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RESEARCH SUPPORT FOR PLASMA DIAGNOSTICS ON

ELMO BUMPY TORUS⁹
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STUDY OF DIAMAGNETIC MEASUREMENTS FOR
THE ELECTRON RINGS AND DEVELOPMENT OF A
FERROMAGNETIC RESONANCE MAGNETOMETER

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October 1981

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ELECTROMAGNETICS

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ON ELMO BUMPY TORUS -
STUDY OF DIAMAGNETIC MEASUREMENTS FOR THE
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OF A
FERROMAGNETIC RESONANCE MAGNETOMETER

by

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October 1981

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ABSTRACT

The bumpy cylinder MHD equilibrium code which was compared to the concentric current sheet model for the EBT electron rings in a previous report has been subjected to additional numerical tests which confirm the validity of the previous work. Further analysis of the current sheet model as a means of calibration of the EBT diamagnetic diagnostic for perpendicular energy shows the model's simplicity is not the limiting factor in accuracy of the calibration. The fluctuations of the currents in the vacuum field coils were observed as voltage signals from the generator shunts. Significant low frequency components were observed that cannot be removed from diamagnetic signals by low pass filtering alone. A YIG magnetometer was developed and used to make test measurements of the diamagnetic field of the electron rings on EBT. The field values observed were on the order of 1 Gauss in a region where the vacuum field was about 600 Gauss. These values agree with the perpendicular energy diamagnetic flux diagnostic with reasonable assumptions for ring geometry.

FORWARD

This report covers the work performed during the period February 1, 1981, to September 30, 1981, under Basic Agreement No. 7676, Project Authorization No. X01, a subcontract from Union Carbide Corporation to the University of Missouri. This is the final report under this Project Authorization for this time period. The work was performed by the Principal Investigator, Dr. Kenneth H. Carpenter, with assistance from Mr. Marcus da Silva during the period February to September 1981. Dr. Carpenter is Associate Professor in the Department of Electrical Engineering of the University of Missouri - Rolla, and Mr. da Silva was a Graduate Research Assistant in that department.

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Research Support for Plasma Diagnostics on Elmo Bumpy Torus - Study of
Diamagnetic Measurements for the Electron Rings and Development of a
Ferromagnetic Resonance Magnetometer

I. INTRODUCTION

Methods for determining the parameters of the hot electron rings in EBT or Elmo type devices have received extensive study by several investigators.¹⁻⁴ Our efforts in regard to diamagnetic ring diagnostics for the period ending January 31, 1981, were reported previously.⁵ Our efforts since that date have been directed to three major topics: first, following up the previous work on comparing MHD equilibrium code calculations to current sheet model calculations, second, re-examining the current sheet model and revising the draft for the report to be issued thereon,⁶ and third, developing a new instrumentation for diamagnetic measurements - the YIG magnetometer.⁷ In the course of the YIG magnetometer diagnostic development, measurements were made of the fluctuations on the generator currents that produce the vacuum field of EBT. A test of the completed magnetometer system was made during EBT-S operation, and the limited data obtained on ring fields during the test has been correlated with the current sheet model. In the following we will describe the work done on each of these topics.

The MHD equilibrium model of the EBT rings, which was described previously,⁵ was subjected to additional test runs to check the sensitivity of the code results to various input parameters. This confirmed the results of initial runs that showed reasonable agreement with the current sheet model. No problems arose with these additional tests and a good agreement was reached between the two models when all factors were taken into account. Details are given in Section II below. A paper was presented at the IEEE International Conference on Plasma Science⁸ on this work, and this (poster session) paper is reproduced in Appendix A.

The draft for the ORNL-TM on the calibration of the perpendicular energy flux pickup loops⁶ was revised extensively after a restudy of the theoretical analysis of the drift current effect. Although no new conclusions were reached the formula used for drift current was given a more lucid explanation. Some of these considerations (not included in the ORNL-TM itself) are presented in Section III, while the abstract of the ORNL-TM is reproduced in Appendix C.

In order to have a design basis for discriminating between diamagnetic signals from the plasma and fluctuations in the confining vacuum field produced by the generator currents, a measurement of the fluctuations on the signals from the generator current shunts was carried out. Results of these measurements are presented in Section IV.

The development of a high field, incremental magnetometer based on ferromagnetic resonance in small YIG spheres was a major effort during this subcontract period. The instrumentation was developed and tested in the laboratory at UMR and was then given a test measuring the ring diamagnetic field during EBT operation at Oak Ridge. The instrumentation and its development will be described in Section V and an analysis of the test data obtained on EBT will be given. The magnetometer development served as the thesis project for one of the authors,⁷ and the abstract of the thesis is included as Appendix D. The computer code used in the analysis of the test data taken on EBT is listed in Appendix E.

II. FURTHER TESTS OF MHD BUMPY CYLINDER RING EQUILIBRIUM CODE AND COMPARISONS TO CURRENT SHEET MODEL

A bumpy cylinder MHD equilibrium computer code has been used to obtain a calibration between diamagnetic flux linking an external pickup loop and the perpendicular energy in an electron ring plasma. Preliminary results from this code were compared to a similar calibration factor obtained using a concentric current sheet model for the plasma in bumpy cylinder geometry, and agreement to within about 20% was obtained. As noted in the previous report⁵, the preliminary results from the MHD code needed further verification to ascertain whether or not numerical precision, finite difference mesh size, or certain numerical method parameters were influencing the result. These additional tests were made on the MHD code, and, while some changes in results were noted, the agreement with the current sheet model was retained. A further run was made with the MHD code to determine sensitivity of the result to pickup loop position, since the actual pickup loops are not placed on EBT in precisely the same relative location for each cavity. The compensation factor for the neighboring cavity effects in the bumpy current sheet model was calculated to make comparison of bumpy cylinder to bumpy torus results more meaningful. Finally, it was observed that the most significant factor in the agreement (or lack of it) between the models is the value assumed for mean magnetic field over the ring in the current sheet model and how that value should be related to fields at the ring position in the MHD model. Details on each of these topics follow. In addition the (poster session) paper presented on this subject at the 1981 IEEE International Conference on Plasma Science is reproduced in Appendix A, and the computer output from the additional test runs of the MHD code is given in Appendix B.

Numerical tests of the bumpy cylinder MHD equilibrium code

The four test runs of the MHD code, whose results were reported in the previous report, assumed four different sets of electron ring parameters to produce results of 2, 8, 18, and 23 percent ring "beta"

and triangular and trapezoidal electron distributions in the radial coordinate. Changing the ring parameters involves changing only the input parameters RSI1-4, BC, and S.⁹ Other input variables which affect the numerical method were not changed for these four test cases. In order to keep the ring parameters constant while checking effects of numerical method variables, all the additional test runs were made assuming a triangular electron distribution in radius with a beta of 2%, corresponding to the first case in the previous report.¹⁰ We shall refer to this case as Run 1 in what follows.

The first numerical test was to repeat Run 1 but with the code converted from single precision variables (32 bit words) to double precision (64 bit words). This was accomplished by use of the AUTODBL feature of the IBM FORTRAN IV-H(extended) compiler.¹¹ The result of this repeat of Run 1 in double precision (to be referred to as Run 2 - the computer outputs from Run 2 through Run 5 are given in Appendix B below) was to change nearly all the output numerical values in the third significant figure but to change the final values for flux linkage and perpendicular energy by 1/10 percent or less. Thus it was concluded that single precision runs were sufficient.

The next test was to reduce the size of the finite difference mesh by increasing the number of mesh points in the radial direction from 181 to 225 and the number in the axial direction from 42 to 52. The number of iterations on the outer and inner loops were also increased to converge to the equilibrium over this finer mesh. The result of this run (referred to as Run 3) was to change most numerical values in the second or third significant figure. The perpendicular energy calibration factor (for 5 kG central field) was changed from 32.4 J/V (for Run 1) to 29.3 J/V. While this change is enough to cause one to wish to pursue the effect of still smaller mesh sizes, it was judged unlikely that any qualitative conclusions would be affected (since agreement with the current sheet model was on the order of 20%, and the smaller mesh size tended to improve agreement). Further, to efficiently carry out the computations at smaller mesh sizes extensive rewriting of the computer code would be required in order to introduce

variable mesh size to allow smaller steps in the ring region than outside. This was deferred to a later project.

Next, Run 1 was repeated with input variable JCUT, which is the number of terms used in the multipole expansion to set the boundary condition, increased from 10 to 12, the maximum allowed by the code. The numbers output were identical to Run 1. Hence the use of JCUT=10 was sufficient.

For the last numerical test, two partially converged runs (shortened to 2 outer loop and 25 inner loop iterations) were made to check the effect of parameter RMSC used by the multipole expansion. No change occurred for RMSC changed from 8 to 4. Hence the value RMSC=8 used in Run 1 was retained.

Effects of small changes in pickup loop geometry

With the numerical questions settled, a repeat of Run 1 was made (to be called Run 4) with additional input lines added to produce output values for flux linkage for pickup loops having small changes in radius and axial location from that of Run 1. Results of these variations in pickup loops are summarized in Table 1. We note that the effect of loop radius change is minimal while a 1 cm change in axial position causes up to 3% change in flux linkage for this particular set of ring parameters. Thus lack of precision in placement of pickup loops could make a noticeable contribution to the uncertainty in loop calibration factor.

Effects of separation of mirror coils on flux-energy calibration factor

In the bumpy cylinder model used for the MHD code, one of the parameters is the separation of adjacent cavities - the separation of vacuum field coils. This separation affects both the mirror ratio of the confining field and the contribution of flux from rings in adjacent cavities to the diamagnetic flux linking the pickup loops.

axial location cm	radius cm	diamagnetic flux linked (normalized)	percent change
10.00	28.25	9.58	(Run 1 value)
10.56	28.25	9.45	-1.4
8.89	28.25	9.87	+3.0
10.00	30.25	9.55	-0.3
10.00	26.25	9.60	+0.2

Table 1. Effect of flux pickup loop axial distance (from center of midplane) and radius on linkage to ring diamagnetic flux.

It is not clear what separation makes the bumpy cylinder most like the bumpy torus since all factors cannot be made to agree simultaneously. The separation variable input to the code is SEP which had the value 44.45 for all runs described thus far. One last run was made (to be called Run 5) with SEP set to 39.00. Significant changes in both perpendicular energy and flux linkage were obtained with the other parameters fixed as for Run 1. The flux loop calibration factor was reduced from 32 J/V for Run 1 to 23 J/V for Run 5. However, when properly interpreted there is no contradiction.

First, the total perpendicular energy increase was due to an increase in the equilibrium beta from 2% to 3.5% for the same cutoff field, BC, in the ring pressure model. This in turn was due to the change in vacuum field with chosen coil spacing.

Second, the decrease in flux loop calibration, while due in part to the trend to lower values for higher beta, was intensified by the increased contribution due to the rings in neighboring cavities. To make a meaningful comparison of pickup loop calibration for different separations or between bumpy cylinder and bumpy torus the flux linkage

due to the neighboring cavities must be separately calculated and compensated for the effect of the neighbors.

Since the MHD equilibrium code does not provide any means for removing the flux contribution due to rings in neighboring cavities, the current sheet model in bumpy cylinder geometry (code BUMCAL)¹² was used to take this effect into account. The results obtained were that for SEP=39 the total diamagnetic flux linking the pickup loop was 1.63 times the flux due only to the ring in the cavity about which the loop was placed, while for SEP=44.45 this ratio was 1.46. In the current sheet model for EBT¹³ the corresponding ratio is approximately 1.5. Thus using these ratios to infer perpendicular energy per volt from the pickup coil with only flux from a single cavity producing the signal, one finds (for 5000 Gauss vacuum field at the center of the midplane) the values 38 J/V for the bumpy cylinder MHD equilibrium with SEP=39 and 46 J/V for the bumpy cylinder MHD equilibrium with SEP=44.45. Thus the difference attributable to different magnetic geometry and ring beta between the two separations, while still significant, is reduced from the values obtained with neighboring cavity linkages included.

Final observations reconciling current sheet and MHD ring models

The current sheet model gives identical results in either toroidal or cylindrical geometry if the same ring radius and average field is used and if compensation for the neighboring cavity flux linkages is included in the calculation. The questions then remain as to, first, why the bumpy torus and bumpy cylinder current sheet model flux pickup loop calibration factors are different, and, second, why the current sheet and MHD code values are different. The first question is easily answered when one observes that the particular ring model used in the bumpy cylinder code tests differed in values assumed for average magnetic field over the ring from the values in the bumpy torus cases, even though the field at the center of the midplane was the same for each (5000 Gauss). The second question does not have such a definitive answer, but one can surmise that the discrepancy

between the bumpy cylinder current sheet value of 26 J/V (for SEP=44.45 and neighboring cavity flux included) and the MHD value of about 32 J/V is due to the choice of average magnetic field over the ring for the current sheet model - the value of 26 J/V results when the average field is taken as the value at the center of the ring in the midplane. However, by looking at the magnetic field contours one can see that for low beta rings of appreciable length the average field must be greater than this value. If one uses the field value near the inner edge of the ring in the midplane for the average field in the current sheet model one obtains agreement with the MHD value of 32 J/V.

In conclusion, although not all uncertainties were resolved, we feel the current sheet model results are confirmed and reinforced as to validity by the MHD equilibrium code calculations.

III. REVISION OF DRAFT FOR ORNL-TM ON CALIBRATION OF EBT PERPENDICULAR ENERGY DIAGNOSTIC

The draft for the ORNL-TM,⁶ originally written in 1979, on calibration of the EBT ring perpendicular energy flux pickup loop diagnostic by use of a current sheet ring model was revised in preparation for its issuance. The changes consisted in rewriting the section where the drift current effect is derived, and writing a new concluding section taking advantage of the insight gained from the studies of the MHD equilibrium ring model discussed above. The computer code, WPER1, documented by this ORNL-TM was also revised to use more efficient numerical techniques for the calculations and to correct minor "bugs" (which had no significant effect on the numerical results). The complete code listing is given in the ORNL-TM and so is not included here. The abstract of the paper is reproduced in Appendix C.

