312$
			$f_r = 2764$
			$f_z = -251$

Figure 4-7. End Cell Coils Off, All Others On Case

CENTRAL CELL

$f_r = 3761$ $f_z = 451$	$f_r = 3878$ $f_z = 192$	$f_r = 3925$ $f_z = \approx 0$	$f_r = 3878$ $f_z = -190$	$f_r = 3763$ $f_z = -448$
$f_r = 3534$ $f_z = 415$	$f_r = 3876$ $f_z = 169$	$f_r = 3732$ $f_z = \approx 0$	$f_r = 3676$ $f_z = -167$	$f_r = 3539$ $f_z = -412$
$f_r = 3300$ $f_z = 365$	$f_r = 3460$ $f_z = 145$	$f_r = 3510$ $f_z = \approx 0$	$f_r = 3460$ $f_z = -143$	$f_r = 3302$ $f_z = -363$
$f_r = 3057$ $f_z = 310$	$f_r = 3237$ $f_z = 122$	$f_r = 3305$ $f_z = \approx 0$	$f_r = 3237$ $f_z = -120$	$f_r = 3059$ $f_z = -308$
$f_r = 2810$ $f_z = 249$	$f_r = 2990$ $f_z = 99$	$f_r = 3039 \text{ lbf}$ $f_z = \approx 0 \text{ lbf}$	$f_r = 2990$ $f_z = -98$	$f_r = 2812$ $f_z = -247$

END CELL

Figure 4-8. Design Basis Case, All Coils Under Normal Operating Conditions

Figure 4-9. Axial Stress Distribution Along the Z Axis in the 5th Layer at Normal Operating Conditions

Figure 4-10. Hoop Stress Variation With the Z Axis Under Normal Operating Conditions

4.3 POWER

Power consumption and field calculations have been summarized for each of four alternative configurations in Table 4-4. The alternatives are:

- 1) The LLNL baseline coil having a 3.1 tesla central field.
- 2) The LLNL baseline coil having a maximized central field.
- 3) An axially graded coil having the baseline dimensions and producing 3.1 tesla.
- 4) An $\alpha = 3$, $\beta = 2$ coil having a 3.1 tesla central field.

Table 4-4. The Summary of the Analysis Results Shows That There is a Wide Range of Field, Power and Volume Options Available to the Resistive Insert Magnet Designer

	BASELINE 3.1 T	BASELINE MAX FIELD	BASELINE GAUME	$\alpha=3, \beta=2$ 3.1 T
COIL WIDTH (CM)	40.8	40.8	40.8	51.6
COIL INNER RADIUS (CM)	12.9	12.9	12.9	12.9
COIL OUTER RADIUS (CM)	25.8	25.8	25.8	38.7
COIL VOLUME (M**3)	.064	.064	.064	.216
HOOP STRESS (KSI)	18.5	37	24	11.4
MAXIMUM CONDUCTOR TEMPERATURE (DEG C)	118	160	ND	84
CENTRAL FIELD (T)	3.1	4.6	3.1	3.1
POWER CONSUMPTION (MW)	1.9	6.14	1.76	1.43

4.4 THERMAL

This section has been intentionally left blank due to lack work in this area over the past year. Thermal analysis for the cooling of the resistive insert coil was done the previous year in 1984. See Report Number 18T-090-84, Section 4.3 Magnet Cooling, page 4-7 through 4-21.

4.5 STRESS ANALYSIS

This section presents the stress analysis which was performed to verify the structural integrity of the machined conductor pancakes used in the resistive insert coil. The coil loading used in the analysis is the internal electromagnetic field force. In particular, the analysis is concerned with the stresses imposed by the radial component of the electromagnetic load. The analysis relies on a NASTRAN finite-element computer model of the conductor pancake. The model is described in Section 4.5.4.

4.5.1 ELECTROMAGNETIC LOAD. The design load for the conductor pancake is the radial electromagnetic. This load is non-linear and acts along the entire conductor spiral. At any point along the spiral, the radial load is equal to:

$$\frac{F}{L} = \frac{I \times B}{175.1} = \frac{(14,671) B}{175.1} \quad \begin{array}{l} F/L = \text{Force/Length (lbs/in)} \\ B = \text{Field Strength (Tesla)} \\ I = \text{Current (amps)} \end{array}$$

where B is given by,

$$B = (-0.32397) R_i + 22.3145 \quad R_i = \text{Inner Radius (cm)}$$

and R_i is equal to:

For $\theta = 0^\circ$ to 360° (Note that the spiral starts at $\theta = 45^\circ$)

$$R_i = 12.89 + 1.605 (\theta/180) + .055 (\theta/180)^2$$

For $\theta = 360^\circ$ to 540°

$$R_i = 11.62 + 2.24 (\theta/180) + .055 (\theta/180)^2$$

For $\theta = 540^\circ$ to 720°

$$R_i = 9.715 + 2.875 (\theta/180) + .055 (\theta/180)^2$$

An IBM p.c. program was written to perform the above calculations for every five degrees of arc along the pancake spiral. Portions of the output are provided in Table 4-5. The loads shown are indicative of the overall load magnitudes involved.

Table 4-5. IBM P.C. Output--Coil Loads Were for Every
Five Degrees of Conductor Arc Segment

THETA (DEGREES)	R _L (CM)	FIELD (TESLA)	F/L (LBS/IN)
45	13.095	18.072	1514.21
50	13.140	18.056	1512.98
55	13.186	18.043	1511.74
60	13.231	18.028	1510.50
65	13.277	18.013	1509.27
70	13.322	17.999	1508.02
75	13.367	17.984	1506.78
80	13.414	17.969	1505.53
85	13.460	17.954	1504.29
90	13.506	17.939	1503.03
95	13.552	17.924	1501.78
100	13.599	17.989	1500.53
105	13.645	17.894	1499.27
180	14.350	17.666	1480.13
270	15.221	17.383	1456.48
360	16.320	17.027	1426.66
450	17.564	16.624	1392.90
540	18.835	16.213	1358.39
585	19.640	15.952	1336.55
630	20.451	15.689	1314.52
720	22.095	15.156	1269.90

4.5.2 DESIGN HISTORY. Finite-element analysis of the initial conductor pancake design indicated that the conductor would be locally overstressed by the electromagnetic load (i.e. stressed beyond 2/3's of the material's yield.) The excessive stresses were attributed to the bending moments imposed on the conductor by radial load imbalances. Therefore, at critical locations along the spiral, the conductor cross sectional depth was increased; thus increasing the section modulus and decreasing bending stresses. (e.g. at $\theta = 585^\circ$ along the spiral, the location of the maximum bending moment, the section modulus was increased approximately 9-1/2 times.)

4.5.3 MATERIAL PROPERTIES. The room temperature material properties used in the analysis of the conductor pancake are given in Table 4-6 below.

Table 4-6. Material Properties

MATERIAL	USE	E (KSI)	Y.S. (KSI)	ALLOWABLE ⁽²⁾ (KSI)
Amzirc Copper Alloy C15000	Conductor Pancake	18.7×10^3	60.0 ⁽¹⁾	40.0
Titanium 6AL-4V	Inter-Turn ⁽³⁾ Insulation	5.66×10^3	128.0	85.3

(1) 62% Cold Worked

(2) 2/3 (Y.S.)

(3) 5 Layers, 8 Mils Thick

The value given for the modulus of elasticity of the inter-turn insulation is an equivalent modulus based on test results. The testing which was performed is explained fully in Section 8 of GDC-ERR-84-904, "Hybrid, High Field Magnets." The equivalent modulus was arrived at by averaging the test data.

4.5.4 NASTRAN FINITE-ELEMENT DESCRIPTION. The principal analysis tool used, is a MSC/NASTRAN finite-element computer model of the conductor pancake. A computer graphic display of the model is shown in Figure 4-11. In the figure, the stressed shape is represented by the dashed lines.

The model consists of the conductor spirals and the inter-turn titanium insulation. It does not include the central conductor hub. Both spirals are fixed at their starting points (nodes 10 & 510). The end points (nodes 145 & 645) are fixed in 5 degrees of freedom and are free in radial translation.

Each spiral of the model is made up of 127 "CBEND" (curved beam elements) and 9 "CBEAM" elements. There is an element for every 5 degrees of arc along each spiral. Beam elements are used because they accurately model the bending behavior of the actual conductor spiral.

The inter-turn titanium insulation is modeled using "CROD" elements connected between adjacent conductor turns. These elements provide resistance only to axial displacements (relative to the elemental axis.) Note in figure 1 that "CROD" elements are not modeled around the outer 195 degrees of each spiral. Around this locale, the outer conductor turn displaces away from the insulation.

4.5.5 STRESS ANALYSIS RESULTS.

4.5.5.1 Combined Stress. Table 4-7 summarizes the results of the analysis.

Using the Von Mises failure criteria to combine stresses, the maximum combined stress occurs at the starting point of each conductor spiral, nodes 10 and 510.

$$\sigma_{VM} = \frac{1}{\sqrt{2}} [(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z + \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)]^{1/2}$$

$$\begin{aligned} \sigma_{VM \text{ nodes } 10 \text{ \& } 510} &= \frac{1}{\sqrt{2}} [2(38,900)^2 + 6(2580)^2]^{1/2} \\ &= 39,160 \text{ psi} \end{aligned}$$

At this location the tight radius at the end of the insulation slot results in an abrupt change in the conductor cross-section. Thus this is a region of stress concentration. The conductor will be stressed beyond its allowable if this factor is included in the above calculations.

Further analysis is required however to determine whether this region needs to be redesigned. In particular, the analysis needs to include the effects of the stress concentration around the bolt holes in the hub.

Figure 4-11. NASTRAN F.E.M. of a Conductor Pancake

Table 4-17. Stress Analysis Results, Finite Element Model

LOCATION ON THE SPIRAL Θ (DEG), NODE	σ_{MEMBRANE} (psi)	$\sigma_{\text{BENDING}_{\text{max}}}$ (psi)	$\tau_{\theta\text{max}}$ (psi)	DISPLACEMENTS	
				Δ RADIAL (IN)	Δ HOOP (DEG)
45 , NODE 10 & 510	38,900	NEGLIGIBLE	2,580	FIXED	FIXED
90 , NODE 19 & 519	38,060	--	950	--	.009
180 , NODE 37 & 537	35,500	--	524	--	.028
270 , NODE 55 & 555	27,345	--	356	NEGLIGIBLE	.047
360 , NODE 73 & 573	22,155	--	1,170	--	.065
450 , NODE 91 & 591	19,800	--	1,311	--	.083
540 , NODE 109 & 609	17,170	3,270	1,075	--	.101
585 , NODE 118 & 618	8,400	13,140	1,680	.014	.111
630 , NODE 127 & 627	9,760	6,360	730	.044	.093
720 , NODE 145 & 645	14,640	13,740	550	.075	FIXED

*AT THE INNER RADIUS OF THE SPIRAL

**NEGLECTING SHIFT IN THE NEUTRAL AXIS

4.5.6 SAMPLE CALCULATIONS.

STRESS CALCULATIONS:

(1.) at Node 118 (& 618)

$$M_{F.E.M.} = 6,720 \text{ in-lbs.}$$

MAX.

Solving for the shift (due to curvature) of the location of the neutral axis,

$$r_{inner} = 7.732 \text{ in.}$$

$$r_{outer} = 10.138 \text{ in.}$$

X-SECT AT NODE 118

$$\begin{aligned} *r_{N.A.} &= \frac{A}{\sum \left[b \log_e \left(\frac{r_o}{r_i} \right) \right]} & A &= \text{area (in}^2\text{)} \\ & & b &= \text{width (in)} \\ &= \frac{(1.057)(.63) + (.338)(.292) + (1.057)(.63)}{.63 \log_e \left(\frac{8.789}{7.732} \right) + .338 \log_e \left(\frac{9.081}{8.789} \right) + .63 \log_e \left(\frac{10.138}{9.081} \right)} \\ &= 8.885 \text{ in.} \end{aligned}$$

$$r_{C.G.} = 8.935 \text{ in.}$$

$$e = r_{C.G.} - r_{N.A.} = .05 \text{ in.}$$

$$c_o = r_o - r_{N.A.} = 1.253 \text{ in.}$$

$$c_i = r_{N.A.} - r_i = 1.153 \text{ in.}$$

*Ref. "Design of Weldments", Section 2.8-4, Blodgett

Bending stress at the inner face is,

$$\sigma_{b_i} = \frac{M c_i}{A e r_i}$$

Where the moment arm used in calculating M is measured from the neutral axis and not from the center of gravity of the cross section, therefore,

$$M = \left(\frac{r_{N.A.}}{r_{C.G.}} \right) M_{F.E.M.} = 6300 \text{ in-lbs.}$$

$$\sigma_{b_i} = \frac{6300 (1.153)}{1.43 (.05) 7.732} = 13,140 \text{ psi}$$

(The maximum bending stress is on the inner face.)

The membrane stress is,

$$\sigma_m = \frac{P}{A} = \frac{12,000}{1.43} = 8,400 \text{ psi}$$

Neglecting the shift in the neutral axis, the transverse shear is equal to:

$$\tau_{r\theta_{\max}} = \left(\frac{3}{2} \right) \frac{V}{A} = \left(\frac{3}{2} \right) \frac{1600}{1.43} = 1,680 \text{ psi}$$

4.6 PROTECTION

The coil protection is provided by turning the power supply off through the thyristor timing circuits (less than 1 cycle). Stored energy is dissipated in about 0.5 seconds via the internal coil resistance, and in a free-wheeling diode across the coil. The diode will limit the coil discharge voltage to approximately 0.7 volts. The insert coil power system is shown in Figure 4-12.

- POWER SUPPLY TURNED OFF IN msec THROUGH TIMING CIRCUIT
- DISCHARGE TIME $\leq 0.5 \text{ sec.}$
- 2.4 MVA INPUT

Figure 4-12. Insert Coil Power System

SECTION 5

MATERIALS

5.1 ELECTRICAL INSULATION (PROPRIETARY)

The nuclear radiation environment in which the 18T resistive insert coil operates renders conventional organic electrical insulations inadequate. The electrical insulation recommended for the coil is a metallic oxide foil which is nuclear radiation resistant. General Dynamics has invented, developed and tested such an insulation with their own internal research and development (IRAD) funds. The process is a proprietary anodize for titanium alloy foil. The foil is 0.20 mm thick and anodize is applied to all surfaces and edges. The coating is adherent, ductile and has good electrical insulation properties. Five layers of the foil insulation are installed between conductor turns and between each conductor pancake. This provides ten electrical insulation barriers for increased reliability and protection.

The anodized titanium foil has been compression fatigue tested combined with a sliding motion between foil strips and was found to have adequate electrical characteristics and mechanical properties. A test coil has been wound using the proprietary foil electrical insulation and a copper conductor. The coil will be tested to demonstrate the electrical characteristics of the insulation as well as suitability of the insulation to the winding process. The coil will be tested at room temperature, 77K and 423K (150°C). The normal operating temperature range for the resistive coil is room temperature to 423K.

5.2 SOLDERING

The hub region of a double pancake assembly, and the cupronickel coolant tubes to the double pancake are soldered with 63Sn-37Pb eutectic solder. Using a torch to heat the Amzirc pancake, a solder paste worked the best. The solder paste contains a flux, type RMA per QQ-S-571 which is non-corrosive and electrically non-conductive. The solder melts at 361°F, and there is virtually no risk of softening the 80% coldworked Amzirc pancake.

We also explored the possibility of brazing the cupronickel tube to the Amzirc pancake. A silver braze such as Easy Flo-45 has a brazing temperature range of 1144°F to 1292°F. Assuming a minimum of five minutes brazing time at temperature, 80% cold worked Amzirc cannot be brazed without considerable softening. However, it appears that copper-chromium alloys, such as Amax-M2C

stand a better chance of being brazed without softening. Amax-MZC 40% cold worked copper can withstand 1292°F for five minutes without softening. Figure 5-1 shows the room temperature softening of cold worked Amzirc and MZC copper after short time exposure to elevated temperature. This data was compiled from Amax Copper, Inc. supplied information. Data on the softening of 80% cold work Amax-MZC copper, after exposure to elevated temperature is not available. Additional investigation or testing is required to determine the suitability of brazing cupronickel to Amax-MZC or copper-chromium alloy.

5.3 AMZIRC PROCESS SPECIFICATIONS

These processing specifications are based on General Dynamics' experience of processing Amzirc cake into a 1.0 inch thick plate. Amzirc has not been processed into a 1.0 inch thick plate before. The processing parameters like hot forging temperature, solution annealing temperature and again temperature and time, were selected on the basis of recommendations by Amax Copper Inc., the producer of Amzirc material. The processing of the Amzirc cake was done at the rolling mills of Teledyne Wah-Chang, Albany, OR. The processing sequence is shown in Figure 5-2. The tensile properties and the electrical conductivity of the processed Amzirc plate material were measured and the results are shown in Table 5-1. This information was included in last year's report and has been repeated here for the sake of continuity. An examination of Table 5-1 reveals that there is a slight anisotropy (less than 4% at room temperature, and less than 8% at 200°C) in the yield strength in longitudinal and long transverse direction of the Amzirc plate material. Also, metallurgical examination of the Amzirc plate microstructure revealed there was room for reducing grain size. Thus for future processing of Amzirc plate, we recommend that the hot forging temperature and the solution annealing temperatures be restricted to 850°C and 900°C respectively. Also, the time for the hot forging operation should be limited to a practical minimum. For reducing anisotropy material properties in the longitudinal and the long transverse directions, we recommend cross rolling. The recommended processing details are shown in Figure 5-3.

Figure 5-1. Cold Worked MZC Has Better Annealing Characteristics than Amzirc

Figure 5-2. Processing Details for Rolling Amzirc Copper Plate

Table 5-1. Results of Tensile Test on Amzirc Standard Tensile Specimens

SAMPLE ORIENTATION	TEST TEMPERATURE (°C)	TEMPER	TENSILE STRENGTH (KSI)	YIELD STRENGTH (KSI)	% ELONGATION (2")	REDUCTION IN AREA %	HARDNESS ROCKWELL 'B'	ELECTRICAL CONDUCTIVITY % IACS
Longitudinal (3 specimens)	R.T.	Solution annealed at 925°C for 1 hr., water quenched, cold-rolled, 80% C.W., aged at 400°C for 1 hr.	65.7	55.6	20.0	57.8		
			66.5	59.6	16.5	57.2	76.7	79.3
			65.4	58.1	21.0	55.4		
			65.9 Avg	57.8 Avg	19.2 Avg	56.8 Avg		
Long-Transverse (3 specimens)	R.T.	"	60.8	54.5	18.0	59.9		
			62.4	55.0	20.0	58.5	76.0	79.3
			62.2	56.4	21.5	59.4		
			61.8 Avg	55.3 Avg	20.3 Avg	59.3 Avg		
Longitudinal (3 specimens)	200	"	60.1	54.4	14.0	40.6		
			59.7	53.4	16.0	48.3		
			60.9	55.3	16.5	50.3		
			60.2 Avg	54.4 Avg	15.8 Avg	46.4 Avg		
Long-Transverse (3 specimens)	200	"	55.2	52.1	15.0	48.6		
			55.1	49.2	14.5	49.8		
			56.0	50.9	10.4	29.4		
			55.4 Avg	50.7 Avg	13.3 Avg	42.5 Avg		
Longitudinal (2 specimens)	R.T.	Above plus 1 hr. aging at 425°C	62.4	56.4	17.5	52.7		
			61.4	56.8	17.5	60.5	77.3	87.6
			61.9 Avg	56.6 Avg	17.5 Avg	56.6 Avg

Figure 5-3. Recommended Process Details for Rolling Amzirc Plate

SECTION 6

TESTING FOR THE
18T RESISTIVE INSERT COIL

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SECTION 6.1

TEST REPORT FOR
COIL PACK MODULUS TEST

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Materials & Process

Approved by: J. F. Parmer
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TESTING

6.1 COIL PACK MODULUS

6.1.1 BRIEF DESCRIPTION OF THE TEST. A compressive modulus test was conducted on a simulated 18T resistive coil conductor pack. Detailed dimensions and assembly of the conductor test pack are shown in Figure 6-1 and Figure 6-2. The insulation material was anodized strips of Ti-15V-3Al-3Cr-3Sn Titanium alloy in the as rolled condition in 0.004 inch and 0.008 inch thicknesses. The thickness of the oxide coating was approximately 0.007 inch on either side. A pack of five strips of either thickness was used in the test. Thus total anodize material thickness is approximately 0.007 inch for either insulation package. The conductor material was C15000 Amzirc (a copper alloy with 0.15-0.20% zirconium and balance oxygen free copper in 80% cold-worked and aged condition (room temperature yield strength approximately 57 KSI). A channel for coolant tubes was cut into Amzirc conductor, and 0.3125" O.D. x 0.016" wall thickness, hard drawn brass tube was soldered into the coolant channel. A brass tube was substituted in the modulus test for cupronickel tube selected for the 18T coil design. Clip gauges were glued on both sides of the conductor pack assembly.

Conductor pack modulus test was conducted on two test machines. The first test was conducted on an Instron test machine which had a maximum load capacity of 10,000 lbs. (4,000 psi stress on the conductor pack). The load range was subsequently increased to 25,000 lbs. in a second test carried out on an MTS test machine. Traces of deflection versus load curves were obtained for each configuration of the test pack. Table 6-1 summarizes all test configurations used for obtaining various traces.

6.1.2 EXPERIMENTAL RESULTS. An examination of various load versus deflection curves led us to following general observations:

1. For the same applied load, the deflection recorded on the tube side of the conductor pack was larger than on the back side of the conductor pack.
2. The deflection recorded on the increasing load cycle was always larger than on the decreasing load cycle.
3. The average deflection recorded by electronically averaging the signal from the two sides, was very nearly equal to the average of the separately read deflections from the two sides.

4. The slope of the load-deflection curve was nearly constant above 5,000 lbs. load. And, the slope was less (i.e. higher modulus) on the decreasing load cycle than on the increasing load cycle.

In the light of these observations and for the sake of reducing repetition of nearly similar data, not all the traces of the load versus deflection curves are included in this report. Only one trace of the load versus deflection curve, recorded with 25,000 lbs. maximum load, and electronically averaged clip gauge deflection readings, is enclosed for each of the two conductor pack insulation thicknesses. Figures 6-3 and 6-4 are the load versus deflection curves for the 0.008 inch and 0.004 inch thick insulation strips. The average value of the conductor pack modulus is 7.01 MSI and the results of the test are summarized in Table 6-2.

Table 6-1. Experimental Configuration Used
For Load-Deflection Curves

CONDUCTOR	MAXIMUM LOAD	LOCATION OF THE CLIP GAUGE USED FOR DEFLECTION
0.004 inch-- 5 strips pack	10,000	1. Tube side of the pack 2. Back side of the pack 3. Both clip gauges--avg.
	25,000	1. Tube side of the pack 2. Back side of the pack 3. Both clip gauges--avg.
0.008 inch-- 5 strips pack	10,000	1. Tube side of the pack 2. Back side of the pack 3. Both clip gauges--avg.
	25,000	1. Tube side of the pack 2. Back side of the pack 3. Both clip gauges--avg.

Table 6-2. Results of Modulus Test
on 18T Conductor Pack

1. Maximum applied load 25,000 lbs.
2. Cross-sectional area of the conductor 2.5 inch²
3. Maximum applied stress 10,000 psi
4. Gauge length (i) with 0.008 inch insulation 1.471"
(ii) with 0.004 inch insulator 1.450"

CONDUCTOR AND TEST NO.	SLOPE OF LOAD VS. DEFLECTION CURVE IN THE LINEAR REGION (MSI)		AVERAGE SLOPE (MODULUS) MSI
	LOAD INCREASING	LOAD DECREASING	
1. 0.008 inch insulation			
Test No. 1	6.054	7.125	6.86
Test No. 2	6.972	7.246	
2. 0.004 inch insulation			
Test No. 1	6.490	7.388	7.16
Test No. 2	7.188	7.600

-4
TEST ASSEMBLY

NOTES:

1. ALL DIMENSIONS IN MILLIMETERS EXCEPT AS NOTED
2. TOLERANCES: $\pm .5$
3. MAT'L FOR -2 AND -3, AMZIRC COPPER, 50 KSI MIN. YIELD
4. HAND FILING PERMITTED TO FIT TUBING
5. SOLDER -3 TUBE TO -2 AND -3 CONDUCTOR WITH 63 Sn/37 Pb EUTECTIC SOLDER. SOLDER FLUX SHALL BE NON-CORROSIVE PER QQ-S-571, TYPE 3, R. OR RMA. HEAT COPPER TO 370° - 400°F DURING SOLDERING OPERATION
6. ULTRASONIC INSPECT - 30% VOID ACCEPT.
7. TUBE WALL MAY BE REAMED DOWN TO .016 FROM AVAILABLE COPPER TUBE

DRAWN BY <i>REVK</i>		CHECKED <i>CHAD B C</i>		ISMAR REV B	
DESIGN ENGR <i>Revk</i>		H.M.A.B.C		PRELIMINARY DESIGN DRAWING	
GROUP ENGR				CONDUCTOR / INSULATION	
STRESS				MODULUS TEST FIXTURE	
WEIGHTS					
MATERIAL					
OPERATIONS					
PROJECT					
GENERAL DYNAMICS Convair Division SAN DIEGO, CALIFORNIA				CODE IDENT. 14170	DRAWING NO. HY-18-027
SCALE FULL				SHEET 1	OF 2

Figure 6-1. Conductor Pack Test Assembly

MAT'L: TITANIUM Ti-15V-3Al-3Cr-3Sn ANODIZED
0.004" AND 0.008" THICK

MAT'L: 0.3125" DIA X 0.016" WALL
BRASS TUBE

DRAWN BY	PGVK	12 FEB 88
DESIGN ENGR	<i>PGVK</i>	15 MAR 88
GROUP ENGR		
STRESS		
WEIGHTS		
MATERIAL		
OPERATIONS		
PROJECT		

GENERAL DYNAMICS
Convair Division
SAN DIEGO, CALIFORNIA

ISMAR . REV B

PRELIMINARY DESIGN DRAWING

CONDUCTOR / INSULATION
MODULUS TEST FIXTURE

- DETAILS -

CODE IDENT.

14170

DRAWING NO.

HY-18-027

SCALE NONE

SHEET 2 OF 2

Figure 6-2. Details of Conductor Test Pack

Figure 6-3. Load Versus Deflection Trace for Five 0.008 Inch Thick Insulation Strips

Figure 6-4. Load Versus Deflection Trace for Four 0.004 Inch Thick Insulation Strips

SECTION 6.2

TEST REPORT FOR
CONDUCTOR STRESS TEST

Prepared by: _____
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Approved by: _____
J. F. Parmer
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Prepared by: _____
P. H. Michels
Electrical Engineer

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6.2.1 SUMMARY. A test specimen of the 18 Tesla resistive insert pancake coil was fabricated and used for structural testing. The purpose of the testing was to verify the accuracy of the stresses predicted by the NASTRAN finite-element model of the coil.

In particular, the testing was concerned with the bending stresses imposed on the spiral configured coil by the radial component of the Lorentz force. For the test a radial force was mechanically applied to the test specimen. Displacements and strains were measured and then compared to those predicted by the finite-element model of the test specimen.

The comparison showed very good agreement between the actual stresses measured and those predicted by the linear, elastic computer model.

6.2.2 TEST PLAN. The test specimen has the same overall geometry as the outer 360 degree portion of the 18 Tesla pancake coil, as shown in Figure 6-5. Test costs were minimized by fabricating the specimen from 6061-T6 aluminum alloy plate instead of Amzirc copper. For the same reason the cooling channel (existing in the actual coil) was not machined into the test specimen.

The test set-up is shown in Figure 6-6. As shown, the inner end of the specimen is fixed while the outer end is guided radially. For the test radial loads of 100 lbs. and 200 lbs. were applied to the guided end. The deflected shape of the coil due to each of these loads was traced on a sheet of vellum located behind the test specimen.

Strain gages were mounted on the specimen at $\theta = 450^\circ$ and at $\theta = 630^\circ$. The gages were located so as to provide data on the bending stresses imposed on the spiral by the radial load.

CONDUCTOR COORDINATES		
ANGLE DEGREES	INNER RADIUS	OUTER RADIUS
360	6.425	7.375
375	6.506	7.482
390	6.587	7.587
405	6.669	7.693
420	6.750	7.799
435	6.832	7.906
450	6.915	8.013
465	6.998	8.120
480	7.080	8.227
495	7.164	8.335
510	7.247	8.443
525	7.331	8.551
540	7.415	8.660
555	7.501	8.768
570	7.526	
585	7.732	
600	7.838	
615	7.945	
630	8.052	
645	8.159	
660	8.266	
675	8.374	
690	8.482	
705	8.590	
720	8.699	

Figure 6-5. Conductor Test Specimen Geometry

Figure 6-6. Set Up for Conductor Deflection and Stress Test

Figure 6-7. Comparison of Actual and F.E.M. Displacements

6.2.3 FINITE-ELEMENT MODEL. The finite-element model of the test specimen is made up from the original 18 Tesla pancake coil F.E.M. (in particular the outer 360° of the model). The specimen is modeled using 65 "CBEND" (curved beam elements) and 7 "CBEAM" (straight beam elements). There is an element for every 5 degrees of arc along the spiral.

The end conditions modeled reflects the actual test configuration. One end of the model (at $\theta = 360^\circ$) is fixed in all six degrees of freedom. The other end (at $\theta = 720^\circ$) is fixed in five degrees of freedom and free in radial translation. Just as in the actual testing, the F.E.M. load cases considered include a 100 and 200 lb. concentrated radial load applied at the guided end.

6.2.4 STRAIN MEASUREMENTS. The strains were recorded using the HP 305YA data acquisition system and HP 1000 computer. Each strain gage is a WK-13-250AF-350. The resistance is $350.0 \pm 0.3\%$ with a gage factor of $2.19 \pm 1.0\%$ at 75°F.

The strain gages were arranged for a 1/4 bridge strain gage measurement.

The data acquisition system recorded bridge imbalance voltages before and after the 100 and 200 lb. loads were applied. These values were then used to calculate the microstrain. The equations used were:

TSTIMB: Imbalance ratio after strain applied

INTINB: Imbalance ratio before strain applied

GAGEF: Gage factor (2.19%)

STRN: Microstrain

DIFF = TSTIMB - INTINB

STRN = $[(-4.0 * \text{DIFF}) / (\text{GAGEF} * (1.0 + 2.0 * \text{DIFF}))] * 10^6$

The results are shown in Table 6-2 through Table 6-5.

Table 6-3. Strain Gage Measurements (At Datum)

```

STRAIN0 = 2.272603 UINCH/INCH
STRAIN1 = .825008 UINCH/INCH
STRAIN2 = 1.303003 UINCH/INCH
STRAIN3 = -.086753 UINCH/INCH
STRAIN4 = 1.052948 UINCH/INCH
STRAIN5 = 1.850741 UINCH/INCH
TEMP = 20.1 DEGREE C
TIME = 10.0.6
THE DATA IS FILED IN JPSTRN.
.LI,JPSTRN
JPSTRN T=00003 IS ON CR00001 USING 00140 BLKS R=0000

0001 10 0 3 18.2
0002 4.21516 -.02164 -.02042 -.02151 -.02545 -.02244 -.02281
0003 10 0 6 20.1
0004 4.21511 -.02165 -.02042 -.02151 -.02545 -.02245 -.02282
0005 10 0 7 19.4
0006 2.2726030 .8250079 1.3030031
0007 -.0867533 1.0529485 1.8507414

```

Table 6-4. Strain Gage Measurements (Strain In Going From Datum to a 75 lb. Load)

STRAIN0 = 282.629460 UINCH/INCH
 STRAIN1 = 9.493635 UINCH/INCH
 STRAIN2 = -332.348390 UINCH/INCH
 STRAIN3 = 208.435880 UINCH/INCH
 STRAIN4 = -7.278718 UINCH/INCH
 STRAIN5 = -175.663790 UINCH/INCH
 TEMP = 19.6 DEGREE C
 TIME = 10:20:34

THE DATA IS FILED IN JPSTRN.

!L1,JPSTRN

JPCTRN T=00003 IS ON CR00001 USING 00140 BLKS R=0000

0001	10 17 2 20.2							
0002	4.21414	-.02167	-.02046	-.02155	-.02549	-.02248	-.02286	
0003	10 20 34 19.6							
0004	4.21361	-.02232	-.02048	-.02078	-.02596	-.02246	-.02245	
0005	10 20 34 19.9							
0006	282.6294600		9.4936352		-332.3483900			
0007	208.4358800		-7.2787100		-175.6637900			

THIS IS WITH 75 POUNDS MASS.

Table 6-5. Strain Gage Measurements (Strain In Going From a 75 lb. Load to a 100 lb. Load)

STRAIN0 = 98.043488 UINCH/INCH
 STRAIN1 = 5.149095 UINCH/INCH
 STRAIN2 = -105.136340 UINCH/INCH
 STRAIN3 = 67.379990 UINCH/INCH
 STRAIN4 = -1.575166 UINCH/INCH
 STRAIN5 = -55.763680 UINCH/INCH

TEMP = 20.2 DEGREE C

TIME = 10,23, 6

THE DATA IS FILED IN JPSTRN.

LI,JPSTRN

JPSTRN T=00003 IS ON CR00001 USING 00140 BLKS R=0000

0001	10 21 44	20.5						
0002	4.21346	-.02233	-.02049	-.02079	-.02597	-.02247	-.02245	
0003	10 23 6	20.2						
0004	4.21277	-.02255	-.02050	-.02054	-.02612	-.02246	-.02232	
0005	10 23 6	19.9						
0006	98.0434880		5.1490946		-105.1363400			
0007	67.3799900		-1.5751657		-55.7636800			

THIS IS FROM 75 LBS TO 100 LBS.