Further comments on drift current calculation

The drift current was calculated in the current sheet model from the single particle drift velocity.¹⁴ Assuming a constant electron dipole moment density, M , the result derived for equivalent drift surface current density was

$$j_d = M \ln(B_1/B_2) \quad (1)$$

where B_1 is the greater and B_2 the lesser of the mod B values at the inner and outer radial edges of the electron ring (in the midplane). Of course, the actual electron ring will not have such a rectangular distribution of M versus radius. To see how a non-uniform M might affect the drift current we carried out the integration in radius, r , for the drift current assuming a triangular distribution for M over a thickness Δr at mean radius r_m .

$$M = \begin{cases} \frac{2M_m}{r}(r - r_m + \Delta r/2), & r_m - \Delta r/2 < r < r_m \\ \frac{-2M_r}{r}(r - r_m - \Delta r/2), & r_m < r < r_m + \Delta r/2 \\ 0 & , \text{ otherwise} \end{cases} \quad (2)$$

We also assumed B is linear with r in this region.

$$B = B_m - (r - r_m)\Delta B/\Delta r, \Delta B > 0 \quad (3)$$

$$\text{or } dB = -dr(\Delta B/\Delta r) \quad (4)$$

Thus the integral for drift current became

$$\begin{aligned} j_d &= \int M \frac{|dB|}{|B|} \\ &= \int_{r_m - \Delta r/2}^{r_m} \frac{2M_m}{\Delta r} \frac{(r - r_m + \Delta r/2)}{[B_m - (r - r_m)(\Delta B/\Delta r)]} dr \\ &\quad + \int_{r_m}^{r_m + \Delta r/2} \frac{-2M_m}{\Delta r} \frac{(r - r_m - \Delta r/2)}{[B_m - (r - r_m)(\Delta B/\Delta r)]} dr \end{aligned} \quad (5)$$

Carrying out the integration using the relationship

$$\int \frac{x - a}{c - x} dx = (a - c)\ln(c - x) - x, \quad (6)$$

after much algebra gave the result

$$j_d = M_m \left[\left(1 + \frac{2B_m}{\Delta B}\right) \ln\left(1 + \frac{\Delta B}{2B_m}\right) - \left(1 - \frac{2B_m}{\Delta B}\right) \ln\left(1 - \frac{\Delta B}{2B_m}\right) \right]. \quad (7)$$

For $\frac{\Delta B}{B} \ll 1$ this expands to lowest order to

$$j_d = M_m \frac{\Delta B}{B} \quad (8)$$

which looks like the formula to which Eq. (1) for the rectangular distribution reduces when $\Delta B = B_1 - B_2$ is small compared to $B_m = (B_1 + B_2)/2$. Thus, at least for low beta cases, this indicates the assumption of a constant dipole moment density - and hence a current sheet model - for the rings should yield valid results for drift current.

IV. MEASUREMENT OF THE FLUCTUATIONS ON THE EBT GENERATOR CURRENTS

In the course of designing the YIG magnetometer instrumentation to be described below it was necessary to know the level of fluctuations in time to be expected on the EBT vacuum confining field. These were measured by observing the voltage signal from the generator current shunts while the EBT field was energized at operating conditions with 5000 A and 7200 A current.

The generator current shunt signals were observed at the outputs of buffer amplifiers having low output impedance and calibrated to give a signal output of 1 volt per 1000 amperes of generator current. The observations were made using a Tektronix model 434 storage oscilloscope. As the fluctuation level was too low to observe on top of the 5 or 7 volt DC level directly, the oscilloscope was set for AC input and the vertical gain increased to 1 mV per division. The AC input to similar oscilloscopes typically have coupling capacitors of about 0.1 μ F and input impedance of about 1 M Ω giving a low frequency roll-off with the 3 dB point between 1 and 10 Hz. The calibrations of either the horizontal or vertical scales on the oscilloscope were not checked.

The observation on the current of generator no. 12 was typical. While the DC current was 5000 A the current shunt signal showed a ripple of approximately 1 mV peak to peak (=1 A) with a 10 mS period (100 Hz). (One conjectures that with a calibrated time scale this would have been 120 Hz.) This ripple had a pronounced third harmonic present (approximately 50% harmonic distortion). Setting the horizontal sweep to 0.1 S/div and using the oscilloscope storage feature, one could observe a lower frequency ripple of 0.2 mV peak to peak with a 0.1 S period. As this is near the input coupling 3 dB point the actual 10 Hz component may have been greater. Using even slower sweep rates one observed a 1 Hz signal of about 0.2 mV - but input roll-off must have a serious effect at this low a frequency.

Observation of current from generator no. 11 showed a more erratic behavior with disturbances of around 4 mV occurring with a 5 S period in addition to the higher frequency ripple seen on generator no. 12. Generator no. 10 had the least ripple, while no. 9 was fairly erratic also. When the DC currents were increased to 7200 A no qualitative changes in the ripple were noted.

With this information it was decided to filter the YIG magnetometer instrumentation to a cutoff of about 1 Hz in order to eliminate the effects of higher frequency vacuum field fluctuations. The low frequency, erratic field fluctuations still presented a problem however. This is discussed in the following section.

V. DEVELOPMENT OF A HIGH FIELD, INCREMENTAL MAGNETOMETER BASED ON FERROMAGNETIC RESONANCE IN SMALL YIG SPHERES

Diamagnetic flux pickup loops have been used on EBT as a ring energy diagnostic since the beginning of the experiment. However, the importance of the rings in the EBT concept suggests that another independent confirmation of the data from these energy diagnostic loops would be desirable. The need for a diagnostic for the geometry of the electron rings in EBT has been apparent for years but no simple approach to this problem has been found. Studies have indicated that diamagnetic measurements made outside the plasma could provide information on geometry but most likely could not determine all the parameters in even the simplest ring model. Further, to be useful, the diamagnetic field measurements require high precision in the difficult magnetic environment of the vacuum field. The YIG-tuned filter concept used in microwave applications suggested a possible magnetometer design that could meet the requirements for a ring diagnostic.

YIG magnetometer design

Ferromagnetic resonance in small spheres (either single crystal or polycrystalline) of yttrium iron garnet (YIG) provides a convenient basis for point measurement of magnetic fields in the presence of high field gradients. Single crystal probes yield the highest resolution for incremental measurements but anisotropy effects make absolute measurements difficult. Polycrystalline probes allow absolute measurement of magnetic field magnitude without knowledge of field direction. Although the resonance in polycrystalline YIG spheres is broad (50 to 500 Gauss) compared to single crystal spheres (1 to 10 Gauss), resolutions of one-half Gauss or better can be obtained with polycrystalline probes by utilizing the phase characteristic of the resonance in a phase locked loop. The design of an appropriate magnetometer probe and accompanying instrumentation to implement this concept formed the M.S. thesis topic for one of us.⁷ One should refer

to this thesis for details of the design and literature references. The thesis abstract is reproduced in Appendix D of this report.

The YIG magnetometer consists of a probe and microwave instrumentation. The YIG magnetometer probe is a small YIG sphere (either single crystal or polycrystalline) mounted in the center of orthogonal one turn RF pickup loops. These loops are attached to a brass block which serves as a ground plane, and to coaxial transmission lines. The transmission coefficient through this probe is observed with a network analyzer and S-parameter test set driven by a microwave sweep generator. A resonance maximum in transmission amplitude occurs at a frequency given by the linear relationship $f = \gamma B + C$ where $\gamma = 2.8 \text{ MHz/Gauss}$, B is the magnitude of the magnetic flux density vector at the probe, and C is a constant dependent on probe orientation and temperature. Passing through the resonance frequency causes a phase shift of 180 degrees in the transmitted signal from the probe. A phase lock circuit is used to hold the sweep oscillator frequency to the resonance, and the frequency is read directly from a counter. In addition the control voltage to the sweep oscillator is displayed on an oscilloscope to give a continuous view of frequency and hence B .

YIG magnetometer test on EBT

During the week of July 13 the YIG magnetometer measurement system, which had been assembled and tested at UMR, was brought to Oak Ridge, installed on EBT, and given a test in actual diamagnetic and vacuum field measurement during EBT operation. The measurement system performed as expected and was capable of observing the diamagnetic field at the outside of the plasma. Because of concentration of EBT time on the ICRH experiment no systematic study of the rings could be made. However, we were able to verify the validity of the YIG magnetometer concept as a ring diagnostic and to identify problem areas for further work.

Data was taken at three probe locations, all along the outside of cavity W5 on EBT (no. 23 in computer data base). The probe was oriented to have the YIG sphere in the horizontal midplane as near the cavity outer surface as possible and located at different distances from the vertical midplane. If we label distance from the cavity center line toward the outside of the torus as R and distance along the toroidal axis from the vertical midplane as Z then the three probe locations had approximate values in centimeters of

location 1: R = 30, Z = 1.3

2: R = 31, Z = 7.3

3: R = 28, Z = 11.4

(For location 1, Z = 0 was correct when the probe was first placed on EBT but the location slipped during operation on July 15 to Z = 1.3 which then remained a stable location.)

In order to determine the value of the constant C for probe location 1 in the equation $f = \gamma B + C$, readings were taken of resonant frequency as the vacuum field current was increased:

current(amp)	frequency(MHz)
4000 $\pm$ 1	822
5000 $\pm$ 5	1064
7250 $\pm$ 50	1608

A straight line through the frequency versus current values gives $C = -145.3$ MHz and hence the formula valid for this probe position and temperature is $B = (f + 145)/2.8$, where f is in MHz and B in Gauss. The vacuum field at probe location 1 during EBT-S operation (7250 A) is thus 626 Gauss. This is a field to current ratio of 0.086 Gauss/A. From calculated tables of field versus position (made using computer code FULT in December 1976) one finds that the radial location of the probe should be R = 30 cm to give this field to current value. This agrees with the physical location of the probe.

Data taken with the probe at location 1 on plasma turn downs for which $W_{\perp}$ values (voltage signals from diamagnetic flux pickup loop integrators) were also available are given in Table 2. Lack of consistency between ΔB and ΔV is obvious. Seven other plasma

Date - time	B (Gauss)	W (volts) for W5	W (volts) corrected			
			W4	W5	W6	
7/15 2:59	1.5	0.36				
7/15 4:17	1.0	0.33				
7/16 10:08	1.21	0.355	0.226	0.209	0.219	
7/16 10:23	1.42		0.217	0.194	0.202	
7/16 10:36	1.07	0.324	0.291	0.185	0.189	

Table 2. Diamagnetic data from plasma turn downs.

turn-downs were observed with the YIG probe in location 1 but no corresponding ΔV readings were available due to integrator drift causing the values to be off scale. All readings on 7/16 were for a plasma of 100 KW @ 28 GHz, 7250 A generator current, and pressure value 4.7×10^6 T; the readings were made by turning the plasma pressure to a high value manually to destroy the rings.

At probe position 2 one reading was taken for the same plasma conditions as the readings at position 1. The value was $\Delta B = 1.03$ Gauss for a $W_{\perp}$ reading of 0.342 V and corrected $W_{\perp}$ values of 0.226, 0.196, 0.207 V for W4, W5, W6 respectively. (Corrected values are the voltages that would have been read if only the ring in the corresponding cavity had been present and producing flux. The values were obtained from computer code RUNDWN on the PDP-10, which is an adaption of code EBTOFF for the new EBT data base.)

At probe position 3 three readings of ΔB were obtained but only one had corresponding $W_{\perp}$ values - it gave $\Delta B = 1.03$ G, $W_{\perp}$ reading 0.371 V, and corrected $W_{\perp}$ values 0.222, 0.224, 0.206 V for W4, W5, W6 respectively.

Analysis of data using current sheet model

Analysis of this data in terms of the concentric current sheet model for the rings was carried out by writing a computer code WPERB based on the code WPER1 which calculates perpendicular energy calibration values. (A listing of WPERB is given in Appendix E.) WPERB takes as input the corrected $W_{\perp}$ readings for the central cavity (W5) and the two adjacent cavities (W5 & W6) and the assumed ring parameters. It outputs the ΔB field components at the specified probe location. The ring parameters can be changed until agreement is obtained between calculated and observed ΔB .

The ΔB values obtained with the YIG magnetometer system are actually changes in magnitude of total B field, assuming the direction of B relative to the probe is constant or varies less than a prescribed tolerance. For the EBT measurement $\Delta B \approx 1$ while $B \approx 600$. This means that the ΔB value observed by the magnetometer is, to a high degree of accuracy, the component of the diamagnetic flux density vector in the direction of the vacuum field. (This can be seen easily with the aid of a vector diagram.) The measurement at probe location 1 had the vacuum field approximately in the Z direction. Hence $\Delta B = B_z$. At locations 2 & 3 a calculation of the vacuum field is necessary to interpret the data quantitatively - this remains to be done. However, a qualitative look at the arrow plots for ring field (produced by code FM2PLT) and the field lines of the vacuum B indicates that the diamagnetic field is still close to parallel to the vacuum field at these locations. This accounts for the observed ΔB staying large where B_z should be significantly reduced in size.

For quantitative analysis we took the mean of the three readings at probe location 1 where corrected $W_{\perp}$ voltages are available. The mean readings are $\Delta B = 1.23 \pm .17$, $W_{\perp}$ corrected values $0.221 \pm .004$, $0.196 \pm .012$, $0.203 \pm .015$. Using the corrected $W_{\perp}$ values as input to WPERB we chose various combinations of ring parameters mean radius, RR, thickness, RT, and length, AL, and observed how ΔB compared to the value B_z output by WPERB. (In all cases examined here the drift

current factor, DF, was set automatically at the theoretical value based on the vacuum field.) Fig. 1 shows the results for BZ versus AL with RT = 5 cm and RR = 12.3 cm. Although there is some variation of BZ with AL the desired value of BZ = 1.23 is not on the plot; hence RR or RT must be increased. Fig. 2 shows BZ versus RT with RR = 12.3 cm and AL = 5 cm. In this case the solution for BZ = 1.23 occurs at RT = 9 cm. However, Fig. 3 also gives a solution for different RT. Fig. 3 shows BZ versus RR with AL = 5 and RT = 5. In this case BZ = 1.23 for RR = 13.7 cm. Repeating the plots with different values for the fixed parameters would yield still different solutions. Thus although the ΔB value at probe position 1 provides independent information from the W_1 values, this information is still not enough to give a unique solution for the model parameters.

Quantitative analysis of the ΔB values observed at probe positions 2 and 3 have not been carried out since no new information is anticipated due to, first, the problem of low frequency fluctuation on generator currents remaining to be resolved, and, second, because on the basis of the earlier studies using the current sheet model these values are not expected to provide independent information from that obtained at probe position 1 unless a high degree of accuracy is obtained. This does not mean, however, that field measurements at alternate locations should not be made, for the current sheet model is probably inadequate to represent the field away from the midplane, if the results of measurements on STM¹⁵ are valid for EBT. Further, measurements of ΔB along the opposite side of the midplane (towards the center of the torus) should yield additional insight into ring structure. Thus ΔB measurements at multiple locations are desirable.

Conclusions from tests, and recommendations

The preliminary tests of the YIG system on EBT are encouraging enough to warrant planning for an improved, permanent YIG magnetometer diagnostic set-up. In addition to adding compensation for erratic, low frequency generator caused vacuum field fluctuations (higher frequency fluctuations - above about 1 Hz - are effectively removed by

FIG. 1. B_z AT PROBE POSITION 1 VS. AL WITH $RR = 12.3$
FOR CHOICES OF $RT = 2, 5, \text{ AND } 8$.