Table 6-6. Strain Gage Measurements (Strain In Going From a 100 lb. Load to a 200 lb. Load)

STRAIN0 = 378.462590 UINCH/INCH
 STRAIN1 = 31.771538 UINCH/INCH
 STRAIN2 = -439.372740 UINCH/INCH
 STRAIN3 = 285.713680 UINCH/INCH
 STRAIN4 = -10.328634 UINCH/INCH
 STRAIN5 = -228.653470 UINCH/INCH
 TEMP = 73.6 DEGREE C
 TIME = 8: 9.11

THE DATA IS FILED IN JPSTRN.

LI,JPSTRN

JPSTRN T=00003 IS ON CR00001 USING 00140 BLKS R=0000

0001	8 7 54 17.8						
0002	4.24034	-.02264	-.02055	-.02058	-.02623	-.02252	-.02238
0003	8 9 11 73.6						
0004	4.23917	-.02351	-.02062	-.01956	-.02689	-.02249	-.02185
0005	8 9 12 17.5						
0006	378.4625900		31.7715380		-439.3727400		
0007	285.7136800		-10.3286340		-228.6534700		

6.2.5 COMPARISON OF TEST RESULTS & F.E.M. OUTPUT. The results of the testing and the F.E.M. analysis are provided below. Figure 6-7 shows the actual deformed shape of the coil due to the 100 lb. and the 200 lb. applied load. The displacements predicted by the F.E.M. analysis for the 100 lb. applied load are also plotted for comparison purposes. As can be seen, there is very good agreement between the F.E.M. predictions and the actual test results.

A comparison of the bending stresses also show similar agreement. The data from the strain gages are provided in Table 6-3 through Table 6-6 as is the F.E.M. output in Table 6-8. Strain gage locations are shown in Figure 6-7. The results are summarized in Table 6-7 below.

Table 6-7. Comparison of Actual and F.E.M. Stresses

	STRAIN GAGE LOCATION ⁽¹⁾	ϵ (μ IN/IN)	σ (PSI) ⁽²⁾ (TEST)	σ (PSI) (FEM)	PERCENT VARIANCE FROM ⁽³⁾ TEST RESULTS
100 LB. LOAD	0	382.9	3791	3460	8.7
	1	15.5 ⁽⁴⁾	--	--	--
	2	-436.2	-4318	-3788	12.3
	3	275.1	2730	2830	3.7
	4	-7.8 ⁽⁴⁾	--	--	--
	5	-229.6	-2273	-2435	7.1
200 LB. LOAD	0	761.4	7538		
	1	47.2 ⁽⁴⁾	--		
	2	-875.6	-8668		
	3	561.4	5558		
	4	-18.1 ⁽⁴⁾	--		
	5	-458.2	-4536		

Notes: (1) Locations shown in Figure 6-6.

(2) Stresses calculated using $E = 9.9 \times 10^6$ PSI

(3)
$$\left| \frac{\sigma_{F.E.M.} - \sigma_{TEST}}{\sigma_{TEST}} \right| \times 100$$

(4) Negligible values 6-23

For the 200 lb. load case, strain gage measurements are presented to illustrate the linear behavior of the test specimen and confirm that the strain gages are giving correct results.

F.E.M. Analysis -- Sample Stress Calculation:

Stress at $\theta = 450^\circ$ (Grid Pt. 591), 100 lb. load

$$\begin{aligned} R_{\text{inner}} &= 6.915 \text{ in.} & A &= (.63)(1.097) = .691 \text{ in}^2 \\ R_{\text{outer}} &= 8.012 \text{ in.} \\ R_{\text{C.G.}} &= 7.464 \text{ in.} & I &= \frac{bh^3}{12} = \frac{(.63)(1.097)^3}{12} = .07 \text{ in}^4 \end{aligned}$$

Solving for the shift in the location of the neutral axis due to curvature*,

$$R_{\text{N.A.}} = \frac{\Sigma A}{\Sigma \left[\log_e \left(\frac{R_o}{R_i} \right) \right]} = \frac{.691}{.63 \log_e \left(\frac{8.012}{6.915} \right)} = 7.449 \text{ in}$$

$$\text{Define: } e = R_{\text{C.G.}} - R_{\text{N.A.}} = .015 \text{ in.}$$

$$C_o = R_{\text{outer}} - R_{\text{N.A.}} = 0.563 \text{ in.}$$

$$C_i = R_{\text{N.A.}} - R_{\text{inner}} = 0.534 \text{ in.}$$

*Reference: "Design of Weldments", Section 2.8-4, Blodgett
The James F. Lincoln Arc Welding Foundation

The bending stress at the inner face is:

$$\sigma_{b_i} = \frac{Mc_i}{AeR_{\text{inner}}}$$

Where the moment arm used in calculating M is measured from the neutral axis and not from the center of gravity of the cross section. Therefore,

$$M = \left(\frac{R_{\text{N.A.}}}{R_{\text{C.G.}}} \right) M_{\text{F.E.M.}} = \left(\frac{7.449}{7.464} \right) (-490) =$$

$$M = -489 \text{ IN-LBS}$$

$$\sigma_{b_i} = \frac{(-489)(0.534)}{(.691)(.015)(6.915)} = -3643 \text{ PSI}$$

The membrane stress is equal to:

$$\sigma_m = \frac{P_{F.E.M.}}{A} = \frac{-100 \text{ LB}}{.69 \text{ in}^2} = -145 \text{ PSI}$$

$$\sigma_{F.E.M.} = \sigma_{b_i} + \sigma_m = -3643 - 145 = -3788 \text{ PSI}$$

ECHO
AL SPIRAL COIL TEST CONFIGURATION
CREND ELEMENTS

SEPTEMBER 5, 1985 MSC/HASTMAN 11/23/83 PAGE 2

CASE CONTROL CHECK ECHO

CARD	COUNT	TEXT
1		ECHO=SOFT
2		TITLE= AL SPIRAL COIL TEST CONFIGURATION
3		SORTITLE=CREND ELEMENTS
4		DISP=ALL
5		FORCE=ALL
6		STRESS=ALL
7		SPOF=ALL
8		SUBCASE=1
9		LOTO=10
10		SUBCASE=2
11		LOAD=20
12		OUTPUT(PLOT)
13		PLOTTER HAST
14		PAPER SIZE 26 X 20
15		CSCALE=100
16		SET 1 = ALL
17		AREAS 42,Y,X
18		VIEW 1,1,1,0,0,0
19		FIND SCALE,ORIGIN 1,SET 1
20		PLOT STATIC DEFORMATION 0 THRU 1,SET 1,ORIGIN 1,LABEL BOTH
21		END

SORTED BULK DATA ECHO

CARD COUNT	1	2	3	4	5	6	7	8	9	10
1-	CBEND 573	573	573	574	574	1.0	1.0	0.0		
2-	CBEND 608	608	608	609	609	1.0	1.0	0.0		
3-	CBEND 609	609	609	610	610	1.0	1.0	0.0		
4-	CBEND 610	610	610	611	611	1.0	1.0	0.0		
5-	CBEND 613	613	613	614	614	1.0	1.0	0.0		
6-	CBEND 614	614	614	615	615	1.0	1.0	0.0		
7-	CBEND 615	615	615	616	616	1.0	1.0	0.0		
8-	CBEND 574	574	574	575	575					
9-	CBEND 575	575	575	576	576					
10-	CBEND 576	576	576	577	577					
11-	CBEND 577	577	577	578	578					
12-	CBEND 578	578	578	579	579					
13-	CBEND 579	579	579	580	580					
14-	CBEND 580	580	580	581	581					
15-	CBEND 581	581	581	582	582					
16-	CBEND 582	582	582	583	583					
17-	CBEND 583	583	583	584	584					
18-	CBEND 584	584	584	585	585					
19-	CBEND 585	585	585	586	586					
20-	CBEND 586	586	586	587	587					
21-	CBEND 587	587	587	588	588					
22-	CBEND 588	588	588	589	589					
23-	CBEND 589	589	589	590	590					
24-	CBEND 590	590	590	591	591					
25-	CBEND 591	591	591	592	592					
26-	CBEND 592	592	592	593	593					
27-	CBEND 593	593	593	594	594					
28-	CBEND 594	594	594	595	595					
29-	CBEND 595	595	595	596	596					
30-	CBEND 596	596	596	597	597					
31-	CBEND 597	597	597	598	598					
32-	CBEND 598	598	598	599	599					
33-	CBEND 599	599	599	600	600					
34-	CBEND 600	600	600	601	601					
35-	CBEND 601	601	601	602	602					
36-	CBEND 602	602	602	603	603					
37-	CBEND 603	603	603	604	604					
38-	CBEND 604	604	604	605	605					
39-	CBEND 605	605	605	606	606					
40-	CBEND 606	606	606	607	607					
41-	CBEND 607	607	607	608	608					
42-	CBEND 611	611	611	612	612					
43-	CBEND 612	612	612	613	613					
44-	CBEND 616	616	616	617	617					
45-	CBEND 617	617	617	618	618					
46-	CBEND 618	618	618	619	619					
47-	CBEND 619	619	619	620	620					
48-	CBEND 620	620	620	621	621					
49-	CBEND 621	621	621	622	622					
50-	CBEND 622	622	622	623	623					

SORTED BULK DATA ECHO

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SORTED BULK DATA ECHO

CARD COUNT		1	2	3	4	5	6	7	8	9	10
101-	GRID	595	2	7.590	470.0	0.0	2	3			
102-	GRID	596	2	7.622	475.	0.0	2	3			
103-	GRID	597	2	7.654	480.	0.0	2	3			
104-	GRID	598	2	7.685	485.0	0.0	2	3			
105-	GRID	599	2	7.717	490.	0.0	2	3			
106-	GRID	600	2	7.749	495.	0.0	2	3			
107-	GRID	601	2	7.781	500.	0.0	2	3			
108-	GRID	602	2	7.813	505.	0.0	2	3			
109-	GRID	603	2	7.845	510.	0.0	2	3			
110-	GRID	604	2	7.877	515.	0.0	2	3			
111-	GRID	605	2	7.909	520.	0.0	2	3			
112-	GRID	606	2	7.941	525.	0.0	2	3			
113-	GRID	607	2	7.973	530.	0.0	2	3			
114-	GRID	608	2	8.005	535.	0.0	2	3			
115-	GRID	609	2	8.037	540.	0.0	2	3			
116-	GRID	610	2	8.069	545.0	0.0	2	3			
117-	GRID	611	2	8.101	550.	0.0	2	3			
118-	GRID	612	2	8.133	555.	0.0	2	3			
119-	GRID	613	2	8.165	560.0	0.0	2	3			
120-	GRID	614	2	8.197	565.0	0.0	2	3			
121-	GRID	615	2	8.229	570.	0.0	2	3			
122-	GRID	616	2	8.261	575.	0.0	2	3			
123-	GRID	617	2	8.293	580.	0.0	2	3			
124-	GRID	618	2	8.325	585.0	0.0	2	3			
125-	GRID	619	2	8.357	590.	0.0	2	3			
126-	GRID	620	2	8.389	595.	0.0	2	3			
127-	GRID	621	2	8.421	600.	0.0	2	3			
128-	GRID	622	2	8.453	605.	0.0	2	3			
129-	GRID	623	2	8.485	610.	0.0	2	3			
130-	GRID	624	2	8.517	615.	0.0	2	3			
131-	GRID	625	2	8.549	620.	0.0	2	3			
132-	GRID	626	2	8.581	625.	0.0	2	3			
133-	GRID	627	2	8.613	630.0	0.0	2	3			
134-	GRID	628	2	8.645	635.0	0.0	2	3			
135-	GRID	629	2	8.677	640.	0.0	2	3			
136-	GRID	630	2	8.709	645.	0.0	2	3			
137-	GRID	631	2	8.741	650.	0.0	2	3			
138-	GRID	632	2	8.773	655.0	0.0	2	3			
139-	GRID	633	2	8.805	660.	0.0	2	3			
140-	GRID	634	2	8.837	665.	0.0	2	3			
141-	GRID	635	2	8.869	670.	0.0	2	3			
142-	GRID	636	2	8.901	675.	0.0	2	3			
143-	GRID	637	2	8.933	680.0	0.0	2	3			
144-	GRID	638	2	8.965	685.	0.0	2	3			
145-	GRID	639	2	8.997	690.	0.0	2	3			
146-	GRID	640	2	9.029	695.	0.0	2	3			
147-	GRID	641	2	9.061	700.	0.0	2	3			
148-	GRID	642	2	9.093	705.0	0.0	2	3			
149-	GRID	643	2	9.125	710.	0.0	2	3			
150-	GRID	644	2	9.157	715.	0.0	2	3			

SORTED BULK DATA CCMO

CARD COUNT	1	2	3	4	5	6	7	8	9	10
151-	GRID	645	2	9.42	720.0	0.0	2	236		
152-	GRID	763	2	10.5	361.25	0.0	2	123456		
153-	GRID	764	2	10.5	366.25	0.0	2	123456		
154-	GRID	765	2	10.5	371.25	0.0	2	123456		
155-	GRID	766	2	10.5	376.25	0.0	2	123456		
156-	GRID	767	2	10.5	381.25	0.0	2	123456		
157-	GRID	768	2	10.5	386.25	0.0	2	123456		
158-	GRID	769	2	10.5	391.25	0.0	2	123456		
159-	GRID	770	2	10.5	396.25	0.0	2	123456		
160-	GRID	771	2	10.5	401.25	0.0	2	123456		
161-	GRID	772	2	10.5	406.25	0.0	2	123456		
162-	GRID	773	2	10.5	411.25	0.0	2	123456		
163-	GRID	774	2	10.5	416.25	0.0	2	123456		
164-	GRID	775	2	10.5	421.25	0.0	2	123456		
165-	GRID	776	2	10.5	426.25	0.0	2	123456		
166-	GRID	777	2	10.5	431.25	0.0	2	123456		
167-	GRID	778	2	10.5	436.25	0.0	2	123456		
168-	GRID	779	2	10.5	441.25	0.0	2	123456		
169-	GRID	780	2	10.5	446.25	0.0	2	123456		
170-	GRID	781	2	10.5	451.25	0.0	2	123456		
171-	GRID	782	2	10.5	456.25	0.0	2	123456		
172-	GRID	783	2	10.5	461.25	0.0	2	123456		
173-	GRID	784	2	10.5	466.25	0.0	2	123456		
174-	GRID	785	2	10.5	471.25	0.0	2	123456		
175-	GRID	786	2	10.5	476.25	0.0	2	123456		
176-	GRID	787	2	10.5	481.25	0.0	2	123456		
177-	GRID	788	2	10.5	486.25	0.0	2	123456		
178-	GRID	789	2	10.5	491.25	0.0	2	123456		
179-	GRID	790	2	10.5	496.25	0.0	2	123456		
180-	GRID	791	2	10.5	501.25	0.0	2	123456		
181-	GRID	792	2	10.5	506.25	0.0	2	123456		
182-	GRID	793	2	10.5	511.25	0.0	2	123456		
183-	GRID	794	2	10.5	516.25	0.0	2	123456		
184-	GRID	795	2	10.5	521.25	0.0	2	123456		
185-	GRID	796	2	10.5	526.25	0.0	2	123456		
186-	GRID	797	2	10.5	531.25	0.0	2	123456		
187-	GRID	798	2	10.5	536.25	0.0	2	123456		
188-	GRID	799	2	10.5	541.25	0.0	2	123456		
189-	GRID	800	2	10.5	546.25	0.0	2	123456		
190-	GRID	801	2	10.5	551.25	0.0	2	123456		
191-	GRID	802	2	10.5	556.25	0.0	2	123456		
192-	GRID	803	2	10.5	561.25	0.0	2	123456		
193-	GRID	804	2	10.5	566.25	0.0	2	123456		
194-	GRID	805	2	10.5	571.25	0.0	2	123456		
195-	GRID	806	2	10.5	576.25	0.0	2	123456		
196-	GRID	807	2	10.5	581.25	0.0	2	123456		
197-	GRID	808	2	10.5	586.25	0.0	2	123456		
198-	GRID	809	2	10.5	591.25	0.0	2	123456		
199-	GRID	810	2	10.5	596.25	0.0	2	123456		
200-	GRID	811	2	10.5	601.25	0.0	2	123456		

SORTED BULK DATA (CNO)

CARD COUNT		1	2	3	4	5	6	7	8	9	10
201-	GRID	812	2	10.5	606.25	0.0	2			123456	
202-	GRID	813	2	10.5	611.25	0.0	2			123456	
203-	GRID	814	2	10.5	616.25	0.0	2			123456	
204-	GRID	815	2	10.5	621.25	0.0	2			123456	
205-	GRID	816	2	10.5	626.25	0.0	2			123456	
206-	GRID	817	2	10.5	631.25	0.0	2			123456	
207-	GRID	818	2	10.5	636.25	0.0	2			123456	
208-	GRID	819	2	10.5	641.25	0.0	2			123456	
209-	GRID	820	2	10.5	646.25	0.0	2			123456	
210-	GRID	821	2	10.5	651.25	0.0	2			123456	
211-	GRID	822	2	10.5	656.25	0.0	2			123456	
212-	GRID	823	2	10.5	661.25	0.0	2			123456	
213-	GRID	824	2	10.5	666.25	0.0	2			123456	
214-	GRID	825	2	10.5	671.25	0.0	2			123456	
215-	GRID	826	2	10.5	676.25	0.0	2			123456	
216-	GRID	827	2	10.5	681.25	0.0	2			123456	
217-	GRID	828	2	10.5	686.25	0.0	2			123456	
218-	GRID	829	2	10.5	691.25	0.0	2			123456	
219-	GRID	830	2	10.5	696.25	0.0	2			123456	
220-	GRID	831	2	10.5	701.25	0.0	2			123456	
221-	GRID	832	2	10.5	706.25	0.0	2			123456	
222-	GRID	833	2	10.5	711.25	0.0	2			123456	
223-	GRID	834	2	10.5	716.25	0.0	2			123456	
224-	GRID	835	2	10.5	721.25	0.0	2			123456	
225-	PBCAM	573	1	.5137	.0445	1.0	0.0	0.0	0.0	0.0	
226-	PBCAM	608	1	.6934	.0985	1.0	0.0	0.0	0.0	0.0	
227-	PBCAM	609	1	.6983	.1003	1.0	0.0	0.0	0.0	0.0	
228-	PBCAM	610	1	.69927	.10078	1.0	0.0	0.0	0.0	0.0	
229-	PBCAM	613	1	0.70152	0.10168	1.0	0.0	0.0	0.0	0.0	
230-	PBCAM	614	1	0.84727	0.18768	1.0	0.0	0.0	0.0	0.0	
231-	PBCAM	615	1	0.99296	0.26258	1.0	0.0	0.0	0.0	0.0	
232-	PBCNO	574	1	.5189	.0457	1.0	1.0			5.0	
233-	PBCNO	575	1	.5240	.0483	1.0	1.0			5.0	
234-	PBCAG	576	1	.5291	.0481	1.0	1.0			5.0	
235-	PBCNO	577	1	.5343	.0493	1.0	1.0			5.0	
236-	PBCNO	578	1	.5394	.0506	1.0	1.0			5.0	
237-	PBCNO	579	1	.5445	.0518	1.0	1.0			5.0	
238-	PBCNO	580	1	.5497	.0531	1.0	1.0			5.0	
239-	PBCNO	581	1	.5548	.0544	1.0	1.0			5.0	
240-	PBCNO	582	1	.5599	.0558	1.0	1.0			5.0	
241-	PBCNO	583	1	.5651	.0571	1.0	1.0			5.0	
242-	PBCNO	584	1	.5702	.0585	1.0	1.0			5.0	
243-	PBCNO	585	1	.5753	.0599	1.0	1.0			5.0	
244-	PBCNO	586	1	.5805	.0613	1.0	1.0			5.0	
245-	PBCNO	587	1	.5856	.0628	1.0	1.0			5.0	
246-	PBCNO	588	1	.5907	.0643	1.0	1.0			5.0	
247-	PBCNO	589	1	.5959	.0657	1.0	1.0			5.0	
248-	PBCNO	590	1	.6010	.0672	1.0	1.0			5.0	
249-	PBCNO	591	1	.6062	.0688	1.0	1.0			5.0	
250-	PBCNO	592	1	.6113	.0703	1.0	1.0			5.0	

SPRINT BULK DATA FOR

CASE	1	2	3	4	5	6	7	8	9	10
251	PBEAD	594	1	.6164	.0719	1.0	1.0		5.0	
252	PBEAD	594	1	.6215	.0735	1.0	1.0		5.0	
253	PBEAD	595	1	.6267	.0752	1.0	1.0		5.0	
254	PBEAD	596	1	.6318	.0768	1.0	1.0		5.0	
255	PBEAD	597	1	.6369	.0785	1.0	1.0		5.0	
256	PBEAD	598	1	.6421	.0802	1.0	1.0		5.0	
257	PBEAD	599	1	.6472	.0819	1.0	1.0		5.0	
258	PBEAD	600	1	.6523	.0836	1.0	1.0		5.0	
259	PBEAD	601	1	.6575	.0854	1.0	1.0		5.0	
260	PBEAD	602	1	.6626	.0872	1.0	1.0		5.0	
261	PBEAD	603	1	.6677	.0890	1.0	1.0		5.0	
262	PBEAD	604	1	.6729	.0909	1.0	1.0		5.0	
263	PBEAD	605	1	.6780	.0927	1.0	1.0		5.0	
264	PBEAD	606	1	.6831	.0946	1.0	1.0		5.0	
265	PBEAD	607	1	.6883	.0966	1.0	1.0		5.0	
266	PBEAD	611	1	.070802	.070802	1.0	1.0		5.0	
267	PBEAD	612	1	.070877	.070877	1.0	1.0		5.0	
268	PBEAD	616	1	.13864	.03864	1.0	1.0		5.0	
269	PBEAD	617	1	.128830	.053876	1.0	1.0		5.0	
270	PBEAD	618	1	.14383	.07303	1.0	1.0		5.0	
271	PBEAD	619	1	.14080	.06585	1.0	1.0		5.0	
272	PBEAD	620	1	.133857	.06677	1.0	1.0		5.0	
273	PBEAD	621	1	.13634	.06377	1.0	1.0		5.0	
274	PBEAD	622	1	.13410	.06086	1.0	1.0		5.0	
275	PBEAD	623	1	.13187	.05804	1.0	1.0		5.0	
276	PBEAD	624	1	.12963	.05530	1.0	1.0		5.0	
277	PBEAD	625	1	.12739	.05265	1.0	1.0		5.0	
278	PBEAD	626	1	.12515	.05009	1.0	1.0		5.0	
279	PBEAD	627	1	.12290	.04760	1.0	1.0		5.0	
280	PBEAD	628	1	.12065	.04520	1.0	1.0		5.0	
281	PBEAD	629	1	.11840	.04280	1.0	1.0		5.0	
282	PBEAD	630	1	.11615	.04063	1.0	1.0		5.0	
283	PBEAD	631	1	.11390	.03846	1.0	1.0		5.0	
284	PBEAD	632	1	.11164	.03637	1.0	1.0		5.0	
285	PBEAD	633	1	.10939	.03436	1.0	1.0		5.0	
286	PBEAD	634	1	.10713	.03242	1.0	1.0		5.0	
287	PBEAD	635	1	.10488	.03058	1.0	1.0		5.0	
288	PBEAD	636	1	.10260	.02875	1.0	1.0		5.0	
289	PBEAD	637	1	.10033	.02703	1.0	1.0		5.0	
290	PBEAD	638	1	.09807	.02537	1.0	1.0		5.0	
291	PBEAD	639	1	.09580	.02378	1.0	1.0		5.0	
292	PBEAD	640	1	.09352	.02225	1.0	1.0		5.0	
293	PBEAD	641	1	.09125	.02077	1.0	1.0		5.0	
294	PBEAD	642	1	.08897	.01940	1.0	1.0		5.0	
295	PBEAD	643	1	.08669	.01807	1.0	1.0		5.0	
296	PBEAD	644	1	.08441	.01679	1.0	1.0		5.0	

TOTAL COUNT= 297

ENDDATA

***MODULE ENG	DMAP 31	MATRIX KEEB	COLS= 72, ROWS= 78, FORM= 2, TYPE=1, NZWD= 42, DEN= .5584, BLKS= 10
***MODULE ENG	DMAP 31	MATRIX PEEL	COLS= 72, ROWS= 78, FORM= 2, TYPE=1, NZWD= 42, DEN= .5517, BLKS= 9
***MODULE ENA	DMAP 31	MATRIX SCRATCH3	COLS= 145, ROWS= 145, FORM= 1, TYPE=1, NZWD= 3, DEN= .0103, BLKS= 4
***MODULE ENA	DMAP 37	MATRIX KGGX	COLS= 870, ROWS= 870, FORM= 6, TYPE=1, NZWD= 9, DEN= .0095, BLKS= 18
***MODULE ENA	DMAP 41	MATRIX SCRATCH3	COLS= 145, ROWS= 145, FORM= 1, TYPE=1, NZWD= 3, DEN= .0103, BLKS= 4
***MODULE ENA	DMAP 41	MATRIX KGGX	COLS= 870, ROWS= 870, FORM= 6, TYPE=1, NZWD= 9, DEN= .0097, BLKS= 18
***MODULE EPA	DMAP 97	MATRIX YSB	COLS= 512, ROWS= 512, FORM= 2, TYPE=1, NZWD= 0, DEN= .0000, BLKS= 1
***MODULE SCE1	DMAP 110	MATRIX SCRATCH1	COLS= 1, ROWS= 870, FORM= 2, TYPE=1, NZWD= 512, DEN= .5685, BLKS= 2
***MODULE SCE1	DMAP 110	MATRIX KFF	COLS= 358, ROWS= 358, FORM= 6, TYPE=1, NZWD= 9, DEN= .0215, BLKS= 12
***MODULE SCE1	DMAP 110	MATRIX KFS	COLS= 512, ROWS= 358, FORM= 2, TYPE=1, NZWD= 6, DEN= .0024, BLKS= 6
***MODULE SCE1	DMAP 110	MATRIX KSS	COLS= 512, ROWS= 512, FORM= 6, TYPE=1, NZWD= 5, DEN= .0009, BLKS= 5

***USER INFORMATION MESSAGE 415A--STATISTICS FOR SYMMETRIC DECOMPOSITION OF DATA BLOCK KLL FOLLOW

MAXIMUM RATIO OF MATRIX DIAGONAL TO FACTOR DIAGONAL = 3.5E+04 AT ROW NUMBER 358									
***MODULE DCP	- DMAP 140 -	MATRIX LLL	- COLS=	358, ROWS=	358, FORM=	4, TYPE=1, NZWD=	8, DEN=	.0198, BLKS=	11
***MODULE SSG1	- DMAP 145 -	MATRIX SCRATCH1	- COLS=	2, ROWS=	470, FORM=	2, TYPE=1, NZWD=	1, DEN=	.0011, BLKS=	1
***MODULE SSG1	- DMAP 145 -	MATRIX KFC	- COLS=	2, ROWS=	470, FORM=	2, TYPE=1, NZWD=	1, DEN=	.0011, BLKS=	1
***MODULE SSG2	- DMAP 145 -	MATRIX SCRATCH1	- COLS=	1, ROWS=	470, FORM=	2, TYPE=1, NZWD=	512, DEN=	.5885, BLKS=	2
***MODULE SSG2	- DMAP 145 -	MATRIX SCRATCH2	- COLS=	2, ROWS=	358, FORM=	2, TYPE=1, NZWD=	1, DEN=	.0027, BLKS=	1
***MODULE SSG2	- DMAP 145 -	MATRIX KFS	- COLS=	2, ROWS=	512, FORM=	2, TYPE=1, NZWD=	0, DEN=	.0000, BLKS=	1
***MODULE SSG2	- DMAP 145 -	MATRIX PA	- COLS=	2, ROWS=	358, FORM=	2, TYPE=1, NZWD=	1, DEN=	.0027, BLKS=	1
***MODULE SSG2	- DMAP 145 -	MATRIX KL	- COLS=	2, ROWS=	358, FORM=	2, TYPE=1, NZWD=	1, DEN=	.0027, BLKS=	1
***MODULE SSG3	- DMAP 155 -	MATRIX ULV	- COLS=	2, ROWS=	358, FORM=	2, TYPE=1, NZWD=	214, DEN=	.5977, BLKS=	2
***MODULE SSG3	- DMAP 155 -	MATRIX RULV	- COLS=	2, ROWS=	358, FORM=	2, TYPE=1, NZWD=	210, DEN=	.5865, BLKS=	2

***USER INFORMATION MESSAGE 305: FOR DATA BLOCK KLL

LOAD SEQ. NO.	SPILLEN		STRAIN ENERGY		EPSILONS LARGER THAN .001 ARE FLAGGED WITH ASTERISKS	
1	-1.3693375E-04		4.8127567E+00			
2	-1.3693375E-06		7.4231947E-01			
***MODULE SDR1	DMAP 160	MATRIX PGG	COLS= 2, ROWS= 870, FORM= 2, TYPE=1, NZWD= 1, DEN= .0011, BLKS= 1	1	**	
***MODULE SDR1	DMAP 160	MATRIX SCRATCH1	COLS= 1, ROWS= 870, FORM= 2, TYPE=1, NZWD= 512, DEN= .5885, BLKS= 2	1	**	
***MODULE SDR1	DMAP 160	MATRIX SCRATCH1	COLS= 2, ROWS= 870, FORM= 2, TYPE=1, NZWD= 214, DEN= .5859, BLKS= 2	2	**	
***MODULE SDR1	DMAP 160	MATRIX SCRATCH1	COLS= 2, ROWS= 512, FORM= 2, TYPE=1, NZWD= 5, DEN= .0097, BLKS= 1	1	**	
***MODULE SDR1	DMAP 160	MATRIX SCRATCH4	COLS= 1, ROWS= 870, FORM= 2, TYPE=1, NZWD= 358, DEN= .4114, BLKS= 1	1	**	
***MODULE SDR1	DMAP 160	MATRIX SCRATCH6	COLS= 2, ROWS= 870, FORM= 2, TYPE=1, NZWD= 5, DEN= .0057, BLKS= 1	1	**	
***MODULE SDR1	DMAP 160	MATRIX OG	COLS= 2, ROWS= 870, FORM= 2, TYPE=1, NZWD= 5, DEN= .0057, BLKS= 1	1	**	
***MODULE SDR1	DMAP 160	MATRIX UGV	COLS= 2, ROWS= 870, FORM= 2, TYPE=1, NZWD= 214, DEN= .5859, BLKS= 2	1	**	
***MODULE SDR2	DMAP 176	MATRIX PUGV1	COLS= 2, ROWS= 870, FORM= 2, TYPE=1, NZWD= 144, DEN= .7655, BLKS= 1	1	**	

SUBCASE=1

DISPLACEMENT VECTOR

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
573	G	0.0	0.0	0.0	0.0	0.0	0.0
574	G	1.225557E-04	-1.198191E-05	0.0	0.0	0.0	-5.2789993E-04
575	G	3.612760E-04	-1.822448E-05	0.0	0.0	0.0	-4.926889E-04
576	G	6.946373E-04	-1.148524E-04	0.0	0.0	0.0	-6.112331E-04
577	G	1.071116E-03	-2.152768E-04	0.0	0.0	0.0	-5.652992E-04
578	G	1.441212E-03	-3.467169E-04	0.0	0.0	0.0	-6.119668E-04
579	G	1.754081E-03	-5.103365E-04	0.0	0.0	0.0	-5.173818E-04
580	G	1.973075E-03	-6.915065E-04	0.0	0.0	0.0	-5.557272E-04
581	G	2.061286E-03	-8.801135E-04	0.0	0.0	0.0	-1.270244E-04
582	G	1.972079E-03	-1.060995E-03	0.0	0.0	0.0	1.496505E-04
583	G	1.679532E-03	-1.215594E-03	0.0	0.0	0.0	4.722316E-04
584	G	1.157953E-03	-1.325028E-03	0.0	0.0	0.0	8.356885E-04
585	G	2.466045E-04	-1.364964E-03	0.0	0.0	0.0	1.233139E-03
586	G	-6.493826E-04	1.531448E-03	0.0	0.0	0.0	1.658866E-03
587	G	-1.359251E-03	-1.146112E-03	0.0	0.0	0.0	2.106352E-03
588	G	-3.546292E-03	-8.391827E-04	0.0	0.0	0.0	2.563989E-03
589	G	-5.407765E-03	-3.644240E-04	0.0	0.0	0.0	3.004208E-03
590	G	-7.335471E-03	2.964814E-04	0.0	0.0	0.0	3.520041E-03
591	G	-9.495587E-03	1.172584E-03	0.0	0.0	0.0	3.996768E-03
592	G	-1.252842E-02	2.271679E-03	0.0	0.0	0.0	4.465823E-03
593	G	-1.534409E-02	3.639094E-03	0.0	0.0	0.0	4.922811E-03
594	G	-1.834785E-02	5.263873E-03	0.0	0.0	0.0	5.361712E-03
595	G	-2.149024E-02	7.175739E-03	0.0	0.0	0.0	5.779687E-03
596	G	-2.473759E-02	9.379661E-03	0.0	0.0	0.0	6.171239E-03
597	G	-2.804762E-02	1.188208E-02	0.0	0.0	0.0	6.533823E-03
598	G	-3.137493E-02	1.467879E-02	0.0	0.0	0.0	6.868994E-03
599	G	-3.467339E-02	1.776347E-02	0.0	0.0	0.0	7.181897E-03
600	G	-3.788643E-02	2.111735E-02	0.0	0.0	0.0	7.483187E-03
601	G	-4.097013E-02	2.442588E-02	0.0	0.0	0.0	7.672113E-03
602	G	-4.396473E-02	2.694164E-02	0.0	0.0	0.0	7.776624E-03
603	G	-4.653030E-02	3.299500E-02	0.0	0.0	0.0	7.895017E-03
604	G	-4.898296E-02	3.741744E-02	0.0	0.0	0.0	7.938832E-03
605	G	-5.093605E-02	4.202200E-02	0.0	0.0	0.0	7.988762E-03
606	G	-5.258075E-02	4.679334E-02	0.0	0.0	0.0	7.962745E-03
607	G	-5.379066E-02	5.168796E-02	0.0	0.0	0.0	7.887882E-03
608	G	-5.452244E-02	5.666448E-02	0.0	0.0	0.0	7.764582E-03
609	G	-5.476331E-02	6.168242E-02	0.0	0.0	0.0	7.593388E-03
610	G	-5.445117E-02	6.689945E-02	0.0	0.0	0.0	7.375542E-03
611	G	-5.355410E-02	7.167614E-02	0.0	0.0	0.0	7.107443E-03
612	G	-5.261517E-02	7.653152E-02	0.0	0.0	0.0	6.789388E-03
613	G	-5.168374E-02	8.160895E-02	0.0	0.0	0.0	6.416393E-03
614	G	-5.070113E-02	8.641950E-02	0.0	0.0	0.0	5.998444E-03
615	G	-4.957076E-02	9.125462E-02	0.0	0.0	0.0	5.656408E-03
616	G	-4.860118E-02	9.573527E-02	0.0	0.0	0.0	5.482381E-03
617	G	-4.781704E-02	9.980138E-02	0.0	0.0	0.0	5.319799E-03
618	G	-4.636077E-02	1.034560E-01	0.0	0.0	0.0	5.192044E-03
619	G	-4.525175E-02	1.055149E-01	0.0	0.0	0.0	5.092342E-03
620	G	-4.438275E-02	1.070519E-01	0.0	0.0	0.0	4.982180E-03
621	G	-4.361827E-02	1.086342E-01	0.0	0.0	0.0	4.861359E-03
622	G	-4.314994E-03	1.107122E-01	0.0	0.0	0.0	4.721621E-03