YIG PROBE DATA ANALYSIS

ORNL DWG 81-23350

FIG. 2. BZ AT PROBE POSITION 1 VS. RT WITH RR = 12.9, AL = 5.

YIG PROBE DATA ANALYSIS

ORNL DWG 81-23351

FIG. 3. BZ AT PROBE POSITION 1 VS. RR WITH RT = 5, AL = 5.

filtering in the phase locked loop and counting) the YIG measurement system can be improved by incorporating an output signal to the EBT data acquisition system, and by designing automatic lock acquisition circuitry. The capital equipment needed to construct a permanent YIG magnetometer diamagnetic ring diagnostic system for EBT-I/S would cost between \$15,000 & \$17,000 for a minimum configuration that could measure in a vacuum field up to 920 Gauss. For approximately an additional \$5,000, more versatile microwave equipment could be substituted which would have the capability for measurement in vacuum fields up to 6400 Gauss (by addition of proper plug-in units at additional cost).

In conclusion, we note that this preliminary test of the YIG magnetometer measurement system on EBT was successful in demonstrating that the instrumentation will function and give useful readings in the EBT environment. The data obtained is consistent with the diamagnetic flux data of the $W_{\perp}$ measurement, which is an independent confirmation of the correctness of the $W_{\perp}$ loop electrical calibration. The data from the YIG probe provides an independent piece of information on ring geometry, but in itself is not sufficient to fix all parameters in a simple ring model. The instrumentation could be improved to eliminate the effects of generator fluctuations and a permanent installation made on EBT for a capital cost in the range of \$15,000 - 22,000. Since the capital equipment would be useful as general laboratory instrumentation in any case, this would seem to be a reasonable investment as a part of ring diagnostics.

VI. FINAL COMMENTS

The work reported above has covered a wide range of topics from experimental instrumentation design to MHD equilibrium code evaluations. All these efforts have been directed to the goal of a better understanding of the structure and energy content of the EBT electron rings. While none of the topics discussed are closed in the sense that more work could not be done on them, some are obviously in need of more study than others.

There remains much to be done in refining and exploiting 2-d and 3-d MHD equilibrium codes for the rings. However it is unlikely that further insights would be gained into the validity of using simple electron distribution models, such as the current sheet model. Hopefully one might learn better ways to parameterize an ad hoc model by more MHD studies. This still remains to be done.

The calibration of the signal from the diamagnetic flux pickup loops in terms of ring perpendicular energy has been completed insofar as the current sheet model can be used. Further, this calibration has been shown to be consistent with the measurement of the diamagnetic field with the YIG magnetometer. No additional work is anticipated in this topic.

The observations of the generator current fluctuations were made in a short time near the end of a visit to ORNL using readily available instrumentation. A more careful study of this phenomenon should be made with a view to finding possible ways to reduce the effects on plasma diamagnetic diagnostics and to identifying any other diagnostics besides the diamagnetic ones that might be affected thereby.

The YIG magnetometer system needs to be improved to include compensation for generator fluctuations. Along with this improvement other refinements in design detail can also be made and additional applications explored. Work will continue in this direction as

funding permits.

These investigations have brought new insights on ring diagnostics and their interpretations. It is hoped that further progress can be made in each area in the future.

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APPENDIX A

COMPARISON OF FLUX-ENERGY CALIBRATIONS FOR DIAMAGNETIC DIAGNOSTIC OF EBT ELECTRON RINGS FOR MHD AND CURRENT SHEET MODELS - 1981 IEEE INTERNATIONAL CONFERENCE ON PLASMA SCIENCE, PAPER 1P4.

The following 16 pages are a reproduction of the poster paper as presented in Santa Fe, New Mexico, on May 18, 1981.

1P4: COMPARISON OF FLUX-ENERGY CALIBRATIONS FOR DIAMAGNETIC DIAGNOSTIC OF EBT ELECTRON RINGS FROM MHD AND CURRENT SHEET MODELS.--KENNETH H. CARPENTER, UNIVERSITY OF MISSOURI - ROLLA*.

DIAMAGNETIC FLUX LINKING PICKUP LOOPS PROVIDES A USEFUL INDICATION OF PLASMA STORED ENERGY. TO OBTAIN QUANTITATIVE ENERGY VALUES FROM DIAMAGNETIC SIGNALS REQUIRES KNOWLEDGE OF THE PLASMA GEOMETRICAL DISTRIBUTION RELATIVE TO THE PICKUP LOOP AND KNOWLEDGE OF THE TOTAL MAGNETIC FIELD IN THE REGION OCCUPIED BY THE PLASMA. THE ENERGY-TO-FLUX CALIBRATION FACTOR CAN BE MADE INSENSITIVE TO DETAILS OF THE PLASMA GEOMETRY BY PROPER PLACEMENT OF PICKUP LOOPS. IN THE ELMO BUMPY TORUS EXPERIMENT (EBT), DIAMAGNETIC FLUX PICKUP LOOPS ARE PLACED ON EACH OF THE TWENTY-FOUR MIRROR SECTIONS IN SUCH A WAY AS TO APPROXIMATE A HELMHOLTZ COIL CONFIGURATION. THESE LOOPS PROVIDE THE PRIMARY DIAGNOSTIC FOR THE PERPENDICULAR ENERGY OF THE ENERGETIC ELECTRON RINGS. (1) CALCULATION WITH A SIMPLE CURRENT SHEET MODEL DEMONSTRATES THE INSENSITIVITY OF THE COUPLING OF THE RING PLASMA DIPOLE MOMENTS TO THE FLUX PICKUP LOOPS ON EBT. ACTUAL ENERGY CALIBRATION REQUIRES ASSUMPTIONS ON THE TOTAL MAGNETIC FLUX DENSITY AND THE MAGNETIC EFFECTS OF PLASMA DRIFT CURRENTS. CROSS COUPLING BETWEEN ADJACENT CAVITIES CONTRIBUTES ABOUT A THIRD OF THE SIGNAL AND MUST BE TAKEN INTO ACCOUNT.

IN ORDER TO ASSESS THE EFFECTS OF THE CRUDENESS OF THE CURRENT SHEET MODEL OF THE ELECTRON RINGS ON THE FLUX-ENERGY CALIBRATION, THE RESULTS FROM THE CURRENT SHEET MODEL HAVE BEEN COMPARED TO CALCULATIONS OBTAINED FOR AN ANALOGOUS "BUMPY CYLINDER" (HENCE TWO-DIMENSIONAL) MHD EQUILIBRIUM CODE. THE CODE DUE TO HEDRICK (2) HAS BEEN MODIFIED TO OUTPUT RING ENERGY AND FLUX LINKING THE PICKUP LOOP LOCATION, AND RUNS HAVE BEEN MADE FOR SEVERAL LIKELY RING PLASMA CONFIGURATIONS. IN EACH CASE CLOSE AGREEMENT IS FOUND TO THE ENERGY-FLUX CALIBRATION FACTOR OBTAINED FROM THE CORRESPONDING CURRENT SHEET MODEL IN "BUMPY-CYLINDER" GEOMETRY. RESULTS SHOWING THE RELATIVE UNCERTAINTIES AND SENSITIVITIES TO GEOMETRY IN THE CALIBRATION FACTOR WILL BE PRESENTED.

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Section through EBT-I in the horizontal midplane. Solid lines indicate surfaces of constant $|B|$, and dotted lines indicate flux lines. Shaded areas are regions of cyclotron resonance for electrons when $B_0 = 4.55$ kG.

CURRENT SHEET MODEL IN BUMPY TORUS GEOMETRY

CURRENT SHEET MODEL IN BUMPY CYLINDER GEOMETRY

CURRENT SHEET MODEL - BASIC FORMULAS

- (A) VECTOR POTENTIAL OF A CURRENT SHEET (PER UNIT SURFACE CURRENT)

$$A_{\phi}(\rho, z) = \frac{\mu_0}{4\pi} \int_{z-L/2}^{z+L/2} dz' \int_0^{2\pi} d\phi' \frac{\cos \phi'}{\sqrt{\rho^2 + z^2 + a^2 - 2a\rho \cos \phi'}}$$

WHICH REDUCES TO ELLIPTIC INTEGRALS.

- (B) FLUX LINKAGE OF 1 TURN PICKUP LOOP TO ONE CURRENT SHEET (PER UNIT SURFACE CURRENT)

$$\Phi_1 = \oint \bar{A} \cdot d\bar{l}$$

- (C) COMBINED FLUX LINKAGE FROM INNER AND OUTER CURRENT SHEETS USING

$$j_{s \text{ outer}} = M \left(1 + \frac{\Delta B}{2B} \right)$$

$$j_{s \text{ inner}} = M \left(1 - \frac{\Delta B}{2B} \right)$$

IS
$$\Phi = \Phi_{1, \text{out}} M \left(1 + \frac{\Delta B}{2B} \right) - \Phi_{1, \text{in}} M \left(1 - \frac{\Delta B}{2B} \right)$$

- (D) PERPENDICULAR ENERGY

$$\mathcal{E}_{\perp} = M \cdot B_{\text{avg}} \cdot \text{vol}$$

- (E) CALIBRATION FACTOR $\mathcal{E}_{\perp} / \Phi$

$$\mathcal{E}_{\perp} / \Phi = \frac{B_{\text{avg}} \cdot \text{vol}}{\Phi_{1, \text{out}} \left(1 + \frac{\Delta B}{2B} \right) - \Phi_{1, \text{in}} \left(1 - \frac{\Delta B}{2B} \right)}$$

(JOULE/WEBER)

2D - MHD EQUILIBRIUM - BASIC FORMULAS

(REF: NELSON & HEDRICK, NUCL. FUSION 19, 283 (1979).

COMPUTER CODE ITERATES TO SOLUTION OF

$$\Delta^* \psi_p + \nabla(\ln \sigma) \cdot \nabla \psi_p = \frac{r^2}{\sigma} \frac{\partial p_{||}}{\partial \psi} - \nabla(\ln \sigma) \cdot \nabla \psi_c$$

WHERE

$$\sigma = 1 + (p_{\perp} - p_{||})/B^2$$

$$\psi = \psi_p + \psi_c$$

 ψ_c IS VACUUM FLUX FUNCTION ψ_p IS DIAMAGNETIC FLUX

PRESSURE MODEL IS

$$g(\psi) = \begin{cases} (\psi - \psi_1)^2 (\psi + \psi_1 - 2\psi_2)^2 / (\psi_2 - \psi_1)^4, & \psi_1 \leq \psi \leq \psi_2 \\ 1, & \psi_2 \leq \psi \leq \psi_3 \\ (\psi - \psi_4)^2 (\psi + \psi_4 - 2\psi_3)^2 / (\psi_3 - \psi_4)^4, & \psi_3 \leq \psi \leq \psi_4 \\ 0, & \text{OTHERWISE} \end{cases}$$

AS THE FLUX FUNCTION AND

$$p_{\perp} = \frac{1}{2} S (B_c^2 - B^2) g(\psi)$$

$$p_{||} = \frac{1}{2} S (B_c - B)^2 g(\psi)$$

AS THE PRESSURE FUNCTIONS.

INPUT TO THE COMPUTER CODE FIXES MIDPLANE RADIAL LOCATIONS OF $\psi_1, \psi_2, \psi_3, \psi_4$ AND SUPPLIES VALUES OF B_c, S AND PARAMETERS

FOR THE NUMERICAL METHOD. BOUNDARY CONDITION ARE SET BY A

MULTIPOLE EXPANSION. THE RESULTING PERPENDICULAR ENERGY CALIBRATION FACTOR IS PROPORTIONAL TO $\sum p_{\perp} / \psi_p$ WITH ψ_p

THE VALUE AT THE PICKUP LOOP.

BASIS FOR EQUATING "BUMPY TORUS" & "BUMPY CYLINDER"

FLUX LINKAGE OF A PICKUP LOOP TO RINGS IN ADJACENT CAVITIES CAN BE CALCULATED. ASSUMING IDENTICAL RINGS, ONE FINDS FOR EBT "BUMPY TORUS" GEOMETRY THAT FLUX LINKAGE DUE TO THE RING IN SAME CAVITY AS THE PICKUP LOOP ALONE IS APPROXIMATELY $2/3$ OF THE TOTAL FLUX LINKAGE DUE TO ALL RINGS. TO GIVE AN EQUIVALENT "BUMPY CYLINDER" THE SEPARATION BETWEEN CAVITIES IS CHOSEN TO MAKE FLUX LINKAGE DUE TO THE RING IN SAME CAVITY AS THE PICKUP LOOP, AGAIN, APPROXIMATELY $2/3$ OF THE TOTAL FLUX LINKAGE.

THE "BUMPY TORUS" AND "BUMPY CYLINDER" MAGNETIC GEOMETRIES ARE STILL NOT IDENTICAL. FOR COMPARISON OF EBT AND CYLINDRICAL GEOMETRY CALIBRATION RESULTS, THE MEAN RADII ASSUMED FOR THE RINGS ARE TAKEN THE SAME AND PICKUP LOOP PLACEMENT RELATIVE TO THE RINGS IS TAKEN APPROXIMATELY THE SAME.

THE MAGNETIC FIELD VALUES CANNOT BE TAKEN THE SAME AT THE CENTER OF THE MIDPLANE FOR BOTH THE BUMPY CYLINDER AND BUMPY TORUS IF EQUIVALENT RESULTS ARE TO BE OBTAINED FOR RING ENERGY CALIBRATION. INSTEAD THE MEAN MOD B VALUES OVER THE ELECTRON DISTRIBUTIONS MUST BE MADE EQUAL BY PROPER CHOICES OF THE MIDPLANE VALUES.