SUBCASE=1

DISPLACEMENT VECTOR

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
623	G	-2.308922E-03	1.112690E-01	0.0	0.0	0.0	4.586927E-03
624	G	3.744791E-03	1.112947E-01	0.0	0.0	0.0	7.433220E-03
625	G	1.010031E-02	1.107683E-01	0.0	0.0	0.0	4.268537E-03
626	G	1.641139E-02	1.096936E-01	0.0	0.0	0.0	4.893033E-03
627	G	2.274020E-02	1.080033E-01	0.0	0.0	0.0	5.397382E-03
628	G	2.904027E-02	1.067989E-01	0.0	0.0	0.0	5.711780E-03
629	G	3.529201E-02	1.0530613E-01	0.0	0.0	0.0	5.986476E-03
630	G	4.143531E-02	9.977866E-02	0.0	0.0	0.0	5.292179E-03
631	G	4.743755E-02	9.596140E-02	0.0	0.0	0.0	5.069522E-03
632	G	5.325964E-02	9.157710E-02	0.0	0.0	0.0	4.839708E-03
633	G	5.886277E-02	8.675229E-02	0.0	0.0	0.0	4.603765E-03
634	G	6.420918E-02	8.142795E-02	0.0	0.0	0.0	4.362834E-03
635	G	6.926204E-02	7.564478E-02	0.0	0.0	0.0	4.118393E-03
636	G	7.398545E-02	6.942296E-02	0.0	0.0	0.0	3.872724E-03
637	G	7.834452E-02	6.279642E-02	0.0	0.0	0.0	3.626250E-03
638	G	8.230502E-02	5.581091E-02	0.0	0.0	0.0	3.382978E-03
639	G	8.5863427E-02	4.839833E-02	0.0	0.0	0.0	3.149544E-03
640	G	8.890073E-02	4.088496E-02	0.0	0.0	0.0	2.918886E-04
641	G	9.147398E-02	3.302475E-02	0.0	0.0	0.0	2.693802E-04
642	G	9.352452E-02	2.478522E-02	0.0	0.0	0.0	2.484933E-04
643	G	9.502344E-02	1.672673E-02	0.0	0.0	0.0	2.014021E-04
644	G	9.594290E-02	8.591889E-03	0.0	0.0	0.0	1.378208E-04
645	G	9.622573E-02	0.0	0.0	0.0	0.0	0.0
763	G	0.0	0.0	0.0	0.0	0.0	0.0
764	G	0.0	0.0	0.0	0.0	0.0	0.0
765	G	0.0	0.0	0.0	0.0	0.0	0.0
766	G	0.0	0.0	0.0	0.0	0.0	0.0
767	G	0.0	0.0	0.0	0.0	0.0	0.0
768	G	0.0	0.0	0.0	0.0	0.0	0.0
769	G	0.0	0.0	0.0	0.0	0.0	0.0
770	G	0.0	0.0	0.0	0.0	0.0	0.0
771	G	0.0	0.0	0.0	0.0	0.0	0.0
772	G	0.0	0.0	0.0	0.0	0.0	0.0
773	G	0.0	0.0	0.0	0.0	0.0	0.0
774	G	0.0	0.0	0.0	0.0	0.0	0.0
775	G	0.0	0.0	0.0	0.0	0.0	0.0
776	G	0.0	0.0	0.0	0.0	0.0	0.0
777	G	0.0	0.0	0.0	0.0	0.0	0.0
778	G	0.0	0.0	0.0	0.0	0.0	0.0
779	G	0.0	0.0	0.0	0.0	0.0	0.0
780	G	0.0	0.0	0.0	0.0	0.0	0.0
781	G	0.0	0.0	0.0	0.0	0.0	0.0
782	G	0.0	0.0	0.0	0.0	0.0	0.0
783	G	0.0	0.0	0.0	0.0	0.0	0.0
784	G	0.0	0.0	0.0	0.0	0.0	0.0
785	G	0.0	0.0	0.0	0.0	0.0	0.0
786	G	0.0	0.0	0.0	0.0	0.0	0.0
787	C	0.0	0.0	0.0	0.0	0.0	0.0
788	L	0.0	0.0	0.0	0.0	0.0	0.0
789	L	0.0	0.0	0.0	0.0	0.0	0.0

SUBCASE=1

DISPLACEMENT VECTOR

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
790	G	0.0	0.0	0.0	0.0	0.0	0.0
791	G	0.0	0.0	0.0	0.0	0.0	0.0
792	G	0.0	0.0	0.0	0.0	0.0	0.0
793	G	0.0	0.0	0.0	0.0	0.0	0.0
794	G	0.0	0.0	0.0	0.0	0.0	0.0
795	G	0.0	0.0	0.0	0.0	0.0	0.0
796	G	0.0	0.0	0.0	0.0	0.0	0.0
797	G	0.0	0.0	0.0	0.0	0.0	0.0
798	G	0.0	0.0	0.0	0.0	0.0	0.0
799	G	0.0	0.0	0.0	0.0	0.0	0.0
800	G	0.0	0.0	0.0	0.0	0.0	0.0
801	G	0.0	0.0	0.0	0.0	0.0	0.0
802	G	0.0	0.0	0.0	0.0	0.0	0.0
803	G	0.0	0.0	0.0	0.0	0.0	0.0
804	G	0.0	0.0	0.0	0.0	0.0	0.0
805	G	0.0	0.0	0.0	0.0	0.0	0.0
806	G	0.0	0.0	0.0	0.0	0.0	0.0
807	G	0.0	0.0	0.0	0.0	0.0	0.0
808	G	0.0	0.0	0.0	0.0	0.0	0.0
809	G	0.0	0.0	0.0	0.0	0.0	0.0
810	G	0.0	0.0	0.0	0.0	0.0	0.0
811	G	0.0	0.0	0.0	0.0	0.0	0.0
812	G	0.0	0.0	0.0	0.0	0.0	0.0
813	G	0.0	0.0	0.0	0.0	0.0	0.0
814	G	0.0	0.0	0.0	0.0	0.0	0.0
815	G	0.0	0.0	0.0	0.0	0.0	0.0
816	G	0.0	0.0	0.0	0.0	0.0	0.0
817	G	0.0	0.0	0.0	0.0	0.0	0.0
818	G	0.0	0.0	0.0	0.0	0.0	0.0
819	G	0.0	0.0	0.0	0.0	0.0	0.0
820	G	0.0	0.0	0.0	0.0	0.0	0.0
821	G	0.0	0.0	0.0	0.0	0.0	0.0
822	G	0.0	0.0	0.0	0.0	0.0	0.0
823	G	0.0	0.0	0.0	0.0	0.0	0.0
824	G	0.0	0.0	0.0	0.0	0.0	0.0
825	G	0.0	0.0	0.0	0.0	0.0	0.0
826	G	0.0	0.0	0.0	0.0	0.0	0.0
827	G	0.0	0.0	0.0	0.0	0.0	0.0
828	G	0.0	0.0	0.0	0.0	0.0	0.0
829	G	0.0	0.0	0.0	0.0	0.0	0.0
830	G	0.0	0.0	0.0	0.0	0.0	0.0
831	G	0.0	0.0	0.0	0.0	0.0	0.0
832	G	0.0	0.0	0.0	0.0	0.0	0.0
833	G	0.0	0.0	0.0	0.0	0.0	0.0
834	G	0.0	0.0	0.0	0.0	0.0	0.0

SURCASE=2

COORDINATES VECTOR

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
573	G	0.0	0.0	0.0	0.0	0.0	0.0
574	G	2.451114E-04	-2.360381E-05	0.0	0.0	0.0	-5.798889E-04
575	G	7.229520E-04	-9.644896E-05	0.0	0.0	0.0	-9.853779E-04
576	G	1.354775E-02	-7.247047E-04	0.0	0.0	0.0	-1.224464E-03
577	G	2.142712E-03	-4.355355E-04	0.0	0.0	0.0	-1.385955E-03
578	G	2.482473E-03	-4.974339E-04	0.0	0.0	0.0	-1.239371E-03
579	G	3.418161E-03	-1.070673E-03	0.0	0.0	0.0	-1.034764E-03
580	G	3.956110E-03	-1.235013E-03	0.0	0.0	0.0	-7.824552E-04
581	G	4.122772E-03	-1.760228E-03	0.0	0.0	0.0	-2.540468E-04
582	G	3.944156E-03	-2.121810E-03	0.0	0.0	0.0	2.993011E-04
583	G	3.354166E-03	-2.431929E-03	0.0	0.0	0.0	9.447632E-04
584	G	2.315705E-03	-2.650056E-03	0.0	0.0	0.0	1.671361E-03
585	G	7.732659E-04	-2.729228E-03	0.0	0.0	0.0	2.466370E-03
586	G	-1.293765E-03	-2.626133E-03	0.0	0.0	0.0	3.317320E-03
587	G	-3.919533E-03	-2.292224E-03	0.0	0.0	0.0	4.212705E-03
588	G	-7.702845E-03	-1.678365E-03	0.0	0.0	0.0	5.139219E-03
589	G	-1.081553E-02	-7.268488E-04	0.0	0.0	0.0	4.084811E-03
590	G	-1.507049E-02	-9.288028E-04	0.0	0.0	0.0	7.040008E-03
591	G	-1.738317E-02	-7.345767E-03	0.0	0.0	0.0	7.982536E-03
592	G	-2.505645E-02	-4.555357E-03	0.0	0.0	0.0	8.530045E-03
593	G	-3.069114E-02	-7.278175E-03	0.0	0.0	0.0	9.844232E-03
594	G	-3.669571E-02	-1.052775E-02	0.0	0.0	0.0	1.072142E-02
595	G	-4.299049E-02	-1.435148E-02	0.0	0.0	0.0	1.155937E-02
596	G	-4.947518E-02	-1.675932E-02	0.0	0.0	0.0	1.234248E-02
597	G	-5.604524E-02	-2.376415E-02	0.0	0.0	0.0	1.306605E-02
598	G	-6.274546E-02	-2.935758E-02	0.0	0.0	0.0	1.372189E-02
599	G	-6.934277E-02	-3.556295E-02	0.0	0.0	0.0	1.430379E-02
600	G	-7.577366E-02	-4.235470E-02	0.0	0.0	0.0	1.480621E-02
601	G	-8.194026E-02	-4.971162E-02	0.0	0.0	0.0	1.522423E-02
602	G	-8.773746E-02	-5.760329E-02	0.0	0.0	0.0	1.555325E-02
603	G	-9.306059E-02	-6.599801E-02	0.0	0.0	0.0	1.579003E-02
604	G	-9.780593E-02	-7.462289E-02	0.0	0.0	0.0	1.593207E-02
605	G	-1.018721E-01	-8.404394E-02	0.0	0.0	0.0	1.597752E-02
606	G	-1.051615E-01	-9.358667E-02	0.0	0.0	0.0	1.592549E-02
607	G	-1.075813E-01	-1.033759E-01	0.0	0.0	0.0	1.577574E-02
608	G	-1.090453E-01	-1.133290E-01	0.0	0.0	0.0	1.552916E-02
609	G	-1.095276E-01	-1.233648E-01	0.0	0.0	0.0	1.518678E-02
610	G	-1.089035E-01	-1.333989E-01	0.0	0.0	0.0	1.475108E-02
611	G	-1.071042E-01	-1.433523E-01	0.0	0.0	0.0	1.421488E-02
612	G	-1.040304E-01	-1.530630E-01	0.0	0.0	0.0	1.357878E-02
613	G	-9.967189E-02	-1.632019E-01	0.0	0.0	0.0	1.283386E-02
614	G	-9.403225E-02	-1.728390E-01	0.0	0.0	0.0	1.190089E-02
615	G	-8.714151E-02	-1.825172E-01	0.0	0.0	0.0	1.139281E-02
616	G	-7.920236E-02	-1.914705E-01	0.0	0.0	0.0	1.096476E-02
617	G	-7.034046E-02	-1.996163E-01	0.0	0.0	0.0	1.063959E-02
618	G	-6.072155E-02	-2.069114E-01	0.0	0.0	0.0	1.038409E-02
619	G	-5.046216E-02	-2.119698E-01	0.0	0.0	0.0	1.018468E-02
620	G	-3.965517E-02	-2.161038E-01	0.0	0.0	0.0	9.964361E-03
621	G	-2.733857E-02	-2.192685E-01	0.0	0.0	0.0	9.722677E-03
622	G	-1.666300E-02	-2.214244E-01	0.0	0.0	0.0	9.459246E-03

DISPLACEMENT VECTOR

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
623	G	4.617864E-03	2.223380E-01	0.0	0.0	0.0	9.173753E-03
624	G	7.695621E-03	2.225623E-01	0.0	0.0	0.0	8.864411E-03
625	G	2.020163E-02	2.215367E-01	0.0	0.0	0.0	8.537873E-03
626	G	3.282279E-02	2.193873E-01	0.0	0.0	0.0	8.165062E-03
627	G	4.544040E-02	2.160070E-01	0.0	0.0	0.0	7.814603E-03
628	G	5.504414E-02	2.115977E-01	0.0	0.0	0.0	7.423359E-03
629	G	7.058403E-02	2.063226E-01	0.0	0.0	0.0	7.012932E-03
630	G	8.287863E-02	1.995573E-01	0.0	0.0	0.0	6.584357E-03
631	G	9.487509E-02	1.919228E-01	0.0	0.0	0.0	6.139844E-03
632	G	1.065193E-01	1.831876E-01	0.0	0.0	0.0	5.679477E-03
633	G	1.177255E-01	1.735046E-01	0.0	0.0	0.0	5.207530E-03
634	G	1.280134E-01	1.620559E-01	0.0	0.0	0.0	4.725675E-03
635	G	1.375241E-01	1.512294E-01	0.0	0.0	0.0	4.236751E-03
636	G	1.470704E-01	1.398544E-01	0.0	0.0	0.0	3.744249E-03
637	G	1.566440E-01	1.285542E-01	0.0	0.0	0.0	3.252500E-03
638	G	1.664100E-01	1.176218E-01	0.0	0.0	0.0	2.765951E-03
639	G	1.764456E-01	1.064842E-01	0.0	0.0	0.0	2.275053E-03
640	G	1.774014E-01	8.176991E-02	0.0	0.0	0.0	1.827601E-03
641	G	1.827430E-01	6.604444E-02	0.0	0.0	0.0	1.327660E-03
642	G	1.370440E-01	4.990455E-02	0.0	0.0	0.0	9.768066E-04
643	G	1.900469E-01	3.345346E-02	0.0	0.0	0.0	6.028042E-04
644	G	1.918545E-01	1.678379E-02	0.0	0.0	0.0	2.740415E-04
645	G	1.925115E-01	0.0	0.0	0.0	0.0	0.0
763	G	0.0	0.0	0.0	0.0	0.0	0.0
764	G	0.0	0.0	0.0	0.0	0.0	0.0
765	G	0.0	0.0	0.0	0.0	0.0	0.0
766	G	0.0	0.0	0.0	0.0	0.0	0.0
767	G	0.0	0.0	0.0	0.0	0.0	0.0
768	G	0.0	0.0	0.0	0.0	0.0	0.0
769	G	0.0	0.0	0.0	0.0	0.0	0.0
770	G	0.0	0.0	0.0	0.0	0.0	0.0
771	G	0.0	0.0	0.0	0.0	0.0	0.0
772	G	0.0	0.0	0.0	0.0	0.0	0.0
773	G	0.0	0.0	0.0	0.0	0.0	0.0
774	G	0.0	0.0	0.0	0.0	0.0	0.0
775	G	0.0	0.0	0.0	0.0	0.0	0.0
776	G	0.0	0.0	0.0	0.0	0.0	0.0
777	G	0.0	0.0	0.0	0.0	0.0	0.0
778	G	0.0	0.0	0.0	0.0	0.0	0.0
779	G	0.0	0.0	0.0	0.0	0.0	0.0
780	G	0.0	0.0	0.0	0.0	0.0	0.0
781	G	0.0	0.0	0.0	0.0	0.0	0.0
782	G	0.0	0.0	0.0	0.0	0.0	0.0
783	G	0.0	0.0	0.0	0.0	0.0	0.0
784	G	0.0	0.0	0.0	0.0	0.0	0.0
785	G	0.0	0.0	0.0	0.0	0.0	0.0
786	G	0.0	0.0	0.0	0.0	0.0	0.0
787	G	0.0	0.0	0.0	0.0	0.0	0.0
788	G	0.0	0.0	0.0	0.0	0.0	0.0
789	G	0.0	0.0	0.0	0.0	0.0	0.0

SURCASE=2

DISPLACEMENT VECTOR

POINT NO.	TYPE	T1	T2	T3	R1	R2	R3
790	G	0.0	0.0	0.0	0.0	0.0	0.0
791	G	0.0	0.0	0.0	0.0	0.0	0.0
792	G	0.0	0.0	0.0	0.0	0.0	0.0
793	G	0.0	0.0	0.0	0.0	0.0	0.0
794	G	0.0	0.0	0.0	0.0	0.0	0.0
795	G	0.0	0.0	0.0	0.0	0.0	0.0
796	G	0.0	0.0	0.0	0.0	0.0	0.0
797	G	0.0	0.0	0.0	0.0	0.0	0.0
798	G	0.0	0.0	0.0	0.0	0.0	0.0
799	G	0.0	0.0	0.0	0.0	0.0	0.0
800	G	0.0	0.0	0.0	0.0	0.0	0.0
801	G	0.0	0.0	0.0	0.0	0.0	0.0
802	G	0.0	0.0	0.0	0.0	0.0	0.0
803	G	0.0	0.0	0.0	0.0	0.0	0.0
804	G	0.0	0.0	0.0	0.0	0.0	0.0
805	G	0.0	0.0	0.0	0.0	0.0	0.0
806	G	0.0	0.0	0.0	0.0	0.0	0.0
807	G	0.0	0.0	0.0	0.0	0.0	0.0
808	G	0.0	0.0	0.0	0.0	0.0	0.0
809	G	0.0	0.0	0.0	0.0	0.0	0.0
810	G	0.0	0.0	0.0	0.0	0.0	0.0
811	G	0.0	0.0	0.0	0.0	0.0	0.0
812	G	0.0	0.0	0.0	0.0	0.0	0.0
813	G	0.0	0.0	0.0	0.0	0.0	0.0
814	G	0.0	0.0	0.0	0.0	0.0	0.0
815	G	0.0	0.0	0.0	0.0	0.0	0.0
816	G	0.0	0.0	0.0	0.0	0.0	0.0
817	G	0.0	0.0	0.0	0.0	0.0	0.0
818	G	0.0	0.0	0.0	0.0	0.0	0.0
819	G	0.0	0.0	0.0	0.0	0.0	0.0
820	G	0.0	0.0	0.0	0.0	0.0	0.0
821	G	0.0	0.0	0.0	0.0	0.0	0.0
822	G	0.0	0.0	0.0	0.0	0.0	0.0
823	G	0.0	0.0	0.0	0.0	0.0	0.0
824	G	0.0	0.0	0.0	0.0	0.0	0.0
825	G	0.0	0.0	0.0	0.0	0.0	0.0
826	G	0.0	0.0	0.0	0.0	0.0	0.0
827	G	0.0	0.0	0.0	0.0	0.0	0.0
828	G	0.0	0.0	0.0	0.0	0.0	0.0
829	G	0.0	0.0	0.0	0.0	0.0	0.0
830	G	0.0	0.0	0.0	0.0	0.0	0.0
831	G	0.0	0.0	0.0	0.0	0.0	0.0
832	G	0.0	0.0	0.0	0.0	0.0	0.0
833	G	0.0	0.0	0.0	0.0	0.0	0.0
834	G	0.0	0.0	0.0	0.0	0.0	0.0

SUBCASE=1

		SURFACES IN - END ELEMENTS				(ELEMENT)	
		BENDING MOMENTS -		SHEARS -		AXIAL	
		PLANE 1		PLANE 2		FORCE	
ELEMENT-TO	GRID	END	PLANE 1	PLANE 2	PLANE 1	PLANE 2	TORQUE
574	574	A	1.812074E+02	0.0	9.965809E+01	0.0	-5.727651E+00
	575	F	1.207147E+02	0.0	9.697789E+01	0.0	-1.440926E+01
575	575	A	1.205147E+02	0.0	9.897562E+01	0.0	-1.443167E+01
	576	F	6.092195E+01	0.0	9.134119E+01	0.0	-2.300305E+01
576	576	A	6.092195E+01	0.0	9.733602E+01	0.0	-2.302489E+01
	577	F	1.096321E+00	0.0	9.495588E+01	0.0	-3.142067E+01
577	577	A	1.096321E+00	0.0	9.495518E+01	0.0	-3.144179E+01
	578	F	-5.549665E+01	0.0	9.125023E+01	0.0	-3.959775E+01
578	578	A	-5.549665E+01	0.0	9.184150E+01	0.0	-3.961800E+01
	579	F	-1.111064E+02	0.0	8.403906E+01	0.0	-4.747175E+01
579	579	A	-1.111064E+02	0.0	8.402870E+01	0.0	-4.749099E+01
	580	F	-1.643612E+02	0.0	8.385461E+01	0.0	-5.098248E+01
580	580	A	-1.643612E+02	0.0	8.354270E+01	0.0	-5.500059E+01
	581	F	-2.744912E+02	0.0	7.843718E+01	0.0	-6.520725E+01
581	581	A	-2.744912E+02	0.0	7.851651E+01	0.0	-6.196454E+01
	582	F	-2.622499E+02	0.0	7.281717E+01	0.0	-6.857191E+01
582	582	A	-2.622499E+02	0.0	7.269289E+01	0.0	-6.870364E+01
	583	F	-3.060608E+02	0.0	6.642836E+01	0.0	-7.477780E+01
583	583	A	-3.060608E+02	0.0	6.641257E+01	0.0	-7.479182E+01
	584	F	-3.458862E+02	0.0	5.764132E+01	0.0	-8.029346E+01
584	584	A	-3.458862E+02	0.0	5.975055E+01	0.0	-8.021420E+01
	585	F	-3.815170E+02	0.0	5.253205E+01	0.0	-8.511657E+01
585	585	A	-3.815170E+02	0.0	5.238808E+01	0.0	-8.521018E+01
	586	F	-4.124733E+02	0.0	4.475420E+01	0.0	-8.945115E+01
586	586	A	-4.124733E+02	0.0	4.467503E+01	0.0	-8.939066E+01
	587	F	-4.596326E+02	0.0	3.891338E+01	0.0	-9.286150E+01
587	587	A	-4.596326E+02	0.0	3.674900E+01	0.0	-9.302665E+01
	588	F	-4.596263E+02	0.0	2.850135E+01	0.0	-9.587554E+01
588	588	A	-4.596263E+02	0.0	2.882795E+01	0.0	-9.585722E+01
	589	F	-4.753799E+02	0.0	2.016824E+01	0.0	-9.796780E+01
589	589	A	-4.753799E+02	0.0	1.999669E+01	0.0	-9.800296E+01
	590	F	-4.855514E+02	0.0	1.197900E+01	0.0	-9.937205E+01

SUBCASE=1

			FORCES IN BEND ELEMENTS				LCBEND	
			BENDING MOMENTS		SHEARS		TORSION	
ELEMENT-ID	GRID	END	PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
590	590	A	-4.855514E+02	0.0	1.151143E+01	0.0	-9.935761E+01	0.0
591	591	B	-4.402135E+02	0.0	-2.898845E+00	0.0	-9.990262E+01	0.0
591	591	A	-4.402135E+02	0.0	2.634642E+00	0.0	-9.998753E+01	0.0
592	592	B	-4.449839E+02	0.0	-6.889871E+00	0.0	-9.984667E+01	0.0
592	592	A	-4.449839E+02	0.0	-9.959824E+00	0.0	-9.984466E+01	0.0
593	593	B	-4.423220E+02	0.0	-1.463719E+01	0.0	-9.892544E+01	0.0
593	593	A	-4.423220E+02	0.0	-1.468717E+01	0.0	-9.892014E+01	0.0
594	594	B	-4.697391E+02	0.0	-2.337220E+01	0.0	-9.725319E+01	0.0
594	594	A	-4.697391E+02	0.0	-2.324451E+01	0.0	-9.728380E+01	0.0
595	595	B	-4.515659E+02	0.0	-3.163490E+01	0.0	-9.468771E+01	0.0
595	595	A	-4.515659E+02	0.0	-3.145422E+01	0.0	-9.468229E+01	0.0
596	596	B	-4.278084E+02	0.0	-5.980320E+01	0.0	-9.176139E+01	0.0
596	596	A	-4.278084E+02	0.0	-5.982168E+01	0.0	-9.175337E+01	0.0
597	597	B	-4.449839E+02	0.0	-6.766644E+01	0.0	-7.792551E+01	0.0
597	597	A	-4.449839E+02	0.0	-6.781521E+01	0.0	-7.795302E+01	0.0
600	600	B	-4.402135E+02	0.0	-5.524015E+01	0.0	-6.335124E+01	0.0
600	600	A	-4.402135E+02	0.0	-5.518217E+01	0.0	-6.332847E+01	0.0
601	601	B	-4.402135E+02	0.0	-6.224297E+01	0.0	-7.826547E+01	0.0
601	601	A	-4.402135E+02	0.0	-6.225435E+01	0.0	-7.826374E+01	0.0
602	602	B	-2.601956E+02	0.0	-6.884432E+01	0.0	-7.255568E+01	0.0
602	602	A	-2.601956E+02	0.0	-6.885846E+01	0.0	-7.254626E+01	0.0
603	603	B	-2.513769E+02	0.0	-7.491925E+01	0.0	-6.626679E+01	0.0
603	603	A	-2.513769E+02	0.0	-7.493206E+01	0.0	-6.625431E+01	0.0
604	604	B	-1.704524E+02	0.0	-8.042136E+01	0.0	-5.947143E+01	0.0
604	604	A	-1.704524E+02	0.0	-8.043276E+01	0.0	-5.945602E+01	0.0
605	605	B	-1.217364E+02	0.0	-8.530862E+01	0.0	-5.221959E+01	0.0
605	605	A	-1.217364E+02	0.0	-8.531855E+01	0.0	-5.220337E+01	0.0
606	606	B	-6.165518E+01	0.0	-8.954371E+01	0.0	-4.456872E+01	0.0
606	606	A	-6.165518E+01	0.0	-8.955217E+01	0.0	-4.455187E+01	0.0
607	607	B	1.355461E+00	0.0	-9.309429E+01	0.0	-3.657732E+01	0.0
607	607	A	1.355461E+00	0.0	-9.310113E+01	0.0	-3.655990E+01	0.0
608	608	B	5.68370E+01	0.0	-9.593326E+01	0.0	-2.733648E+01	0.0

SUBCASE=1

			FORCES IN BEND ELEMENTS				(CBEND)	
			BENDING MOMENTS		SHEARS		AXIAL	
ELEMENT-IC	GRID	END	PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
0	606	606	6.683370E+01	0.0	-9.593851E+01	0.0	-2.428868E+01	0.0
0	607	607	1.342944E+02	0.0	-9.593851E+01	0.0	-1.781944E+01	0.0
0	607	607	1.342944E+02	0.0	-9.804260E+01	0.0	-1.780139E+01	0.0
0	608	608	2.032515E+02	0.0	-9.939533E+01	0.0	-1.118107E+01	0.0
0	611	611	4.133774E+02	0.0	-9.896776E+01	0.0	-1.498547E+01	0.0
0	611	611	4.834850E+02	0.0	-9.732867E+01	0.0	-2.305595E+01	0.0
0	612	612	4.834850E+02	0.0	-9.887882E+01	0.0	-1.508866E+01	0.0
0	613	613	5.541990E+02	0.0	-9.718819E+01	0.0	-2.354113E+01	0.0
0	616	616	7.660907E+02	0.0	-9.061175E+01	0.0	-4.234266E+01	0.0
0	617	617	9.347376E+02	0.0	-8.658235E+01	0.0	-5.807938E+01	0.0
0	617	617	8.534737E+02	0.0	-8.642967E+01	0.0	-5.835787E+01	0.0
0	618	618	9.009488E+02	0.0	-8.170283E+01	0.0	-5.769830E+01	0.0
0	618	618	9.009488E+02	0.0	-7.184550E+01	0.0	-7.040537E+01	0.0
0	619	619	9.553281E+02	0.0	-6.463940E+01	0.0	-7.632952E+01	0.0
0	619	619	9.553281E+02	0.0	-6.463940E+01	0.0	-7.633321E+01	0.0
0	620	620	1.001816E+03	0.0	-5.773620E+01	0.0	-8.167606E+01	0.0
0	620	620	1.001816E+03	0.0	-5.773319E+01	0.0	-8.167934E+01	0.0
0	621	621	1.044222E+03	0.0	-5.039304E+01	0.0	-8.448816E+01	0.0
0	621	621	1.044222E+03	0.0	-5.038815E+01	0.0	-8.448302E+01	0.0
0	622	622	1.090800E+03	0.0	-4.266589E+01	0.0	-9.046384E+01	0.0
0	622	622	1.090800E+03	0.0	-4.266079E+01	0.0	-9.046825E+01	0.0
0	623	623	1.111242E+03	0.0	-3.461362E+01	0.0	-9.384212E+01	0.0
0	623	623	1.111242E+03	0.0	-3.460836E+01	0.0	-9.384407E+01	0.0
0	624	624	1.135289E+03	0.0	-2.629761E+01	0.0	-9.650328E+01	0.0
0	624	624	1.135289E+03	0.0	-2.629222E+01	0.0	-9.650475E+01	0.0
0	625	625	1.152728E+03	0.0	-1.777812E+01	0.0	-9.842904E+01	0.0
0	625	625	1.152728E+03	0.0	-1.777575E+01	0.0	-9.843003E+01	0.0
0	626	626	1.163598E+03	0.0	-9.129362E+00	0.0	-9.960473E+01	0.0
0	626	626	1.163598E+03	0.0	-7.243149E+00	0.0	-9.975963E+01	0.0
0	627	627	1.165686E+03	0.0	1.479038E+00	0.0	1.080113E+02	0.0
0	627	627	1.165686E+03	0.0	2.216171E+01	0.0	1.080228E+02	0.0
0	628	628	1.162045E+03	0.0	8.53264E+00	0.0	-9.762265E+01	0.0