RESULTS FROM CALCULATIONS --

CURRENT SHEET MODEL - (EFFECTS OF ALL CAVITIES INCLUDED) -

WITH RING MEAN RADIUS OF 13 CM (CORRESPONDING TO 9 GHz
 RESONANCE POSITION IN EBT-I) AND PICKUP LOOP AT
 APPROXIMATE EBT-I LOCATION, THE RATIO OF TOTAL MAGNETIC
 DIPOLE MOMENT IN ONE RING TO FLUX LINKAGE OF 1 TURN OF
 PICKUP COIL DUE TO ALL RINGS IS

$$2.0 \times 10^5 \quad (\text{AMP/TESLA})$$

MHD EQUILIBRIA -

FOR FOUR DIFFERENT DISTRIBUTIONS (LABELED A,B,C,D) THE
 RATIO OF THE QUOTIENT OF PERPENDICULAR ENERGY IN ONE RING
 DIVIDED BY MOD B AT THE CENTER OF THE MIDPLANE TO THE FLUX
 DUE TO ALL RINGS LINKING ONE TURN OF THE PICKUP COIL IS

- (A) 1.27×10^5 (AMP/TESLA)
- (B) 1.26×10^5
- (C) 1.14×10^5
- (D) 1.10×10^5

COMPARISON OF CURRENT SHEET AND MHD EQUILIBRIUM RESULTS

FOR COMPARISON, THE CURRENT SHEET VALUE MUST BE MULTIPLIED BY THE PROPER "AVERAGE" OF MOD B OVER THE RING WHILE THE MHD VALUES MUST BE MULTIPLIED BY THE CORRECT MOD B AT THE CENTER OF THE MIDPLANE TO YIELD THE TRUE VALUE AT THE RING LOCATION. IF ONE ASSUMES THE CORRECT AVERAGE MOD B FOR THE CURRENT SHEET MODEL IS 0.32 TESLA (HEATING RESONANCE VALUE FOR EBT-I) AND ALSO ASSUMES A MOD B AT THE CENTER OF THE MIDPLANE WHICH PUTS 0.32 TESLA AT THE INNER EDGE OF THE RING FOR THE MHD SOLUTIONS, ONE OBTAINS THE VALUES:

CURRENT SHEET	6.4×10^4 (JOULE/WEBER)
MHD (A)	6.9×10^4
(B)	6.6×10^4
(C)	6.3×10^4
(D)	6.0×10^4

UNCERTAINTIES IN RESULTS

STUDIES USING THE EBT CURRENT SHEET MODEL SHOW THAT RESULTS ARE QUITE INSENSITIVE TO THE CHOICE OF RING THICKNESS AND LENGTH PARAMETERS (LESS THAN 2% VARIATION IN DIPOLE MOMENT TO FLUX RATIO).

ABOUT ANOTHER 4% VARIATION TO FLUX LINKAGE COULD BE ATTRIBUTED TO UNCERTAINTY IN LOCATION OF THE PICKUP COIL ON THE CAVITY.

A LARGER UNCERTAINTY IS ASSOCIATED WITH THE ASSUMPTION OF RING MEAN RADIUS - ABOUT A 10% UNCERTAINTY IN COUPLING FOR A 10% UNCERTAINTY IN RADIUS. HOWEVER, THE MEAN RADIUS VALUE IS RELATED TO THE AVERAGE MOD B OVER THE RING, AND IT IS UNCERTAINTY IN THIS LATTER VALUE THAT LIMITS THE USEFULNESS OF THE CURRENT SHEET MODEL, ESPECIALLY FOR HIGH BETA RINGS WHERE VACUUM FIELD VALUES CANNOT BE USED TO DETERMINE THE AVERAGE MOD B. IF MORE ACCURACY IS REQUIRED THAN CAN BE INFERRED FROM COMPARISON OF TYPICAL MHD EQUILIBRIA AND CURRENT SHEET RESULTS, THEN THE ACTUAL RING GEOMETRY MUST BE KNOWN AND THE MHD EQUILIBRIUM METHOD USED TO OBTAIN SELF CONSISTENT FIELDS.

MHD EQUILIBRIA FOR BUMPY CYLINDER

(Pressure Map)

RAD. P-PER: MID TO CJIL

Z =	0.0	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.45	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.45	10.00	10.56	11.
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.75	0.000	0.000	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.25	0.004	0.004	0.003	0.003	0.002	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.75	0.008	0.008	0.008	0.007	0.006	0.005	0.003	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.25	0.011	0.011	0.010	0.010	0.008	0.007	0.005	0.003	0.001	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.75	0.010	0.010	0.009	0.008	0.006	0.005	0.003	0.001	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.25	0.006	0.005	0.005	0.004	0.002	0.001	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.75	0.001	0.001	0.000	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

RS
2.8000E+01ZS
9.5000E+00SI
-9.5891E-02SIV
1.4291E+02STP
1.4282E+02

PRESSURE CONTOURS - CASE (A)

1

RAD P-FER: MID TO COIL

Z =	0.0	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.45	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.45	10.00	10.56	11.
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.000	0.001	0.002	0.002	0.000	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.004	0.004	0.005	0.006	0.009	0.011	0.012	0.012	0.009	0.006	0.001	0.009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.75	0.022	0.022	0.023	0.023	0.023	0.021	0.020	0.017	0.014	0.011	0.007	0.002	0.016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.25	0.029	0.029	0.023	0.028	0.027	0.025	0.024	0.022	0.019	0.016	0.012	0.006	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.75	0.032	0.032	0.032	0.031	0.030	0.029	0.028	0.026	0.023	0.020	0.016	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.25	0.035	0.035	0.035	0.034	0.034	0.033	0.031	0.029	0.020	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.75	0.038	0.038	0.033	0.037	0.036	0.033	0.024	0.012	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.25	0.035	0.034	0.032	0.027	0.019	0.010	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.75	0.008	0.007	0.004	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS	ZS				SI				SIV				STP								
2.8C00E+01	9.5000E+00				-6.8994E-01				1.4291E+02				1.4222E+02								

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PRESSURE CONTOURS - CASE (B)

RAD P-PER: MID TO COIL

Z =	0.0	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.45	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.45	10.00	10.56	11.11
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.25	0.020	0.021	0.021	0.022	0.022	0.022	0.016	0.006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.75	0.068	0.067	0.067	0.066	0.062	0.055	0.041	0.024	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.25	0.089	0.089	0.085	0.078	0.067	0.051	0.032	0.015	0.005	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.75	0.071	0.069	0.063	0.053	0.039	0.024	0.011	0.003	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.25	0.033	0.031	0.026	0.018	0.010	0.004	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.75	0.005	0.004	0.002	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS	ZS				SI				SIV				STP								
2.8000E+01	9.5000E+00				-7.8596E-01				1.4291E+02				1.4213E+02								

RAD P-PER: MID TO COIL

Z =	0.0	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.45	5.00	5.56	6.11	6.67	7.22	7.78	8.33	8.89	9.45	10.00	10.56	11.
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.25	0.023	0.023	0.023	0.023	0.021	0.019	0.016	0.010	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.75	0.062	0.061	0.061	0.061	0.060	0.058	0.053	0.044	0.027	0.003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.25	0.093	0.093	0.093	0.092	0.091	0.086	0.076	0.050	0.014	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.75	0.114	0.113	0.112	0.109	0.101	0.078	0.037	0.005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.25	0.105	0.102	0.092	0.071	0.038	0.009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.75	0.021	0.017	0.009	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS	ZS				SI				SIV				STP								
2.8000E+01	9.5000E+00				-1.2915E+00				1.4291E+02				1.4162E+02								

APPENDIX B - Bumpy Cylinder MHD Code Computer Output From Runs 2 - 5

RUN 2:

```

EBTI KT8
IMX = 181 XMAX = 45.000000
KMXMI = 41 YMAX = 22.225000
IBUG = 0 IBUG OF ZERO GIVES MIN DIAG PRINT
NOTE THAT KMX = 42 LMX = 7602
SEP = 44.450000 RADIUS OF LOOP = 9.525000
NO COIL PAIRS NP = 4
NO PLASMA PAIRS FOR MULTIPOLE NPM = 5
MAX NO OF OVERALL ITERATIONS ITERMX = 20
MAX NO OF ITERATIONS FOR DE INMX = 25
DOUBLE INMX WHEN ITER A MULT. OF IDOUB = 5
TO AVOID THE SINGULARITY FOR THE VAC FLUX FUNCTION
IT IS SET TO ZERO FOR K GE KCUT AND I GE ICUT
K CUT = 38 ICUT = 36
ORC = 1.900000

```

```

DATA FOR CALP
ITNSC = 0 SLOP = 1.000000
INPUT = 1
RADIOI FOR SI DEP OF TENSOR PART
RSI1 = 11.00 RSI2 = 13.00 RSI3 = 13.00 RSI4 = 15.00
BC = 0.60
SINCE INPUT EQUALS ONE WE HAVE THE TAU CONST CASE
S = 0.200000
CONSTANTS FOR JDISP
IMNDL = 20 IMXDL = 80 IMDEL = 2
IBC = 1
RMSC = 8.000000
JCUT = 10
IF IBC IS ZERO FLUX CONSERVING BC ARE USED
RMSC IS USED FOR THE MULTIPOLE EXPANSION
JCUT IS THE NUMBER OF TERMS IN THE MULTIPOLE EXPANSION

```

```

ITER = 0 B AT ORIGIN = 0.100012D+01
N = 1 RES = 0.167680D-01
N = 25 RES = 0.511709D-02
ITER = 1 B AT ORIGIN = 0.100012D+01
N = 1 RES = 0.947452D-02
N = 25 RES = 0.321563D-02
ITER = 2 B AT ORIGIN = 0.100012D+01
N = 1 RES = 0.631150D-02
N = 25 RES = 0.241726D-02
ITER = 3 B AT ORIGIN = 0.100009D+01
N = 1 RES = 0.360643D-02
N = 25 RES = 0.178294D-02
ITER = 4 B AT ORIGIN = 0.100008D+01
N = 1 RES = 0.211983D-02
N = 50 RES = 0.637537D-03
ITER = 5 B AT ORIGIN = 0.100005D+01
N = 1 RES = 0.110583D-02
N = 50 RES = 0.428568D-03
ITER = 6 B AT ORIGIN = 0.100008D+01
N = 1 RES = 0.656444D-03
N = 50 RES = 0.317687D-03
ITER = 7 B AT ORIGIN = 0.100009D+01
N = 1 RES = 0.395681D-03
N = 50 RES = 0.242962D-03
ITER = 8 B AT ORIGIN = 0.100010D+01

```

N =	1	RES =	0.242457D-C3	
N =	50	RES =	0.190935D-03	
ITER =	9	B AT ORIGIN =	0.100011D+01	
N =	1	RES =	0.189816D-C3	
N =	100	RFS =	0.122585D-03	
ITER =	10	B AT ORIGIN =	0.100012D+01	
N =	1	RES =	0.122071D-03	
N =	100	RES =	0.840630D-04	
ITER =	11	B AT ORIGIN =	0.100013D+01	
N =	1	RES =	0.837323D-C4	
N =	100	RES =	0.582908D-04	
ITER =	12	B AT ORIGIN =	0.100014D+01	
N =	1	RES =	0.580658D-04	
N =	100	RES =	0.405564D-04	
ITER =	13	B AT ORIGIN =	0.100014D+01	
N =	1	RES =	0.404009D-04	
N =	100	RES =	0.282439D-04	
ITER =	14	B AT ORIGIN =	0.100014D+01	
N =	1	RES =	0.281359D-04	
N =	200	RES =	0.135209D-04	
ITER =	15	B AT ORIGIN =	0.100015D+01	
N =	1	RES =	0.183321D-04	
N =	200	RES =	0.654062D-05	
ITER =	16	B AT ORIGIN =	0.100015D+01	
N =	1	RES =	0.128067D-04	
N =	200	RES =	0.318771D-05	
ITER =	17	B AT ORIGIN =	0.100015D+01	
N =	1	RES =	0.840290D-05	
N =	200	RES =	0.156589D-05	
ITER =	18	B AT ORIGIN =	0.100015D+01	
N =	1	RES =	0.530924D-05	
N =	200	RES =	0.775884D-06	
ITER =	19	B AT ORIGIN =	0.100015D+01	
N =	1	RES =	0.327326D-05	
N =	400	RES =	0.183595D-06	

RMID	CURD	MODR	P-PERP	P-PARA	DLOB	SI	SIV
0.475D+01	-0.598D-04	0.915D+00	0.0	0.0	0.0	-0.143D-02	0.108D+02
0.500D+01	-0.659D-04	0.906D+00	0.0	0.0	0.0	-0.150D-02	0.119D+02
0.525D+01	-0.729D-04	0.897D+00	0.0	0.0	0.0	-0.155D-02	0.131D+02
0.550D+01	-0.803D-04	0.888D+00	0.0	0.0	0.0	-0.158D-02	0.143D+02
0.575D+01	-0.889D-04	0.878D+00	0.0	0.0	0.0	-0.159D-02	0.155D+02
0.600D+01	-0.982D-04	0.868D+00	0.0	0.0	0.0	-0.156D-02	0.168D+02
0.625D+01	-0.109D-03	0.858D+00	0.0	0.0	0.0	-0.149D-02	0.181D+02
0.650D+01	-0.120D-03	0.848D+00	0.0	0.0	0.0	-0.138D-02	0.195D+02
0.675D+01	-0.134D-03	0.837D+00	0.0	0.0	0.0	-0.121D-02	0.209D+02
0.700D+01	-0.149D-03	0.826D+00	0.0	0.0	0.0	-0.977D-03	0.223D+02
0.725D+01	-0.166D-03	0.814D+00	0.0	0.0	0.0	-0.671D-03	0.238D+02
0.750D+01	-0.185D-03	0.803D+00	0.0	0.0	0.0	-0.277D-03	0.252D+02
0.775D+01	-0.207D-03	0.791D+00	0.0	0.0	0.0	0.218D-03	0.268D+02
0.800D+01	-0.231D-03	0.779D+00	0.0	0.0	0.0	0.831D-03	0.283D+02
0.825D+01	-0.259D-03	0.767D+00	0.0	0.0	0.0	0.158D-02	0.299D+02
0.850D+01	-0.291D-03	0.755D+00	0.0	0.0	0.0	0.249D-02	0.315D+02
0.875D+01	-0.328D-03	0.743D+00	0.0	0.0	0.0	0.358D-02	0.331D+02
0.900D+01	-0.371D-03	0.730D+00	0.0	0.0	0.0	0.489D-02	0.347D+02
0.925D+01	-0.419D-03	0.718D+00	0.0	0.0	0.0	0.644D-02	0.364D+02
0.950D+01	-0.475D-03	0.705D+00	0.0	0.0	0.0	0.829D-02	0.380D+02
0.975D+01	-0.540D-03	0.692D+00	0.0	0.0	0.0	0.105D-01	0.397D+02
0.100D+02	-0.614D-03	0.680D+00	0.0	0.0	0.0	0.130D-01	0.414D+02
0.103D+02	-0.699D-03	0.667D+00	0.0	0.0	0.0	0.161D-01	0.431D+02

0.1050+02	-0.7970-03	0.6540+00	0.0	0.0	0.0	0.1960-01	0.4480+02
0.1080+02	-0.9090-03	0.6410+00	0.0	0.0	0.0	0.2380-01	0.4650+02
0.1100+02	-0.1040-02	0.6280+00	0.0	0.0	0.0	0.2860-01	0.4830+02
0.1130+02	-0.1180-02	0.6160+00	0.0	0.0	0.0	0.3440-01	0.5000+02
0.1150+02	0.3170-03	0.6030+00	0.0	0.0	0.0	0.4100-01	0.5170+02
0.1180+02	0.4490-02	0.5890+00	0.4800-03	0.4310-05	0.0	0.4760-01	0.5340+02
0.1200+02	0.9580-02	0.5750+00	0.1700-02	0.3670-04	0.0	0.5100-01	0.5520+02
0.1230+02	0.1390-01	0.5590+00	0.3560-02	0.1260-03	0.0	0.4720-01	0.5690+02
0.1250+02	0.1640-01	0.5420+00	0.5830-02	0.2940-03	0.0	0.3260-01	0.5860+02
0.1280+02	0.1610-01	0.5250+00	0.8160-02	0.5420-03	0.0	0.4720-02	0.6030+02
0.1300+02	0.1220-01	0.5090+00	0.1010-01	0.8250-03	0.0	-0.3660-01	0.6200+02
0.1330+02	0.5430-02	0.4950+00	0.1120-01	0.1070-02	0.0	-0.8880-01	0.6370+02
0.1350+02	-0.2810-02	0.4820+00	0.1120-01	0.1220-02	0.0	-0.1460+00	0.6540+02
0.1380+02	-0.1100-01	0.4710+00	0.1010-01	0.1220-02	0.0	-0.2030+00	0.6710+02
0.1400+02	-0.1730-01	0.4630+00	0.8180-02	0.1060-02	0.0	-0.2510+00	0.6880+02
0.1430+02	-0.2040-01	0.4560+00	0.5650-02	0.7740-03	0.0	-0.2840+00	0.7040+02
0.1450+02	-0.1890-01	0.4490+00	0.3030-02	0.4380-03	0.0	-0.3000+00	0.7200+02
0.1480+02	-0.1160-01	0.4410+00	0.9070-03	0.1390-03	0.0	-0.2990+00	0.7370+02
0.1500+02	-0.1030-02	0.4310+00	0.0	0.0	0.0	-0.2870+00	0.7530+02
0.1530+02	0.1770-02	0.4190+00	0.0	0.0	0.0	-0.2740+00	0.7690+02
0.1550+02	0.1410-02	0.4070+00	0.0	0.0	0.0	-0.2620+00	0.7850+02
0.1580+02	0.1150-02	0.3960+00	0.0	0.0	0.0	-0.2510+00	0.8000+02
0.1600+02	0.9830-03	0.3850+00	0.0	0.0	0.0	-0.2420+00	0.8160+02
0.1630+02	0.8510-03	0.3740+00	0.0	0.0	0.0	-0.2330+00	0.8310+02
0.1650+02	0.7420-03	0.3630+00	0.0	0.0	0.0	-0.2250+00	0.8460+02
0.1680+02	0.6500-03	0.3530+00	0.0	0.0	0.0	-0.2180+00	0.8610+02
0.1700+02	0.5730-03	0.3430+00	0.0	0.0	0.0	-0.2110+00	0.8750+02
0.1730+02	0.5070-03	0.3320+00	0.0	0.0	0.0	-0.2050+00	0.8900+02
0.1750+02	0.4510-03	0.3230+00	0.0	0.0	0.0	-0.1990+00	0.9040+02
0.1780+02	0.4010-03	0.3130+00	0.0	0.0	0.0	-0.1940+00	0.9180+02
0.1800+02	0.3590-03	0.3030+00	0.0	0.0	0.0	-0.1890+00	0.9310+02
0.1830+02	0.3220-03	0.2940+00	0.0	0.0	0.0	-0.1840+00	0.9450+02
0.1850+02	0.2900-03	0.2850+00	0.0	0.0	0.0	-0.1800+00	0.9580+02
0.1880+02	0.2610-03	0.2760+00	0.0	0.0	0.0	-0.1760+00	0.9710+02
0.1900+02	0.2360-03	0.2680+00	0.0	0.0	0.0	-0.1720+00	0.9840+02
0.1930+02	0.2140-03	0.2590+00	0.0	0.0	0.0	-0.1690+00	0.9970+02
0.1950+02	0.1950-03	0.2510+00	0.0	0.0	0.0	-0.1650+00	0.1010+03
0.1980+02	0.1770-03	0.2430+00	0.0	0.0	0.0	-0.1620+00	0.1020+03

WPER = 0.802860+00 WPAR = 0.485920-01

RAD P-PER: MID TO COIL

Z =	0.0	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.45	5.00	5.56	6.11	6.67	7.22	7.78	8.33
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.75	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12.25	0.0004	0.0004	0.0003	0.0003	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12.75	0.0008	0.0008	0.0008	0.0007	0.0006	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13.25	0.0011	0.0011	0.0010	0.0010	0.0008	0.0007	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13.75	0.0010	0.0010	0.0009	0.0008	0.0006	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14.25	0.0006	0.0005	0.0005	0.0004	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14.75	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS	2.80000+01		ZS	9.50000+00		SI	-9.59040-02		SIV	1.42920+02		STP	1.42820+02			

RUN 3:

```

EBTI KT9
IMX = 225 XMAX = 45.000000
KMXM1 = 51 YMAX = 22.225006
IBUG = 0 IBUG OF ZERO GIVES MIN DIAG PRINT
NOTE THAT KMX = 52 LMX = 11700
SEP = 44.449997 RADIUS OF LOOP = 9.525000
NO COIL PAIRS NP = 4
NO PLASMA PAIRS FOR MULTIPOLE NPM = 5
MAX NO OF OVERALL ITERATIONS ITERMX = 25
MAX NO OF ITERATIONS FOR DE INMX = 30
DOUBLE INMX WHEN ITER A MULT. OF IDOUB = 6
TO AVOID THE SINGULARITY FOR THE VAC FLUX FUNCTION
IT IS SET TO ZERO FOR K GE KCUT AND I GE ICUT
KRCUT = 45 ICUT = 45
CRC = 1.900000

```

```

DATA FOR CALP
ITNSC = 0 SLOP = 1.000000
INPUT = 1
RADI FOR SI DEP OF TENSOR PART.
RSI1 = 11.00 RSI2 = 13.00 RSI3 = 13.00 RSI4 = 15.00
BC = 0.60
SINCE INPUT EQUALS ONE WE HAVE THE TAU CONST CASE
S = 0.200000
CONSTANTS FOR JDISP
IMNDL = 24 IMXDL = 100 IMDEL = 2
IBC = 1
RMSC = 8.000000
JCUT = 10
IF IBC IS ZERO FLUX CONSERVING BC ARE USED
RMSC IS USED FOR THE MULTIPOLE EXPANSION
JCUT IS THE NUMBER OF TERMS IN THE MULTIPLE EXPANSION

```

```

ITER = 0 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.177883E-01
N = 30 RES = 0.420803E-02
ITER = 1 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.997756E-02
N = 30 RES = 0.248444E-02
ITER = 2 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.565023E-02
N = 30 RES = 0.150639E-02
ITER = 3 B AT ORIGIN = 0.100004E+01
N = 1 RES = 0.322070E-02
N = 30 RES = 0.923763E-03
ITER = 4 B AT ORIGIN = 0.100003E+01
N = 1 RES = 0.184744E-02
N = 30 RES = 0.614150E-03
ITER = 5 B AT ORIGIN = 0.100003E+01
N = 1 RES = 0.106684E-02
N = 60 RES = 0.286406E-03
ITER = 6 B AT ORIGIN = 0.100004E+01
N = 1 RES = 0.635416E-03
N = 60 RES = 0.226294E-03
ITER = 7 B AT ORIGIN = 0.100005E+01
N = 1 RES = 0.380207E-03
N = 60 RES = 0.182602E-03
ITER = 8 B AT ORIGIN = 0.100006E+01

```

```

N = 1 RES = 0.232825E-03
N = 60 RES = 0.149977E-03
ITER = 9 B AT ORIGIN = 0.100007E+01
N = 1 RES = 0.149667E-03
N = 60 RES = 0.125066E-03
ITER = 10 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.124819E-03
N = 60 RES = 0.106862E-03
ITER = 11 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.106601E-03
N = 120 RES = 0.791040E-04
ITER = 12 B AT ORIGIN = 0.100009E+01
N = 1 RES = 0.788868E-04
N = 120 RES = 0.590420E-04
ITER = 13 B AT ORIGIN = 0.100010E+01
N = 1 RES = 0.589126E-04
N = 120 RES = 0.443827E-04
ITER = 14 B AT ORIGIN = 0.100010E+01
N = 1 RES = 0.442679E-04
N = 120 RES = 0.335608E-04
ITER = 15 B AT ORIGIN = 0.100011E+01
N = 1 RES = 0.334589E-04
N = 120 RES = 0.253737E-04
ITER = 16 B AT ORIGIN = 0.100011E+01
N = 1 RES = 0.253029E-04
N = 120 RES = 0.192108E-04
ITER = 17 B AT ORIGIN = 0.100011E+01
N = 1 RES = 0.191990E-04
N = 240 RES = 0.110000E-04
ITER = 18 B AT ORIGIN = 0.100011E+01
N = 1 RES = 0.121729E-04
N = 240 RES = 0.634632E-05
ITER = 19 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.914174E-05
N = 240 RES = 0.366677E-05
ITER = 20 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.675047E-05
N = 240 RES = 0.215969E-05
ITER = 21 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.469353E-05
N = 240 RES = 0.132710E-05
ITER = 22 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.309319E-05
N = 240 RES = 0.814029E-06
ITER = 23 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.212191E-05
N = 480 RES = 0.383635E-06
ITER = 24 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.145927E-05
N = 480 RES = 0.248600E-06

```

RMID	CURD	MODB	P-PERP	P-PARA	DLOB	SI	SIV
0.462E+01	-0.548E-04	0.920E+00	0.0	0.0	0.0	-0.217E-02	0.102E+02
0.482E+01	-0.593E-04	0.913E+00	0.0	0.0	0.0	-0.230E-02	0.111E+02
0.502E+01	-0.644E-04	0.906E+00	0.0	0.0	0.0	-0.243E-02	0.120E+02
0.522E+01	-0.697E-04	0.898E+00	0.0	0.0	0.0	-0.255E-02	0.129E+02
0.542E+01	-0.756E-04	0.891E+00	0.0	0.0	0.0	-0.267E-02	0.139E+02
0.562E+01	-0.818E-04	0.884E+00	0.0	0.0	0.0	-0.276E-02	0.149E+02
0.583E+01	-0.890E-04	0.875E+00	0.0	0.0	0.0	-0.285E-02	0.159E+02
0.603E+01	-0.964E-04	0.867E+00	0.0	0.0	0.0	-0.291E-02	0.169E+02

0.623E+01	-0.105E-03	0.859E+00	0.0	0.0	0.0	-0.295E-02	0.180E+02
0.643E+01	-0.114E-03	0.850E+00	0.0	0.0	0.0	-0.297E-02	0.191E+02
0.663E+01	-0.124E-03	0.842E+00	0.0	0.0	0.0	-0.296E-02	0.202E+02
0.683E+01	-0.135E-03	0.834E+00	0.0	0.0	0.0	-0.291E-02	0.213E+02
0.703E+01	-0.147E-03	0.825E+00	0.0	0.0	0.0	-0.283E-02	0.225E+02
0.723E+01	-0.160E-03	0.815E+00	0.0	0.0	0.0	-0.270E-02	0.236E+02
0.743E+01	-0.175E-03	0.806E+00	0.0	0.0	0.0	-0.252E-02	0.248E+02
0.763E+01	-0.192E-03	0.797E+00	0.0	0.0	0.0	-0.228E-02	0.261E+02
0.783E+01	-0.210E-03	0.786E+00	0.0	0.0	0.0	-0.197E-02	0.273E+02
0.804E+01	-0.230E-03	0.777E+00	0.0	0.0	0.0	-0.159E-02	0.285E+02
0.824E+01	-0.253E-03	0.768E+00	0.0	0.0	0.0	-0.113E-02	0.298E+02
0.844E+01	-0.278E-03	0.758E+00	0.0	0.0	0.0	-0.562E-03	0.311E+02
0.864E+01	-0.306E-03	0.748E+00	0.0	0.0	0.0	0.110E-03	0.324E+02
0.884E+01	-0.338E-03	0.738E+00	0.0	0.0	0.0	0.906E-03	0.337E+02
0.904E+01	-0.373E-03	0.728E+00	0.0	0.0	0.0	0.184E-02	0.350E+02
0.924E+01	-0.412E-03	0.718E+00	0.0	0.0	0.0	0.294E-02	0.363E+02
0.944E+01	-0.456E-03	0.708E+00	0.0	0.0	0.0	0.421E-02	0.376E+02
0.964E+01	-0.506E-03	0.698E+00	0.0	0.0	0.0	0.569E-02	0.390E+02
0.984E+01	-0.561E-03	0.688E+00	0.0	0.0	0.0	0.740E-02	0.403E+02
0.100E+02	-0.623E-03	0.677E+00	0.0	0.0	0.0	0.937E-02	0.417E+02
0.102E+02	-0.693E-03	0.667E+00	0.0	0.0	0.0	0.116E-01	0.431E+02
0.104E+02	-0.770E-03	0.656E+00	0.0	0.0	0.0	0.142E-01	0.444E+02
0.106E+02	-0.858E-03	0.646E+00	0.0	0.0	0.0	0.172E-01	0.458E+02
0.108E+02	-0.954E-03	0.636E+00	0.0	0.0	0.0	0.206E-01	0.472E+02
0.110E+02	-0.106E-02	0.626E+00	0.0	0.0	0.0	0.245E-01	0.486E+02
0.112E+02	-0.118E-02	0.616E+00	0.0	0.0	0.0	0.289E-01	0.500E+02
0.115E+02	-0.482E-03	0.606E+00	0.0	0.0	0.0	0.340E-01	0.514E+02
0.117E+02	0.250E-02	0.595E+00	0.196E-03	0.890E-06	0.0	0.394E-01	0.528E+02
0.119E+02	0.664E-02	0.583E+00	0.912E-03	0.130E-04	0.0	0.436E-01	0.541E+02
0.121E+02	0.106E-01	0.571E+00	0.205E-02	0.500E-04	0.0	0.448E-01	0.555E+02
0.123E+02	0.141E-01	0.559E+00	0.360E-02	0.129E-03	0.0	0.408E-01	0.569E+02
0.125E+02	0.163E-01	0.545E+00	0.541E-02	0.259E-03	0.0	0.296E-01	0.583E+02
0.127E+02	0.172E-01	0.532E+00	0.730E-02	0.440E-03	0.0	0.100E-01	0.597E+02
0.129E+02	0.152E-01	0.517E+00	0.916E-02	0.678E-03	0.0	-0.187E-01	0.610E+02
0.131E+02	0.105E-01	0.505E+00	0.105E-01	0.898E-03	0.0	-0.559E-01	0.624E+02
0.133E+02	0.565E-02	0.494E+00	0.112E-01	0.108E-02	0.0	-0.993E-01	0.638E+02
0.135E+02	-0.105E-02	0.483E+00	0.114E-01	0.123E-02	0.0	-0.146E+00	0.651E+02
0.137E+02	-0.863E-02	0.474E+00	0.107E-01	0.126E-02	0.0	-0.194E+00	0.665E+02
0.139E+02	-0.146E-01	0.467E+00	0.940E-02	0.117E-02	0.0	-0.237E+00	0.678E+02
0.141E+02	-0.188E-01	0.461E+00	0.761E-02	0.999E-03	0.0	-0.272E+00	0.692E+02
0.143E+02	-0.208E-01	0.455E+00	0.551E-02	0.756E-03	0.0	-0.298E+00	0.705E+02
0.145E+02	-0.198E-01	0.450E+00	0.339E-02	0.483E-03	0.0	-0.311E+00	0.718E+02
0.147E+02	-0.154E-01	0.444E+00	0.153E-02	0.229E-03	0.0	-0.313E+00	0.731E+02
0.149E+02	-0.683E-02	0.436E+00	0.283E-03	0.447E-04	0.0	-0.306E+00	0.744E+02
0.151E+02	0.163E-02	0.428E+00	0.0	0.0	0.0	-0.295E+00	0.757E+02
0.153E+02	0.147E-02	0.418E+00	0.0	0.0	0.0	-0.285E+00	0.770E+02
0.155E+02	0.132E-02	0.409E+00	0.0	0.0	0.0	-0.275E+00	0.782E+02
0.157E+02	0.119E-02	0.400E+00	0.0	0.0	0.0	-0.266E+00	0.795E+02
0.159E+02	0.106E-02	0.391E+00	0.0	0.0	0.0	-0.258E+00	0.808E+02
0.161E+02	0.955E-03	0.382E+00	0.0	0.0	0.0	-0.250E+00	0.820E+02
0.163E+02	0.859E-03	0.373E+00	0.0	0.0	0.0	-0.243E+00	0.832E+02
0.165E+02	0.774E-03	0.364E+00	0.0	0.0	0.0	-0.237E+00	0.844E+02
0.167E+02	0.698E-03	0.356E+00	0.0	0.0	0.0	-0.231E+00	0.856E+02
0.169E+02	0.631E-03	0.348E+00	0.0	0.0	0.0	-0.225E+00	0.868E+02
0.171E+02	0.572E-03	0.339E+00	0.0	0.0	0.0	-0.219E+00	0.879E+02
0.173E+02	0.519E-03	0.331E+00	0.0	0.0	0.0	-0.214E+00	0.891E+02
0.175E+02	0.472E-03	0.323E+00	0.0	0.0	0.0	-0.209E+00	0.902E+02
0.177E+02	0.431E-03	0.316E+00	0.0	0.0	0.0	-0.205E+00	0.914E+02
0.179E+02	0.393E-03	0.309E+00	0.0	0.0	0.0	-0.201E+00	0.925E+02
0.181E+02	0.360E-03	0.300E+00	0.0	0.0	0.0	-0.197E+00	0.936E+02