SUBCASE31

FORCES IN BEND ELEMENTS				(CBEND)				
BENDING MOMENTS				SHEARS				
ELEMENT-NO	GRID	END	PLANE 1	PLANE 2	PLANE 1	PLANE 2	AXIAL FORCE	TORQUE
628	628	A	1.162005E+03	0.0	8.316533E+00	0.0	9.967589E+01	0.0
629	629	A	1.151771E+03	0.0	1.697221E+01	0.0	9.457176E+01	0.0
630	630	A	1.151771E+03	0.0	1.697763E+01	0.0	9.457082E+01	0.0
631	631	A	1.135014E+03	0.0	2.550403E+01	0.0	9.671603E+01	0.0
632	632	A	1.135014E+03	0.0	2.550932E+01	0.0	9.671464E+01	0.0
633	633	A	1.111271E+03	0.0	3.384149E+01	0.0	9.412333E+01	0.0
634	634	A	1.111271E+03	0.0	3.501704E+01	0.0	9.539234E+01	0.0
635	635	A	1.079996E+03	0.0	4.304961E+01	0.0	9.020380E+01	0.0
636	636	A	1.079996E+03	0.0	4.192251E+01	0.0	9.001226E+01	0.0
637	637	A	1.043229E+03	0.0	4.967879E+01	0.0	8.601282E+01	0.0
638	638	A	1.043229E+03	0.0	4.968346E+01	0.0	8.601013E+01	0.0
639	639	A	1.000292E+03	0.0	5.706042E+01	0.0	8.214959E+01	0.0
640	640	A	1.000292E+03	0.0	5.706465E+01	0.0	8.214632E+01	0.0
641	641	A	9.514865E+02	0.0	6.400724E+01	0.0	7.686048E+01	0.0
642	642	A	9.514865E+02	0.0	6.401136E+01	0.0	7.685966E+01	0.0
643	643	A	9.471592E+02	0.0	7.046630E+01	0.0	7.998594E+01	0.0
644	644	A	9.471592E+02	0.0	7.139080E+01	0.0	7.910661E+01	0.0
645	645	A	9.370754E+02	0.0	7.717952E+01	0.0	8.362207E+01	0.0
646	646	A	9.370754E+02	0.0	7.639012E+01	0.0	8.456777E+01	0.0
647	647	A	7.729911E+02	0.0	8.172688E+01	0.0	5.766423E+01	0.0
648	648	A	7.729911E+02	0.0	8.172994E+01	0.0	5.765990E+01	0.0
649	649	A	7.046837E+02	0.0	8.644433E+01	0.0	5.051725E+01	0.0
650	650	A	7.046837E+02	0.0	8.644698E+01	0.0	5.051268E+01	0.0
651	651	A	6.326575E+02	0.0	9.050307E+01	0.0	4.250688E+01	0.0
652	652	A	6.326575E+02	0.0	9.050531E+01	0.0	4.250212E+01	0.0
653	653	A	5.574470E+02	0.0	9.387218E+01	0.0	3.745320E+01	0.0
654	654	A	5.574470E+02	0.0	9.428903E+01	0.0	3.337703E+01	0.0
655	655	A	4.793782E+02	0.0	9.683923E+01	0.0	2.503219E+01	0.0
656	656	A	4.793782E+02	0.0	9.652669E+01	0.0	2.621734E+01	0.0
657	657	A	3.895183E+02	0.0	9.844366E+01	0.0	1.769894E+01	0.0
658	658	A	3.895183E+02	0.0	9.844479E+01	0.0	1.769382E+01	0.0
659	659	A	3.183654E+02	0.0	9.961229E+01	0.0	9.704649E+00	0.0

AL SPIRAL COIL TEST CONFIGURATION
CBEND ELEMENTS

STRCHSE=1

			FORCES IN BEAD ELEMENTS				CBEND	
			BENDING MOMENTS		SHEARS		AXIAL	
			PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
ELEMENT-ID	GRID	END						
644	644	A	3.183654E+02	0.0	9.961276E+01	0.0	9.041303E+00	0.0
645	645	P	2.262274E+02	0.0	1.000217E+02	0.0	3.250739E+01	0.0

SUBCASE=2

ELEMENT-ID	GRID	STAT. POINT LENGTH	FORCES IN BEAM ELEMENTS				TOTAL FORCE	TOTAL TORQUE	WARPING TORQUE
			BENDING MOMENTS		WEB SHEARS				
			PLANE 1	PLANE 2	PLANE 1	PLANE 2			
573	573	0.000	9.932688E+02	0.0	2.000201E+02	0.0	-2.555188E+00	0.0	0.0
	574	1.000	3.624149E+02	0.0	2.000281E+02	0.0	-2.555166E+00	0.0	0.0
608	608	0.000	4.069701E+02	0.0	-1.995794E+02	0.0	-1.383528E+01	0.0	0.0
	609	1.000	4.462699E+02	0.0	-1.995794E+02	0.0	-1.363328E+01	0.0	0.0
609	609	0.000	5.462179E+02	0.0	-2.000127E+02	0.0	3.366188E+00	0.0	0.0
	610	1.000	6.869498E+02	0.0	-2.000127E+02	0.0	3.566885E+00	0.0	0.0
610	610	0.000	6.469498E+02	0.0	-1.990153E+02	0.0	2.026543E+01	0.0	0.0
	611	1.000	4.275443E+02	0.0	-1.990153E+02	0.0	2.026543E+01	0.0	0.0
613	613	0.000	1.108378E+03	0.0	-1.928005E+02	0.0	5.615687E+01	0.0	0.0
	614	1.000	1.248296E+03	0.0	-1.928005E+02	0.0	5.615687E+01	0.0	0.0
614	614	0.000	1.248296E+03	0.0	-1.911422E+02	0.0	-3.901218E+01	0.0	0.0
	615	1.000	1.391347E+03	0.0	-1.911422E+02	0.0	5.901218E+01	0.0	0.0
615	615	0.000	1.401447E+03	0.0	-1.880104E+02	0.0	7.849427E+01	0.0	0.0
	616	1.000	1.453111E+03	0.0	-1.880104E+02	0.0	7.849427E+01	0.0	0.0

THE CASE

		FORCES IN BEAM ELEMENTS				COORD	
		- BENDING MOMENTS -		- SHEARS -		AXIAL	
ELEMENT-ID	GRID	END	PLANE 1	PLANE 2	PLANE 1	PLANE 2	TORQUE
574	574	A	3.624140E+02	0.0	1.797162E+02	0.0	-1.145570E+01
	575	A	2.416299E+02	0.0	1.979574E+02	0.0	-2.881852E+01
	575	A	2.416299E+02	0.0	1.979512E+02	0.0	-2.886334E+01
576	576	A	1.721643E+02	0.0	1.946824E+02	0.0	-4.606609E+01
	576	A	1.214439E+02	0.0	1.946720E+02	0.0	-4.604978E+01
	577	A	9.492643E+01	0.0	1.899170E+02	0.0	-6.284133E+01
577	577	A	3.492643E+01	0.0	1.789903E+02	0.0	-6.284635E+01
	578	A	-1.165973E+02	0.0	1.837005E+02	0.0	-7.919549E+01
	578	A	-1.165973E+02	0.0	1.836630E+02	0.0	-7.923599E+01
579	579	A	-2.222129E+02	0.0	1.760762E+02	0.0	-9.449435E+01
	579	A	-2.222129E+02	0.0	1.760574E+02	0.0	-9.449819E+01
	580	A	-3.267623E+02	0.0	1.671092E+02	0.0	-1.059965E+02
580	580	A	-3.267623E+02	0.0	1.670854E+02	0.0	-1.060612E+02
	581	A	-4.297724E+02	0.0	1.568624E+02	0.0	-1.241450E+02
	581	A	-4.297724E+02	0.0	1.570330E+02	0.0	-1.239291E+02
582	582	A	-5.245898E+02	0.0	1.456343E+02	0.0	-1.337143E+02
	582	A	-5.245898E+02	0.0	1.453858E+02	0.0	-1.3374073E+02
	583	A	-6.121216E+02	0.0	1.328567E+02	0.0	-1.445556E+02
583	583	A	-6.121216E+02	0.0	1.328231E+02	0.0	-1.4495836E+02
	584	A	-6.917725E+02	0.0	1.192826E+02	0.0	-1.605909E+02
	584	A	-6.917725E+02	0.0	1.195011E+02	0.0	-1.604204E+02
585	585	A	-7.630357E+02	0.0	1.050641E+02	0.0	-1.702331E+02
	585	A	-7.630357E+02	0.0	1.047602E+02	0.0	-1.704204E+02
	586	A	-8.249466E+02	0.0	8.950840E+01	0.0	-1.789023E+02
586	586	A	-8.249466E+02	0.0	8.975006E+01	0.0	-1.787181E+02
	587	A	-8.773051E+02	0.0	7.382672E+01	0.0	-1.859231E+02
	587	A	-8.773051E+02	0.0	7.349600E+01	0.0	-1.860533E+02
587	588	A	-9.192526E+02	0.0	5.700270E+01	0.0	-1.917511E+02
	588	A	-9.192526E+02	0.0	5.725989E+01	0.0	-1.916744E+02
	589	A	-9.507599E+02	0.0	4.033647E+01	0.0	-1.959356E+02
589	589	A	-9.507599E+02	0.0	3.999239E+01	0.0	-1.960059E+02
	590	A	-9.711028E+02	0.0	2.275016E+01	0.0	-1.987457E+02

SUBCASE=2

ELEMENT-10	GRID	END	ELEMENTS				FORCE	
			BENDING MOMENTS -		SHEARS		AXIAL	TORQUE
			PLANE 1	PLANE 2	PLANE 1	PLANE 2		
590	590	A	-9.711028E+02	0.0	2.302207E+01	0.0	-1.7987152E+02	0.0
	591	B	-9.804271E+02	0.0	5.614005E+00	0.0	-1.999656E+02	0.0
591	591	A	-9.804271E+02	0.0	5.269285E+00	0.0	-1.999781E+02	0.0
	592	C	-9.781679E+02	0.0	-1.217974E+01	0.0	-1.7996733E+02	0.0
592	592	A	-9.781679E+02	0.0	-1.191565E+01	0.0	-1.998893E+02	0.0
	593	B	-9.646440E+02	0.0	-2.927438E+01	0.0	-1.971909E+02	0.0
593	593	A	-9.646440E+02	0.0	-2.7961433E+01	0.0	-1.9978805E+02	0.0
	594	B	-9.394703E+02	0.0	-4.674436E+01	0.0	-1.945064E+02	0.0
594	594	A	-9.394703E+02	0.0	-4.648908E+01	0.0	-1.945676E+02	0.0
	595	C	-9.031318E+02	0.0	-6.326986E+01	0.0	-1.897175E+02	0.0
595	595	A	-9.031318E+02	0.0	-6.330840E+01	0.0	-1.877626E+02	0.0
	596	B	-8.556169E+02	0.0	-7.960639E+01	0.0	-1.835228E+02	0.0
596	596	A	-8.556169E+02	0.0	-7.969335E+01	0.0	-1.8353987E+02	0.0
	597	B	-7.971979E+02	0.0	-9.533395E+01	0.0	-1.758671E+02	0.0
597	597	A	-7.971979E+02	0.0	-9.563041E+01	0.0	-1.757060E+02	0.0
	598	C	-7.280728E+02	0.0	-1.195303E+02	0.0	-1.6667027E+02	0.0
598	598	A	-7.280728E+02	0.0	-1.103643E+02	0.0	-1.668457E+02	0.0
	599	B	-6.490190E+02	0.0	-1.244859E+02	0.0	-1.565919E+02	0.0
599	599	A	-6.490190E+02	0.0	-1.245167E+02	0.0	-1.565675E+02	0.0
	600	C	-5.163913E+02	0.0	-1.376886E+02	0.0	-1.451194E+02	0.0
600	600	A	-5.160513E+02	0.0	-1.377163E+02	0.0	-1.4510925E+02	0.0
	601	C	-4.127137E+02	0.0	-1.449355E+02	0.0	-1.325376E+02	0.0
601	601	A	-4.127137E+02	0.0	-1.448643E+02	0.0	-1.325046E+02	0.0
	602	C	-3.567047E+02	0.0	-1.60427E+02	0.0	-1.189429E+02	0.0
602	602	A	-3.569047E+02	0.0	-1.608655E+02	0.0	-1.189120E+02	0.0
	603	C	-2.434727E+02	0.0	-1.706112E+02	0.0	-1.044392E+02	0.0
603	603	A	-2.434727E+02	0.0	-1.706373E+02	0.0	-1.044067E+02	0.0
	604	C	-1.233104E+02	0.0	-1.790874E+02	0.0	-6.913744E+01	0.0
604	604	A	-1.233104E+02	0.0	-1.793104E+02	0.0	-6.910366E+01	0.0
	605	C	2.710522E+00	0.0	-1.861866E+02	0.0	-7.315966E+01	0.0
605	605	A	2.710922E+00	0.0	-1.785203E+02	0.0	-7.311988E+01	0.0
	606	B	1.336674E+02	0.0	-1.918665E+02	0.0	-5.661297E+01	0.0

SURCASE=2

ELEMENT-ID	GRID	END	FORCES IN BEND ELEMENTS				T C BEND	
			- BENDING MOMENTS -		- SHEARS -		AXIAL	
			PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
606	606	A	1.336674E+02	0.0	-1.412770E+02	0.0	-9.657733E+01	0.0
	607	A	2.68557E+02	0.0	-1.960779E+02	0.0	-3.963880E+01	0.0
	607	A	2.68557E+02	0.0	-1.960852E+02	0.0	-3.963880E+01	0.0
	608	B	4.064703E+02	0.0	-1.987907E+02	0.0	-2.236213E+01	0.0
611	611	A	8.275483E+02	0.0	-1.979350E+02	0.0	2.897093E+01	0.0
	612	A	9.669703E+02	0.0	-1.946573E+02	0.0	4.611191E+01	0.0
	612	A	9.669703E+02	0.0	-1.977976E+02	0.0	3.016133E+01	0.0
	613	A	1.104350E+03	0.0	-1.543764E+02	0.0	4.728227E+01	0.0
	616	A	1.532141E+03	0.0	-1.812352E+02	0.0	8.468533E+01	0.0
	617	B	1.669475E+03	0.0	-1.731647E+02	0.0	7.001988E+02	0.0
	617	A	1.669475E+03	0.0	-1.728413E+02	0.0	1.007157E+02	0.0
	618	B	1.801898E+03	0.0	-1.634087E+02	0.0	1.153966E+02	0.0
	618	A	1.801898E+03	0.0	-1.420920E+02	0.0	1.408107E+02	0.0
	619	A	1.907956E+03	0.0	-1.292136E+02	0.0	1.526590E+02	0.0
	619	A	1.907956E+03	0.0	-1.292701E+02	0.0	1.526664E+02	0.0
	620	B	2.005631E+03	0.0	-1.154631E+02	0.0	1.633587E+02	0.0
	620	A	2.003631E+03	0.0	-1.154631E+02	0.0	1.633587E+02	0.0
	621	B	2.088445E+03	0.0	-1.007841E+02	0.0	1.728003E+02	0.0
	622	A	2.161599E+03	0.0	-8.533178E+01	0.0	1.809317E+02	0.0
	622	A	2.161599E+03	0.0	-8.532158E+01	0.0	1.809365E+02	0.0
	623	A	2.222484E+03	0.0	-5.921671E+01	0.0	1.876881E+02	0.0
	623	A	2.222484E+03	0.0	-5.921671E+01	0.0	1.876881E+02	0.0
	624	B	2.270578E+03	0.0	-5.556245E+01	0.0	1.964581E+02	0.0
	624	A	2.270578E+03	0.0	-5.556245E+01	0.0	1.964581E+02	0.0
	625	A	2.305457E+03	0.0	-5.558149E+01	0.0	1.964601E+02	0.0
	625	A	2.305457E+03	0.0	-5.558149E+01	0.0	1.964601E+02	0.0
	626	B	2.326796E+03	0.0	-4.48630E+01	0.0	1.995193E+02	0.0
	626	A	2.326796E+03	0.0	-4.48630E+01	0.0	1.995193E+02	0.0
	627	B	2.331373E+03	0.0	-4.33343E+01	0.0	2.000226E+02	0.0
	627	A	2.331373E+03	0.0	-4.33343E+01	0.0	2.000226E+02	0.0
	628	B	2.324091E+03	0.0	-1.787653E+01	0.0	1.992441E+02	0.0