0.183E+02	0.330E-03	0.293E+00	0.0	0.0	0.0	-0.193E+00	0.946E+02
0.185E+02	0.303E-03	0.285E+00	0.0	0.0	0.0	-0.189E+00	0.957E+02
0.187E+02	0.279E-03	0.279E+00	0.0	0.0	0.0	-0.186E+00	0.968E+02
0.189E+02	0.257E-03	0.272E+00	0.0	0.0	0.0	-0.182E+00	0.978E+02
0.191E+02	0.237E-03	0.265E+00	0.0	0.0	0.0	-0.179E+00	0.988E+02
0.193E+02	0.219E-03	0.258E+00	0.0	0.0	0.0	-0.176E+00	0.998E+02
0.195E+02	0.203E-03	0.251E+00	0.0	0.0	0.0	-0.174E+00	0.101E+03
0.197E+02	0.188E-03	0.245E+00	0.0	0.0	0.0	-0.171E+00	0.102E+03
0.199E+02	0.175E-03	0.239E+00	0.0	0.0	0.0	-0.168E+00	0.103E+03

WPER= 0.78398E+00 WPAR= 0.44775E-01

RAD P-PER: MID TO COIL

Z =	0.0	0.89	1.78	2.67	3.56	4.45	5.33	6.22	7.11	8.00	8.89	9.78	10.67	11.56	12.45	13.34
4.62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.83	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.84	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.85	0.0001	0.0001	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.25	0.0004	0.0003	0.0003	0.0001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.66	0.0007	0.0007	0.0006	0.0005	0.0002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.06	0.0010	0.0010	0.0009	0.0007	0.0004	0.0001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.46	0.0011	0.0011	0.0009	0.0007	0.0003	0.0001	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.86	0.0009	0.0009	0.0007	0.0004	0.0001	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.26	0.0006	0.0005	0.0003	0.0001	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.67	0.0002	0.0001	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS	2.8000E+01		ZS	9.5000E+00		SI	-1.0138E-01		SIV	1.4257E+02		STP	1.4247E+02			

RUN 4:

```

EBTI KT8
IMX = 181 XMAX = 45.000000
KMXM1 = 41 YMAX = 22.225006
IBUG = 0 IBUG OF ZERO GIVES MIN DIAG PRINT
NOTE THAT KMX = 42 LMX = 7602
SEP = 44.449997 RADIUS OF LOOP = 9.525000
NO COIL PAIRS NP = 4
NO PLASMA PAIRS FOR MULTIPOLE NPM = 5
MAX NO OF OVERALL ITERATIONS ITERMX = 20
MAX NO OF ITERATIONS FOR DE INMX = 25
COUPLE INMX WHEN ITER A MULT. OF 10000 = 5
TO AVOID THE SINGULARITY FOR THE VAC FLUX FUNCTION
IT IS SET TO ZERO FOR K GE KCUT AND I GE ICUT
K CUT = 38 ICUT = 36
CRC = 1.900000

```

```

DATA FOR CALP
ITNSC = 0 SLOP = 1.000000
INPUT = 1
RADII FOR SI DEP OF TENSOR PART
RSI1 = 11.00 RSI2 = 13.00 RSI3 = 13.00 RSI4 = 15.00
BC = 0.60
SINCE INPUT EQUALS ONE WE HAVE THE TAU CONST CASE
S = 0.200000
CONSTANTS FOR JDISP
IMNDL = 20 IMXDL = 80 IMDEL = 2
IBC = 1
RMSC = 8.000000
JCUT = 10
IF IBC IS ZERO FLUX CONSERVING BC ARE USED
RMSC IS USED FOR THE MULTIPOLE EXPANSION
JCUT IS THE NUMBER OF TERMS IN THE MULTIPLE EXPANSION

```

```

ITER = 0 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.167818E-01
N = 25 RES = 0.512126E-02
ITER = 1 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.948173E-02
N = 25 RES = 0.321801E-02
ITER = 2 B AT ORIGIN = 0.100012E+01
N = 1 RES = 0.631712E-02
N = 25 RES = 0.241754E-02
ITER = 3 B AT ORIGIN = 0.100009E+01
N = 1 RES = 0.360836E-02
N = 25 RES = 0.178328E-02
ITER = 4 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.212197E-02
N = 50 RES = 0.638005E-03
ITER = 5 B AT ORIGIN = 0.100006E+01
N = 1 RES = 0.110653E-02
N = 50 RES = 0.428791E-03
ITER = 6 B AT ORIGIN = 0.100008E+01
N = 1 RES = 0.656961E-03
N = 50 RES = 0.317713E-03
ITER = 7 B AT ORIGIN = 0.100009E+01
N = 1 RES = 0.395834E-03
N = 50 RES = 0.242864E-03
ITER = 8 B AT ORIGIN = 0.100010E+01

```

N =	1	RES =	0.243099E-03	
N =	50	RES =	0.190866E-03	
ITER =	9	B AT ORIGIN =	0.100011E+01	
N =	1	RES =	0.189859E-03	
N =	100	RES =	0.122536E-03	
ITER =	10	B AT ORIGIN =	0.100012E+01	
N =	1	RES =	0.122095E-03	
N =	100	RES =	0.840853E-04	
ITER =	11	B AT ORIGIN =	0.100013E+01	
N =	1	RES =	0.837450E-04	
N =	100	RES =	0.582655E-04	
ITER =	12	B AT ORIGIN =	0.100014E+01	
N =	1	RES =	0.580286E-04	
N =	100	RES =	0.405851E-04	
ITER =	13	B AT ORIGIN =	0.100014E+01	
N =	1	RES =	0.404433E-04	
N =	100	RES =	0.282933E-04	
ITER =	14	B AT ORIGIN =	0.100014E+01	
N =	1	RES =	0.281512E-04	
N =	200	RES =	0.135819E-04	
ITER =	15	B AT ORIGIN =	0.100015E+01	
N =	1	RES =	0.181005E-04	
N =	200	RES =	0.661921E-05	
ITER =	16	B AT ORIGIN =	0.100015E+01	
N =	1	RES =	0.129368E-04	
N =	200	RES =	0.327134E-05	
ITER =	17	B AT ORIGIN =	0.100015E+01	
N =	1	RES =	0.841391E-05	
N =	200	RES =	0.172169E-05	
ITER =	18	B AT ORIGIN =	0.100015E+01	
N =	1	RES =	0.547791E-05	
N =	200	RES =	0.899626E-06	
ITER =	19	B AT ORIGIN =	0.100015E+01	
N =	1	RES =	0.341564E-05	
N =	400	RES =	0.317566E-06	

RMID	CURD	MODB	P-PERP	P-PARA	DLOB	SI	SIV
0.475E+01	-0.599E-04	0.916E+00	0.0	0.0	0.0	-0.142E-02	0.108E+02
0.500E+01	-0.660E-04	0.907E+00	0.0	0.0	0.0	-0.149E-02	0.119E+02
0.525E+01	-0.730E-04	0.898E+00	0.0	0.0	0.0	-0.154E-02	0.131E+02
0.550E+01	-0.804E-04	0.888E+00	0.0	0.0	0.0	-0.157E-02	0.143E+02
0.575E+01	-0.890E-04	0.878E+00	0.0	0.0	0.0	-0.158E-02	0.155E+02
0.600E+01	-0.983E-04	0.869E+00	0.0	0.0	0.0	-0.155E-02	0.168E+02
0.625E+01	-0.109E-03	0.858E+00	0.0	0.0	0.0	-0.148E-02	0.181E+02
0.650E+01	-0.121E-03	0.848E+00	0.0	0.0	0.0	-0.137E-02	0.195E+02
0.675E+01	-0.134E-03	0.837E+00	0.0	0.0	0.0	-0.120E-02	0.209E+02
0.700E+01	-0.149E-03	0.826E+00	0.0	0.0	0.0	-0.963E-03	0.223E+02
0.725E+01	-0.166E-03	0.815E+00	0.0	0.0	0.0	-0.655E-03	0.238E+02
0.750E+01	-0.185E-03	0.803E+00	0.0	0.0	0.0	-0.260E-03	0.252E+02
0.775E+01	-0.207E-03	0.791E+00	0.0	0.0	0.0	0.237E-03	0.268E+02
0.800E+01	-0.231E-03	0.779E+00	0.0	0.0	0.0	0.852E-03	0.283E+02
0.825E+01	-0.260E-03	0.767E+00	0.0	0.0	0.0	0.160E-02	0.299E+02
0.850E+01	-0.292E-03	0.755E+00	0.0	0.0	0.0	0.251E-02	0.315E+02
0.875E+01	-0.329E-03	0.742E+00	0.0	0.0	0.0	0.361E-02	0.331E+02
0.900E+01	-0.371E-03	0.730E+00	0.0	0.0	0.0	0.492E-02	0.347E+02
0.925E+01	-0.420E-03	0.713E+00	0.0	0.0	0.0	0.648E-02	0.364E+02
0.950E+01	-0.476E-03	0.705E+00	0.0	0.0	0.0	0.832E-02	0.380E+02
0.975E+01	-0.540E-03	0.692E+00	0.0	0.0	0.0	0.105E-01	0.397E+02
0.100E+02	-0.614E-03	0.679E+00	0.0	0.0	0.0	0.131E-01	0.414E+02
0.103E+02	-0.700E-03	0.667E+00	0.0	0.0	0.0	0.161E-01	0.431E+02

0.105E+02	-0.798E-03	0.654E+00	0.0	0.0	0.0	0.197E-01	0.448E+02
0.108E+02	-0.910E-03	0.641E+00	0.0	0.0	0.0	0.238E-01	0.465E+02
0.110E+02	-0.104E-02	0.629E+00	0.0	0.0	0.0	0.287E-01	0.483E+02
0.113E+02	-0.118E-02	0.616E+00	0.0	0.0	0.0	0.344E-01	0.500E+02
0.115E+02	0.335E-03	0.603E+00	0.0	0.0	0.0	0.411E-01	0.517E+02
0.118E+02	0.453E-02	0.589E+00	0.487E-03	0.443E-05	0.0	0.477E-01	0.534E+02
0.120E+02	0.951E-02	0.574E+00	0.171E-02	0.371E-04	0.0	0.511E-01	0.552E+02
0.123E+02	0.137E-01	0.559E+00	0.354E-02	0.125E-03	0.0	0.473E-01	0.569E+02
0.125E+02	0.169E-01	0.543E+00	0.579E-02	0.291E-03	0.0	0.328E-01	0.586E+02
0.128E+02	0.163E-01	0.524E+00	0.825E-02	0.555E-03	0.0	0.478E-02	0.603E+02
0.130E+02	0.115E-01	0.509E+00	0.101E-01	0.832E-03	0.0	-0.370E-01	0.620E+02
0.133E+02	0.520E-02	0.495E+00	0.111E-01	0.106E-02	0.0	-0.890E-01	0.637E+02
0.135E+02	-0.228E-02	0.482E+00	0.112E-01	0.122E-02	0.0	-0.146E+00	0.654E+02
0.138E+02	-0.108E-01	0.471E+00	0.102E-01	0.123E-02	0.0	-0.203E+00	0.671E+02
0.140E+02	-0.175E-01	0.462E+00	0.821E-02	0.106E-02	0.0	-0.251E+00	0.687E+02
0.143E+02	-0.205E-01	0.455E+00	0.566E-02	0.775E-03	0.0	-0.284E+00	0.704E+02
0.145E+02	-0.189E-01	0.449E+00	0.303E-02	0.435E-03	0.0	-0.300E+00	0.720E+02
0.148E+02	-0.115E-01	0.441E+00	0.901E-03	0.137E-03	0.0	-0.299E+00	0.737E+02
0.150E+02	-0.100E-02	0.430E+00	0.0	0.0	0.0	-0.287E+00	0.753E+02
0.153E+02	0.177E-02	0.419E+00	0.0	0.0	0.0	-0.274E+00	0.769E+02
0.155E+02	0.140E-02	0.407E+00	0.0	0.0	0.0	-0.262E+00	0.785E+02
0.158E+02	0.116E-02	0.396E+00	0.0	0.0	0.0	-0.251E+00	0.800E+02
0.160E+02	0.987E-03	0.385E+00	0.0	0.0	0.0	-0.242E+00	0.816E+02
0.163E+02	0.851E-03	0.374E+00	0.0	0.0	0.0	-0.233E+00	0.831E+02
0.165E+02	0.742E-03	0.364E+00	0.0	0.0	0.0	-0.225E+00	0.846E+02
0.168E+02	0.650E-03	0.353E+00	0.0	0.0	0.0	-0.218E+00	0.861E+02
0.170E+02	0.573E-03	0.343E+00	0.0	0.0	0.0	-0.211E+00	0.875E+02
0.173E+02	0.507E-03	0.332E+00	0.0	0.0	0.0	-0.205E+00	0.890E+02
0.175E+02	0.451E-03	0.322E+00	0.0	0.0	0.0	-0.199E+00	0.904E+02
0.178E+02	0.402E-03	0.313E+00	0.0	0.0	0.0	-0.194E+00	0.918E+02
0.180E+02	0.360E-03	0.303E+00	0.0	0.0	0.0	-0.189E+00	0.931E+02
0.183E+02	0.322E-03	0.294E+00	0.0	0.0	0.0	-0.184E+00	0.945E+02
0.185E+02	0.290E-03	0.285E+00	0.0	0.0	0.0	-0.180E+00	0.958E+02
0.188E+02	0.261E-03	0.277E+00	0.0	0.0	0.0	-0.176E+00	0.971E+02
0.190E+02	0.236E-03	0.268E+00	0.0	0.0	0.0	-0.172E+00	0.984E+02
0.193E+02	0.214E-03	0.259E+00	0.0	0.0	0.0	-0.169E+00	0.997E+02
0.195E+02	0.195E-03	0.251E+00	0.0	0.0	0.0	-0.165E+00	0.101E+03
0.198E+02	0.177E-03	0.243E+00	0.0	0.0	0.0	-0.162E+00	0.102E+03

WPER= 0.80354E+00 WPAR= 0.48644E-01

RAD P-PER: MID TO COIL

Z =	0.0	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.45	5.00	5.56	6.11	6.67
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.75	0.0000	0.0000	0.0000	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.25	0.0004	0.0004	0.0003	0.0003	0.0002	0.0001	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.75	0.0008	0.0008	0.0006	0.0007	0.0006	0.0005	0.0003	0.0001	0.0	0.0	0.0	0.0	0.0
13.25	0.0011	0.0011	0.0010	0.0010	0.0008	0.0007	0.0005	0.0003	0.0001	0.0000	0.0	0.0	0.0
13.75	0.0010	0.0010	0.0009	0.0008	0.0006	0.0005	0.0003	0.0001	0.0000	0.0	0.0	0.0	0.0
14.25	0.0006	0.0005	0.0005	0.0004	0.0002	0.0001	0.0000	0.0	0.0	0.0	0.0	0.0	0.0
14.75	0.0001	0.0001	0.0000	0.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	RS		ZS			SI			SIV			STP	
	2.8000E+01		9.5000E+00			-9.5851E-02			1.4291E+02			1.4282E+02	
	2.8000E+01		1.0500E+01			-9.4479E-02			1.4434E+02			1.4424E+02	
	2.8000E+01		8.5000E+00			-9.8745E-02			1.4020E+02			1.4010E+02	
	3.0000E+01		9.5000E+00			-9.5517E-02			1.4398E+02			1.4398E+02	
	2.6000E+01		9.5000E+00			-9.6057E-02			1.4135E+02			1.4125E+02	

RUN 5:

```

EBTI KT8
IMX = 181 XMAX = 45.000000
KMXM1 = 41 YMAX = 19.500000
IBUG = 0 IBUG OF ZERO GIVES MIN DIAG PRINT
NOTE THAT KMX = 42 LMX = 7602
SEP = 39.000000 RADIUS OF LOOP = 9.525000
NO COIL PAIRS NP = 4
NO PLASMA PAIRS FOR MULTIPLE NPM = 5
MAX NO OF OVERALL ITERATIONS ITERM = 20
MAX NO OF ITERATIONS FOR DE INMX = 25
DOUBLE INMX WHEN ITER A MULT. OF IDOUB = 5
TO AVOID THE SINGULARITY FOR THE AC FLUX FUNCTION
IT IS SET TO ZERO FOR K GE KCUT AND I GE ICUT
K CUT = 38 ICUT = 36
ORC = 1.900000

```

```

DATA FOR CALP
ITNSC = 0 SLOP = 1.000000
INPUT = 1
RADI FOR SI DEP OF TENSOR PART
RS11 = 11.00 RS12 = 13.00 RS13 = 13.00 RS14 = 15.00
BC = 0.60
SINCE INPUT EQUALS ONE WE HAVE THE TAU CONST CASE
S = 0.200000
CONSTANTS FOR JDISP
IMNDL = 20 IMXDL = 80 IMDEL = 2
IBC = 1
RMSC = 8.000000
JCUT = 10
IF IBC IS ZERO FLUX CONSERVING BC ARE USED
RMSC IS USED FOR THE MULTIPOLE EXPANSION
JCUT IS THE NUMBER OF TERMS IN THE MULTIPOLE EXPANSION

```

ITER = 0	B AT ORIGIN =	0.100014E+01
N = 1	RES =	0.418962E-01
N = 25	RES =	0.133002E-01
ITER = 1	B AT ORIGIN =	0.100014E+01
N = 1	RES =	0.227095E-01
N = 25	RES =	0.811712E-02
ITER = 2	B AT ORIGIN =	0.100014E+01
N = 1	RES =	0.141156E-01
N = 25	RES =	0.570874E-02
ITER = 3	B AT ORIGIN =	0.100008E+01
N = 1	RES =	0.897962E-02
N = 25	RES =	0.405383E-02
ITER = 4	B AT ORIGIN =	0.100005E+01
N = 1	RES =	0.530037E-02
N = 50	RES =	0.143936E-02
ITER = 5	B AT ORIGIN =	0.100001E+01
N = 1	RES =	0.297817E-02
N = 50	RES =	0.955392E-03
ITER = 6	B AT ORIGIN =	0.100007E+01
N = 1	RES =	0.182955E-02
N = 50	RES =	0.735885E-03
ITER = 7	B AT ORIGIN =	0.100011E+01
N = 1	RES =	0.114094E-02
N = 50	RES =	0.584450E-03
ITER = 8	B AT ORIGIN =	0.100013E+01

N =	1	RES =	0.727794E-03	
N =	50	RES =	0.475106E-03	
ITER =	9	B AT ORIGIN =	0.100016E+01	
N =	1	RES =	0.477476E-03	
N =	100	RES =	0.325641E-03	
ITER =	10	B AT ORIGIN =	0.100019E+01	
N =	1	RES =	0.354419E-03	
N =	100	RES =	0.230605E-03	
ITER =	11	B AT ORIGIN =	0.100021E+01	
N =	1	RES =	0.263248E-03	
N =	100	RES =	0.164102E-03	
ITER =	12	B AT ORIGIN =	0.100023E+01	
N =	1	RES =	0.192657E-03	
N =	100	RES =	0.116911E-03	
ITER =	13	B AT ORIGIN =	0.100024E+01	
N =	1	RES =	0.139726E-03	
N =	100	RES =	0.833961E-04	
ITER =	14	B AT ORIGIN =	0.100025E+01	
N =	1	RES =	0.100924E-03	
N =	200	RES =	0.416951E-04	
ITER =	15	B AT ORIGIN =	0.100026E+01	
N =	1	RES =	0.817527E-04	
N =	200	RES =	0.211273E-04	
ITER =	16	B AT ORIGIN =	0.100026E+01	
N =	1	RES =	0.599207E-04	
N =	200	RES =	0.108598E-04	
ITER =	17	B AT ORIGIN =	0.100027E+01	
N =	1	RES =	0.408100E-04	
N =	200	RES =	0.571871E-05	
ITER =	18	B AT ORIGIN =	0.100027E+01	
N =	1	RES =	0.267411E-04	
N =	200	RES =	0.304515E-05	
ITER =	19	B AT ORIGIN =	0.100027E+01	
N =	1	RES =	0.168215E-04	
N =	400	RES =	0.159038E-05	

RMID	CURD	MODB	P=PERP	P=PARA	DLOB	SI	SIV
0.475E+01	-0.124E-03	0.901E+00	0.0	0.0	0.0	-0.801E-02	0.107E+02
0.500E+01	-0.136E-03	0.891E+00	0.0	0.0	0.0	-0.870E-02	0.118E+02
0.525E+01	-0.151E-03	0.880E+00	0.0	0.0	0.0	-0.938E-02	0.129E+02
0.550E+01	-0.166E-03	0.869E+00	0.0	0.0	0.0	-0.100E-01	0.141E+02
0.575E+01	-0.184E-03	0.859E+00	0.0	0.0	0.0	-0.107E-01	0.153E+02
0.600E+01	-0.203E-03	0.847E+00	0.0	0.0	0.0	-0.113E-01	0.166E+02
0.625E+01	-0.224E-03	0.835E+00	0.0	0.0	0.0	-0.118E-01	0.179E+02
0.650E+01	-0.247E-03	0.823E+00	0.0	0.0	0.0	-0.123E-01	0.192E+02
0.675E+01	-0.275E-03	0.811E+00	0.0	0.0	0.0	-0.127E-01	0.206E+02
0.700E+01	-0.303E-03	0.798E+00	0.0	0.0	0.0	-0.130E-01	0.219E+02
0.725E+01	-0.338E-03	0.785E+00	0.0	0.0	0.0	-0.132E-01	0.234E+02
0.750E+01	-0.374E-03	0.772E+00	0.0	0.0	0.0	-0.132E-01	0.248E+02
0.775E+01	-0.416E-03	0.759E+00	0.0	0.0	0.0	-0.130E-01	0.262E+02
0.800E+01	-0.462E-03	0.745E+00	0.0	0.0	0.0	-0.127E-01	0.277E+02
0.825E+01	-0.514E-03	0.732E+00	0.0	0.0	0.0	-0.121E-01	0.292E+02
0.850E+01	-0.571E-03	0.718E+00	0.0	0.0	0.0	-0.112E-01	0.307E+02
0.875E+01	-0.637E-03	0.704E+00	0.0	0.0	0.0	-0.993E-02	0.323E+02
0.900E+01	-0.708E-03	0.690E+00	0.0	0.0	0.0	-0.831E-02	0.338E+02
0.925E+01	-0.789E-03	0.676E+00	0.0	0.0	0.0	-0.624E-02	0.354E+02
0.950E+01	-0.876E-03	0.662E+00	0.0	0.0	0.0	-0.364E-02	0.369E+02
0.975E+01	-0.974E-03	0.647E+00	0.0	0.0	0.0	-0.452E-03	0.385E+02
0.100E+02	-0.108E-02	0.633E+00	0.0	0.0	0.0	0.342E-02	0.401E+02
0.103E+02	-0.119E-02	0.620E+00	0.0	0.0	0.0	0.808E-02	0.417E+02

0.105E+02	-0.131E-02	0.606E+00	0.0	0.0	0.0	0.136E-01	0.433E+02
0.108E+02	-0.144E-02	0.591E+00	0.0	0.0	0.0	0.202E-01	0.448E+02
0.110E+02	-0.695E-03	0.578E+00	0.0	0.0	0.0	0.279E-01	0.464E+02
0.113E+02	0.274E-02	0.564E+00	0.249E-03	0.770E-05	0.0	0.362E-01	0.480E+02
0.115E+02	0.873E-02	0.548E+00	0.122E-02	0.553E-04	0.0	0.428E-01	0.496E+02
0.118E+02	0.156E-01	0.531E+00	0.307E-02	0.188E-03	0.0	0.432E-01	0.512E+02
0.120E+02	0.216E-01	0.512E+00	0.575E-02	0.456E-03	0.0	0.320E-01	0.527E+02
0.123E+02	0.255E-01	0.492E+00	0.891E-02	0.877E-03	0.0	0.414E-02	0.543E+02
0.125E+02	0.259E-01	0.472E+00	0.122E-01	0.146E-02	0.0	-0.440E-01	0.558E+02
0.128E+02	0.216E-01	0.452E+00	0.151E-01	0.212E-02	0.0	-0.113E+00	0.573E+02
0.130E+02	0.132E-01	0.435E+00	0.171E-01	0.272E-02	0.0	-0.202E+00	0.588E+02
0.133E+02	0.135E-02	0.420E+00	0.178E-01	0.313E-02	0.0	-0.303E+00	0.604E+02
0.135E+02	-0.117E-01	0.408E+00	0.170E-01	0.323E-02	0.0	-0.406E+00	0.618E+02
0.138E+02	-0.236E-01	0.399E+00	0.148E-01	0.297E-02	0.0	-0.502E+00	0.633E+02
0.140E+02	-0.318E-01	0.394E+00	0.116E-01	0.240E-02	0.0	-0.579E+00	0.648E+02
0.143E+02	-0.345E-01	0.390E+00	0.780E-02	0.165E-02	0.0	-0.630E+00	0.662E+02
0.145E+02	-0.304E-01	0.386E+00	0.409E-02	0.889E-03	0.0	-0.650E+00	0.676E+02
0.148E+02	-0.178E-01	0.379E+00	0.120E-02	0.270E-03	0.0	-0.643E+00	0.690E+02
0.150E+02	-0.609E-03	0.370E+00	0.0	0.0	0.0	-0.619E+00	0.704E+02
0.153E+02	0.312E-02	0.358E+00	0.0	0.0	0.0	-0.594E+00	0.717E+02
0.155E+02	0.251E-02	0.346E+00	0.0	0.0	0.0	-0.572E+00	0.731E+02
0.158E+02	0.210E-02	0.334E+00	0.0	0.0	0.0	-0.552E+00	0.744E+02
0.160E+02	0.181E-02	0.323E+00	0.0	0.0	0.0	-0.534E+00	0.757E+02
0.163E+02	0.157E-02	0.312E+00	0.0	0.0	0.0	-0.517E+00	0.769E+02
0.165E+02	0.139E-02	0.301E+00	0.0	0.0	0.0	-0.502E+00	0.782E+02
0.168E+02	0.122E-02	0.291E+00	0.0	0.0	0.0	-0.487E+00	0.794E+02
0.170E+02	0.108E-02	0.281E+00	0.0	0.0	0.0	-0.474E+00	0.806E+02
0.173E+02	0.963E-03	0.271E+00	0.0	0.0	0.0	-0.462E+00	0.817E+02
0.175E+02	0.860E-03	0.261E+00	0.0	0.0	0.0	-0.451E+00	0.829E+02
0.178E+02	0.770E-03	0.252E+00	0.0	0.0	0.0	-0.440E+00	0.840E+02
0.180E+02	0.693E-03	0.243E+00	0.0	0.0	0.0	-0.430E+00	0.851E+02
0.183E+02	0.622E-03	0.234E+00	0.0	0.0	0.0	-0.421E+00	0.862E+02
0.185E+02	0.564E-03	0.225E+00	0.0	0.0	0.0	-0.413E+00	0.872E+02
0.188E+02	0.508E-03	0.217E+00	0.0	0.0	0.0	-0.405E+00	0.882E+02
0.190E+02	0.464E-03	0.209E+00	0.0	0.0	0.0	-0.397E+00	0.892E+02
0.193E+02	0.420E-03	0.201E+00	0.0	0.0	0.0	-0.390E+00	0.902E+02
0.195E+02	0.384E-03	0.194E+00	0.0	0.0	0.0	-0.383E+00	0.912E+02
0.198E+02	0.350E-03	0.186E+00	0.0	0.0	0.0	-0.377E+00	0.921E+02