SUPCASE=2

ELEMENT-IO		GRID	END	BENDING MOMENTS		SHEARS		AXIAL		TOR
				PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE		
0	628	628	A	2.329091E+03	0.0	1.706330E+01	0.0	1.993510E+02	0.0	0.0
		629	B	2.303945E+03	0.0	3.394402E+01	0.0	1.971435E+02	0.0	0.0
		629	A	2.303945E+03	0.0	3.395255E+01	0.0	1.971416E+02	0.0	0.0
		630	C	2.279079E+03	0.0	5.100000E+01	0.0	1.934322E+02	0.0	0.0
		630	B	2.279079E+03	0.0	5.101664E+01	0.0	1.934293E+02	0.0	0.0
		631	D	2.222541E+03	0.0	6.768294E+01	0.0	1.882467E+02	0.0	0.0
0	631	631	A	2.222541E+03	0.0	7.002407E+01	0.0	1.873567E+02	0.0	0.0
		632	B	2.156601E+03	0.0	8.685227E+01	0.0	1.805679E+02	0.0	0.0
		632	A	2.156601E+03	0.0	8.324701E+01	0.0	1.811245E+02	0.0	0.0
		633	C	2.046450E+02	0.0	9.635757E+01	0.0	1.736256E+02	0.0	0.0
		633	B	2.046450E+02	0.0	9.936146E+01	0.0	1.735203E+02	0.0	0.0
		634	A	2.000545E+03	0.0	1.141204E+02	0.0	1.642552E+02	0.0	0.0
0	634	634	A	2.000545E+03	0.0	1.141297E+02	0.0	1.642950E+02	0.0	0.0
		635	B	1.902973E+03	0.0	1.280145E+02	0.0	1.537208E+02	0.0	0.0
0	635	635	A	1.902973E+03	0.0	1.280227E+02	0.0	1.537159E+02	0.0	0.0
		636	C	1.704318E+03	0.0	1.409326E+02	0.0	1.417071E+02	0.0	0.0
		636	B	1.704318E+03	0.0	1.426416E+02	0.0	1.402132E+02	0.0	0.0
		637	A	1.674151E+03	0.0	1.543590E+02	0.0	1.272441E+02	0.0	0.0
0	637	637	A	1.674151E+03	0.0	1.552750E+02	0.0	1.279135E+02	0.0	0.0
		638	B	1.545182E+03	0.0	1.634538E+02	0.0	1.153285E+02	0.0	0.0
0	638	638	A	1.545182E+03	0.0	1.634599E+02	0.0	1.153198E+02	0.0	0.0
		639	C	1.405367E+02	0.0	1.728807E+02	0.0	1.006345E+02	0.0	0.0
0	639	639	A	1.405367E+02	0.0	1.728840E+02	0.0	1.006254E+02	0.0	0.0
		640	B	1.265315E+03	0.0	1.810061E+02	0.0	8.517375E+01	0.0	0.0
0	640	640	A	1.265315E+03	0.0	1.810106E+02	0.0	8.516423E+01	0.0	0.0
		641	B	1.114894E+03	0.0	1.877444E+02	0.0	6.906404E+01	0.0	0.0
0	641	641	A	1.114894E+03	0.0	1.885781E+02	0.0	6.675406E+01	0.0	0.0
		642	C	9.57503E+02	0.0	1.936753E+02	0.0	5.006438E+01	0.0	0.0
0	642	642	A	9.587503E+02	0.0	1.930534E+02	0.0	5.242309E+01	0.0	0.0
		643	B	7.991766E+02	0.0	1.766877E+02	0.0	3.559789E+01	0.0	0.0
0	643	643	A	7.991766E+02	0.0	1.768895E+02	0.0	3.538769E+01	0.0	0.0
		644	B	6.367399E+02	0.0	1.992246E+02	0.0	1.809293E+01	0.0	0.0

SUPCASE=2

				FORCES IN BEND ELEMENTS				(ELEMENT)	
				- BENDING MOMENTS -		- SHEARS -		AXIAL	
ELEMENT-IO		GRID	END	PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
0	644	644	A	6.367399E+02	0.0	1.992255E+02	0.0	1.808261E+01	0.0
		645	B	4.726429E+02	0.0	2.000434E+02	0.0	6.501479E+01	0.0

1

SECTION 6.3

TUBE-TO-TUBE INSULATOR WATER FLOW TEST

Prepared by: P. H. Michels
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1.0 OBJECTIVE

The objective of the water flow test was to measure pressure drop values across the tube-to-tube insulator at different water flow rates.

2.0 TEST CONFIGURATION

The test set-up is shown in Figure 6-8. The source of water was a one-inch water main at the GDSS Harbor Drive Site in San Diego. Flexible hose connected the water main to the test set-up. Different size tubes and reducers were necessary to effect a smooth transition from the flowmeter to the first pressure transducer, then the insulator and finally the second transducer. Figures 6-9 and 6-10 are photographs showing the details of the set-up. The tube-to-tube high alumina ceramic insulator was obtained from the Alberox Corporation, New Bedford, MA 02745.

Prior to the test, calibration of the flowmeter was performed by establishing the time required to fill up a five gallon container.

Figure 6-8. Tube-to-Tube Insulator Water Flow Test Set-up

3.0 TEST EQUIPMENT

- 1.0 Flow Meter - Waugh Manufacturing Co., Model MT-141
- 2.0 Frequency Counter - Hewlett Packard, Model 5315A

Figure 6-9. Tube-to-Tube Insulator Water Flow Test Set Up

Figure 6-10. Tube-to-Tube High Alumina Ceramic Insulator

3.0 Pressure Transducers

- a) Inlet:
Trans-Sonics Co.
Potentiometer Type, Model 2467A
Range: 0-150 psi, Resistance: 7500 ohm
- b) Outlet:
Bourns Co.
Potentiometer Type, GDC P/N 27-01243-9
Range: 0-150 psi, Resistance: 7500 ohm

4.0 Two Digital Multimeters - Fluke Co., Model 8050A

4.0 TEST PROCEDURE

4.1 PRETEST CALIBRATION. The flometer was calibrated using water as a fluid and the test set-up to allow for the restriction of flow through the fittings and tube-to-tube insulator to be experienced in the actual test. To determine the total flow over a period of time, the test set-up outlet was directed into a five gallon container and the time to fill the container was noted, along with the frequency counter value. The following calibration data was taken:

Table 6-9
Flowmeter Calibration Data

<u>Frequency</u> <u>(Hz)</u>	<u>Time</u> <u>(minutes)</u>	<u>Flow Rate</u> <u>(GPM)</u>
24	3:56.42	1.270
51	2:29.88	2.006
64	1:58.96	2.530
77	1:38.56	3.051
91	1:22.73	3.639
99	1:16.98	3.917
124	1:01.98	4.871
149	:49.43	6.090

The above data is plotted in Figure 6-11. The slope of the line from the above is:

$$\text{slope} = (4.871 - 2.006) / (124 - 51) = .03924 \text{ GPM/Hz}$$

Maximum deviations from the calibration are +4.56%, -10.22%

4.2 TEST PERFORMANCE. The water flow rate for the test was increased in approximately even increments, from 24 Hz, .942 GPM (where the flowmeter was able to start measuring) to 151 Hz, 5.93 GPM (the maximum flow rate from the water source).

Figure 6-11. Pretest Calibration Results

65-9
CHANGE IN PRESSURE (PSI)

Figure 6-12. ΔP vs. Flow Velocity for Tube-to-Tube Insulator

The resistance measured from each pressure transducer was normalized to the 0 pressure resistance reading. The calibration for the pressure transducers was 0.02 psi/ohm.

The test results are summarized in Table 6-10.

The equations used for calculating flow rate (Q) and velocity (v) are:

$$Q = \text{flow} \times \text{slope} = \text{flow} \times .03924$$

$$A = \pi \times R^2 = 3.14 (.25"/[2 \times 12])^2 = .000341 \text{ ft}^2$$

$$v = (Q \times .002228) / A = Q \times 6.536$$

Table 6-10
Flow Test Results

Flow Hz	Flow Rate GPM	Velo- city ft/s	Inlet Pressure			Outlet Pressure			Press Drop psi
			Res ohm	/norm ohm	Press psi	Res ohm	/norm ohm	Press psi	
0	0	0	724	0	0	576	0	0	0
24	.942	6.15	804	80	1.60	594	18	.36	1.24
34	1.334	8.72	830	106	2.12	594	18	.36	1.76
49	1.923	12.56	873	149	2.98	594	18	.36	2.62
55	2.158	14.10	945	221	4.42	594	18	.36	4.06
60	2.355	15.39	973	249	4.98	594	18	.36	4.62
66	2.590	16.92	990	266	5.32	594	18	.36	4.96
76	2.982	19.48	1052	328	6.56	594	18	.36	6.20
85	3.336	21.80	1112	388	7.76	594	18	.36	7.40
95	3.728	24.36	1224.5	500.5	10.01	611	35	.70	9.31
105	4.121	26.93	1309	585	11.70	612	36	.72	10.98
116	4.552	29.74	1428.5	704.5	14.09	623	47	.94	13.15
127	4.984	32.56	1563	839	16.78	629	53	1.06	15.72
136	5.337	34.87	1682.5	958.5	19.17	630	54	1.08	18.09
146	5.729	37.43	1846	1122	22.44	642	66	1.32	21.12
151	5.926	38.72	2020	1296	25.92	643.5	67.5	1.35	24.57

The above data, pressure drop versus flow velocity, is plotted in Figure 6-12.

4.3 CALCULATIONS OF PRESSURE DROP. The following calculations were performed to verify the above measured results.

The pressure drop (head losses) occurs between the two pressure gauges. Figure 6-13 shows the layout and dimensions of the tubes and fittings in this area.

Figure 6-13. Layout and Dimensions of Tubing Between Pressure Gauges

The calculations were performed using the highest flow rate (5.926 GPM).

Worse case pressure drop occurs at abrupt contractions and at abrupt enlargements (the angle of reduction/enlargement is 90 degrees). For the worse case calculations, the angle of reduction/enlargement is assumed to be 90 degrees.

Table 6-11 shows the losses for each straight section of tubing (head loss due to friction, hlt). Refer to Figure 6-13 for the labeling of each section.

Table 6-11

Head Loss for Tube-to-Tube Insulator

Section	D (in)	A (in ²)	v (fps)	Re	$\frac{e}{D}$	f	hlt (m)
1	.38	.1134	16.76	5.0×10^4	1.5×10^{-4}	.0217	0.488
2	.21	.0346	54.94	9.0×10^4	2.8×10^{-4}	.0200	1.456
3	.23	.0415	45.81	8.2×10^4	2.5×10^{-4}	.0205	0.825
4	.25	.0491	38.72	7.5×10^4	2.4×10^{-4}	.0208	0.764
5	.23	.0415	45.81	8.2×10^4	2.5×10^{-4}	.0205	1.825
6	.21	.0346	54.94	9.0×10^4	2.8×10^{-4}	.0200	2.178
7	.38	.1134	16.76	5.0×10^4	1.5×10^{-4}	.0217	0.444
							8.980

$$V = (Q \times .002228 \times 144) / A = 1.901/A \quad \frac{\rho}{u} = 1.005 \text{ mm}^2/\text{s}$$

$$Re = \frac{\rho v D}{u} \quad \frac{e}{D} = \frac{k}{D} = \frac{.0015 \text{ mm}}{D} \quad hlf = \left(\frac{L}{D} \right) \left(\frac{v^2}{2 \times g} \right)$$

Where: Re = Reynold's number
 ρ/u = Kinetic viscosity
D = Diameter of tubing
 $e/D = K/D$ = Roughness coefficient
A = Area of cross-section of tubing
f = Friction factor (Moody chart)

Table 6-12 shows the data for the losses at the junction between the above sections (junction head loss, hlj).

Table 6-12
Junction Head Loss

Section Between	Kc	Ke	Kloss	Vc (fps)	Ve (fps)	Vloss (fps)	hlj (m)
1 & 2	.36			54.94			5.145
2 & 3		.05			54.94		0.286
3 & 4			.02			45.81	0.199
4 & 5			.02	54.94			0.199
5 & 6	.05			54.94			0.286
6 & 7		.50			54.94		7.146
							13.243

K = loss coefficient, subscript c for contraction, e for expansion

$$hlj = \frac{1}{2} \frac{v^2 k}{g}$$

$$hlt = hlf + hlj = 8.98 + 13.243 = 22.223 \text{ m}$$

$$\text{Total pressure drop} = 22.223 / .703 = 31.61 \text{ psig}$$

The above calculations were for the worst case of sudden expansions and contractions. Using an angle of 60 degrees instead of 90 degrees gives the following results:
(.07 used for loss of 60 degrees)

$$hl = 2 \times (.07 / .36) \times 5.145 + (.286 + .199) \times 2 + 8.98 = 11.95 \text{ m}$$

$$\text{Total pressure drop} = 11.95 / .703 = 17.00 \text{ psig}$$

5.0 CONCLUSIONS

The best and worst case theoretical values for pressure drop across the tube-to-tube insulator in our test set-up range from 17.00 psig to 31.61 psig, for the maximum flow rate of 5.926 GPM. The measured pressure drop for this flow rate was 24.57 psig.

It indicates that the pressure drop measurement corresponds reasonably well to classical fluid flow calculations. One may also want to note that the actual pressure drop across the tube-to-tube insulator by itself, free from all the reducing and expanding couplings, would be of the order of approximately 25 to 30 percent of what is presented in Figure 6-12.

6.0 REFERENCE

Fox, Robert W. and McDonald, Alan T., "Introduction to Fluid Mechanics", Second Edition, John Wiley & Sons, Inc., 1978.

Massey, B. s., "Mechanics of Fluids", Second Edition, Van Nostrand Reinhold Company, LTD, 1970.

SECTION 6.4

TUBE-TO-TUBE INSULATOR ELECTRICAL TEST

Prepared by: P. H. Michels
Electrical Engineer

Checked by: E. M. Leung

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1.0 OBJECTIVE

The objective of the tube-to-tube insulator electrical test was to find out the resistance degradation effect brought forth by having different types of water inside the tube. This insulator is used in the 18T insert coil water cooling circuit inlet and outlet.

2.0 TEST CONFIGURATION

The test set-up is shown in Figure 6-14. Several types of water were used. The water types used were deionized, distilled, Silver Springs drinking and San Diego city water.

The ends of the tube-to-tube insulator were plugged with corks to hold the water in.

The deionized water was tested first since it was the purest (least contaminants, least ions). A dry (air) run was also performed and used as a reference.

Figure 6-14. Tube-to-Tube Insulator Electrical Test Set-Up

3.0 TEST EQUIPMENT

1.0 Hypot Tester - Associated Research

2.0 Digital Multimeter - Fluke Co., Model 8810A

4.0 TEST PROCEDURE

The resistance of the tube-to-tube insulator was first measured in air with the digital multimeter.

The water coolant tube was filled with the water sample and corked. The resistance was measured with the digital multimeter whenever possible.

The HyPot leads were clipped onto the copper ends of the water coolant tube.

Applied voltage from the HyPot tester was increased slowly. Voltage readings were taken at a leakage current of 1.6 mA.

After the HyPot tester was turned off, the water was poured out and the inside of the insulator air dried.

The test was repeated with the other water samples.

5.0 TEST RESULTS

The test results are summarized in Table 6-13.

Table 6-13

Sample	Multimeter	V(V)	HyPot Tester	
	R(Ω)		I (mA)	R(Ω)
Air	2.00×10^7	--	--	--
Deionized	1.92×10^6	3500	1.6	2.19×10^6
Distilled	*	2600	1.6	1.63×10^6
Silver Springs drinking	*	270	1.6	1.69×10^5
San Diego city	*	110	1.6	6.88×10^4

*Note: There was a steady decrease of this resistive measurement, due to ionic contamination of the water while measurement was taken.

6.0 CONCLUSIONS

The tube-to-tube insulator gives the best performance when deionized water is used as the cooling medium. Distilled water may be used as a substitute when requirements are not as stringent.

SECTION 7

CONCLUSIONS

7.1 DESIGN STATUS

With the submittal of this report, two full years of conceptual design studies have been completed. The resistive insert coil has been the subject of comprehensive electrical, thermal and structural studies. Tests have been performed that confirm design details and manufacturing feasibility has been demonstrated. At this stage in the development, the magnet concept is ready for detail design and analysis as pertinent to a particular magnet application.

7.2 APPLICATIONS

The practicality of using a high alloy copper coil with metal oxide electrical insulation and a variable dimension conductor to obtain a variety of coil current density distributions has been studied and deemed practical. The technique is applicable to any number of magnet configurations in which superconducting material magnetic field limits are exceeded. These applications could include the toroidal field magnets of TOKAMAK fusion reactors as well as Mirror fusion reactors.

7.3 FUTURE R & D SUGGESTIONS

While the design concept reported herein is ready for full scale development, there are still a few items that could be pursued on an R & D basis to improve design confidence and establish an envelope of practical applicability.

1) Manufacturing Methods: The engineering model demonstration hardware was cut from Amzirc plate using electric spark discharge wire cutting. Another method, hydroabrasive cutting, offers the advantage of cutting speeds about ten times faster if larger turn-to-turn insulation spaces could be tolerated. Fabrication of a demonstration plate using hydroabrasive cutting would establish feasibility and provide a cost baseline for this method.

2) Material Properties: The Amzirc plate material should eventually be subjected to low cycle, unidirectional load, fatigue tests. Many magnet applications subject the coil material to 100% load cycles which might approach the material fatigue limit over the projected life of the magnet. If the magnet is to be load cycled any significant number of times, the fatigue limit must be established in order to assure safe, reliable operation.

3) Hydraulic Erosion: The water velocity in the coolant tube is 45 ft/sec. At this order of velocity, no erosion of the copper tube is expected. Because a greater velocity could enable the use of a smaller channel, knowing the erosion velocity would allow the design of a more optimized coil and result in a more economical design. Water erosion tests on cupronickel alloy would make a significant contribution to the design.

4) Full Scale Development: Eventually a full scale engineering prototype should be constructed. Unfortunately, the resistive insert would not perform as designed without the background 15 tesla field present. Therefore, both superconducting background coil and resistive insert would have to be developed at the same time or an existing background coil of appropriate dimensions would have to be found.