WPER= 0.14973E+01 WPAR= 0.11693E+00

RAD P-PER: MID TO COIL

Z =	0.0	0.49	0.97	1.46	1.95	2.44	2.92	3.41	3.90	4.39	4.87	5.36	5.85	6.34	6.82	7.31
4.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.25	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11.75	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12.25	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0008	0.0007	0.0005	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12.75	0.0015	0.0015	0.0015	0.0015	0.0014	0.0013	0.0011	0.0009	0.0007	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
13.25	0.0018	0.0018	0.0017	0.0016	0.0015	0.0013	0.0010	0.0007	0.0004	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13.75	0.0015	0.0015	0.0014	0.0012	0.0010	0.0008	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14.25	0.0008	0.0008	0.0007	0.0005	0.0004	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14.75	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS	ZS			SI			SIV			STP						
	2.8000E+01			9.5000E+00			-2.4607E-01			1.2013E+02			1.1989E+02			

APPENDIX C - Abstract from ORNL/TM-7076

CALIBRATION OF A DIAMAGNETIC DIAGNOSTIC FOR STORED ENERGY OF HIGH
TEMPERATURE ELECTRON ANNULI IN ELMO BUMPY TORUS (EBT)

K. H. Carpenter, R. A. Dandl, M. W. McGuffin

ABSTRACT

The perpendicular energy component of the stored energy of the electron annuli in Elmo Bumpy Torus (EBT) can be observed with diamagnetic flux detecting coils. The calibration of the signal from the coils in terms of stored energy requires a model for the geometrical structure of the annulus. Using a model of concentric cylindrical current sheets, the calibration factor for the diamagnetic perpendicular energy signal is derived, including the effects of drift currents and coupling of flux from adjacent annuli. Numerical calculations show the calibration factor to be insensitive to reasonable variations in the model parameters.

APPENDIX D - Abstract from Master's Thesis

THE DESIGN OF A HIGH FIELD MAGNETOMETER USING FERROMAGNETIC
RESONANCE IN SMALL YIG SPHERES

by

MARCUS DA SILVA

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

1981

ABSTRACT

A magnetometer system designed to operate in harsh environments and to measure fields with high gradients was designed and tested. It consists of a probe which is, in principle, a YIG tuned filter, and a microwave network analyzer to make absolute magnetic field measurements with accuracies that were tested to 2%. A phase locking system is used to lock the frequency of an oscillator to the probe resonance, allowing small changes to be detected. Incremental measurements can be made with a resolution of 0.004 Gauss. The accuracy of such measurements depends on the calibration methods used. A theoretical analysis of ferromagnetic resonance shows that the frequency-field relationship is linear, but that the constant term in the resonance relationship is affected by anisotropy and other effects. These effects can be removed with careful measurement technique and system design.

APPENDIX E - Source Listing of Computer Code WPERB

FILE: WPERB CPR A UNIVERSITY OF MISSOURI COMPUTER NETWORK

:READ WPERB EXEC A1 TEMP 07/29/81 19:12:14

E1 E2 LTWPERB EXEC A1

E1 E2 CWPERB EXEC A1

E1 E2 TWPERB FORTRAN A1

E1 E2 WPERB FORTRAN A1

E1 E2 SOLF FORTRAN A1

E1 E2 SOLBA FORTRAN A1

E1 E2 SGAUS8 FORTRAN A1

E1 E2 ZEROIN FORTRAN A1

*FILES FOR ANNULUS FIELD AND ENERGY CALCULATION.

*K.H.CARPENTER 29JUL81.

:READ LTWPERB EXEC A1 TEMP 07/29/81 19:05:35

LOAD TWPERB WPERB SOLF SOLBA SGAUS8 ZEROIN(NOMAP

GENMOD TWPERB

:READ CWPERB EXEC A1 TEMP 07/29/81 19:04:31

FORTGI TWPERB (NOPRINT NOTERM

FORTGI WPERB (NOPRINT NOTERM

FORTGI SOLF (NOPRINT NOTERM

FORTGI SOLBA (NOPRINT NOTERM

FORTGI SGAUS8 (NOPRINT NOTERM

FORTGI ZEROIN (NOPRINT NOTERM

:READ TWPERB FORTRAN A1 EBT1 07/29/81 18:45:55

C TEST DRIVER PROGRAM FOR WPERB. K.H.CARPENTER 29JUL81

COMMON/CWPERB/RR,XR,BZ,AMC

NAMELIST/TWPERB/WP,BZO,BRO,ZBO,RBO,VMC,VMCL,VMCR,GA,AL,RT,

1 DF,BF,RF,XR,RR,AMC,IERR

10 WRITE(5,20)

20 FORMAT(/' ENTER AL,RT,DF,GA,RF,ZBO,RBO,VMC,VMCL,VMCR,BF:')

READ(5,*)AL,RT,DF,GA,RF,ZBO,RBO,VMC,VMCL,VMCR,BF

IF(AL.LE.0.)STOP

DF=DF0

CALL WPERB(WP,BZO,BRO,ZBO,RBO,VMC,VMCL,VMCR,GA,AL,RT,

1 DF,BF,RF,IERR)

WRITE(6,TWPERB)

GO TO 10

END

:READ WPERB FORTRAN A1 EBT1 07/29/81 18:46:55

SUBROUTINE WPERB(WP,BZO,BRO,ZBO,RBO,VMC,VMCL,VMCR,GA,AL,RT,

1 DF,BF,RF,IERR)

K.H.CARPENTER 29JUL81

THIS SUBROUTINE CALCULATES THE "PERPENDICULAR ENERGY"

IN ONE ANNULUS IN ONE EBT CAVITY BASED ON

THE CURRENT SHEET MODEL DESCRIBED IN ORNL/TM-7076,

AND OUTPUTS THE CORRESPONDING B FIELD AT A SPECIFIED POINT.

ARGUMENTS TO SET ON CALL:

ZBO = AXIAL LOCATION FOR B FIELD CALCULATION

RBO = RADIAL LOCATION FOR B FIELD CALCULATION

VMC = MAGNITUDE OF INTEGRATOR VOLTAGE CHANGE
ON PLASMA TURN-DOWN (IN MILLIVOLTS),

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CORRECTED FOR ADJACENT CAVITIES'
FLUX LINKAGES

VMCL = SAME FOR LEFT (IN NEGATIVE ZBO DIRECTION)
NEIGHBORING CAVITY

VMCR = SAME FOR RIGHT (IN POS. ZBO DIRECTION)

GA = GENERATOR CURRENT (IN AMPERES)

AL = TOTAL LENGTH OF ASSUMED ANNULUS IN
TOROIDAL DIRECTION (IN CM)

RT = RADIAL THICKNESS ASSUMED FOR ANNULUS
(IN CM)

DF = DRIFT CURRENT FACTOR (=1 FOR NONE,
>1 FOR AIDING ANNULUS FLUX, <1 FOR
OPPOSING ANNULUS; =0 FOR ROUTINE TO
CALCULATE VALUE)

BF = GENERATOR GAUSS/AMP AT CENTER OF
MIDPLANE (=1 AGREES WITH MEASURED FIELD)

ARGUMENTS RETURNED:

WP = PERPENDICULAR ENERGY OF ANNULUS
(IN JOULES)

BZO = AXIAL FIELD COMPONENT (IN GAUSS)
(AT ZBO, RBO)

BRD = RADIAL FIELD COMPONENT (IN GAUSS)

DF = UNCHANGED IF >0 ON CALL; SET TO
CALCULATED VALUE IF =0 ON CALL

IERR = 0, IF ACCURACY OK; 1, IF SUBTRACTION
CAUSED WP TO BE LOST IN NOISE;
-1, IF ARGUMENT IN ERROR ON CALL.

EXTERNAL ZERFUN
DOUBLE PRECISION RSD,SLD,RFD,ZFD,BRD,BZD,APD,DPI
COMMON/CISOL/RSD,SLD,RFD,ZFD,BRD,BZD,APD
COMMON/CWPERB/RR,XR,BZ,AMC
COMMON/CSOLF/FL,BL,XB,ZB,ADEG,CX, SX,XBR,BSX,BCX

CONSTANTS PERTAINING TO EBT:

ZBC = DISTANCE OF PICKUP LOOP FROM MIDPLANE (CM)

RB = RADIUS OF PICKUP LOOP (CM)

RM = MAJOR RADIUS (CM)

ANC = NO. OF CAVITIES

AME = $2 \cdot \pi \cdot (\text{ELECTRON MASS}) / (\text{ELECTRON CHARGE})$ IN (GAUSS/CHZ)

ATC = TOTAL NO. TURNS IN SERIES IN PICKUP COILS ON ONE CAVITY

TAU = PICKUP LOOP VOLTAGE INTEGRATION TIME CONSTANT (SECONDS).

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```

C DATA ZB0/9.5/,RB/30.0/,RM/150.0/,ANC/24.0/,AME/357.22/
C DATA ATC/200.0/,TAU/0.1/
C DATA DPI/3.141592653589793D0/
C ACCURACY LEVELS:
C ACC1 FOR LOSS OF PRECISION DUE TO SUBTRACTION
C NG ORDER OF GAUSSIOAN INTEGRATION
C NSUB NO. OF SUBDIVISIONS OVER WHICH TO APPLY GAUSSIAN INT.
C DATA ACC1/1.E-3/,NG/8/,NSUB/1/
C COORDINATE TRANSFORMATIONS FOR ADJACENT CAVITIES:
C DATA INI/0/
C IF(INI.EQ.1)GO TO 10
C INI=1
C ANR=2.*DPI/ANC
C CN=COS(ANR)
C SN=SIN(ANR)
C
C TEST INPUT ARGUMENTS FOR RANGE:
C IF(VMC.LE.0..OR.GA*BF.LE.0..OR.AL.LE.0..OR.RT.LE.0.)GO TO 100
C IF(RF.LE.0.0)GO TO 100
C
C FIND RING MEAN RADIUS AN CENTER FROM RESONANCE AT RF
C (9GHZ FOR EBT-I) AND COLESTOCK FIELD MODEL
C (WARNING - FIELD MODEL VALID ONLY FOR EBT-I/S)
C
C 10 IERR=0
C IF(BOLD.EQ.GA*BF/RF)GO TO 20
C BOLD=GA*BF/RF
C BZ=AME/BOLD
C ZEROIN IS ZERO FINDING ROUTINE BY R. BRENT
C XOUT=ZEROIN(-2.,30.,ZERFUN,0.1)
C XIN=ZEROIN(-30.,-2.,ZERFUN,0.1)
C XR=0.5*(XOUT+XIN)
C RR=0.5*(XOUT-XIN)
C
C IF DF<0, CALCULATE DF FROM COLESTOCK FIELD MODEL AND FORMULA
C DF=1.+0.5*LN(BIN/BOUT)
C
C 20 IF(DF.LE.0)DF=1.+0.5*ALOG(PAT(XOUT-0.5*RT)/PAT(XOUT+0.5*RT))
C DFM2=DF-2.
C
C CALCULATE FLUX LINKAGE FOR 1 TURN DUE TO ANNULUS IN SAME CAVITY
C RSD=RR-0.5*RT
C IF(RSD.LE.0.0)GO TO 100
C SLD=AL
C BL=RB
C ADEG=0.
C XB=XR
C ZB=ZB0
C CALL SOLF(NG,NSUB)
C FS1T=FL*DFM2
C RSD=RSD+RT
C CALL SOLF(NG,NSUB)

```


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```
FSIT=FSIT+FL*DF
IF(FSIT/FL.LT.ACC1)GO TO 200
```

CALCULATE SURFACE CURRENTS FOR USE IN FIELD CALCULATIONS AS
 $\mu O * M/4\pi I$ IN GAUSS

$$AM0=5.E+4*TAU/(ATC*FSIT*BL*AL)$$
$$AMC = AMO * VMC$$
$$AML = APO * VMCL$$
$$AMR = AMO * VMCR$$

CALCULATE FIELDS DUE TO NEAREST ANNULUS:

$$RFD = RBO - XR$$
$$ZF D = Z \dot{B} D$$

CALL SOLBA

CALL SOLBA
BRQ=BRD*DF

$$BZO = BZD * DF$$
$$RSD = RSD - RT$$

CALL SOLBA

BR0=BR0+BRD*DFM2

$$BZC = BZO + BZD * DFM2$$

CALCULATE FIELDS DUE TO ADJACENT CAVITIES' ANNULI:

CAVITY IN NEG. Z DIRECTION

$$RFD = (RM + RBO) * CN - ZBO * SN - RM - XR$$
$$ZF D = (R M + R B O) * S N + Z B O * C N$$

CALL - SOLBA

$$BR1 = BRD * DFM2$$

BZ1=BZD*DFM2

$$RSD = RSD + RT$$

CALL SOLBA

$$BR1 = BR1 + BRD * DF$$
$$BZ1 = BZ1 + BZD * DF$$

CAVITY IN POS. Z DIRECTION

$$RFD = RFD + 2.0 * ZBO * SN$$
$$ZFD = ZFD - 2.0 * (RM + RBD) * SN$$

CALL SOLBA

$$BR2 = BRD * DF$$

BZ2=BZD*DF

$$RSD = RSD - RI$$

CALL SOLBA

$$BR2 = BR2 + BRD * DFM2$$
$$\bar{B}Z\bar{Z} = \bar{B}Z\bar{Z} + \bar{B}ZD * DFM\bar{Z}$$

COMBINE RESULTS AND APPLY SCALE FACTORS:

NUMERICAL FACTOR IN NEXT LINE TAKES INTO ACCOUNT LENGTHS IN CM NOT M, AND VMC IN MILLIVOLTS NOT VOLTS.

WP=1.E-2*DPI*VMC*AME*TAU*RF*RT*RR/(ATC*FSIT*BL)

BRO=BRO*AMC

$$BZO = BZO * AMC$$

BR1=BR1*AML

BZ1=BZ1*AML

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```

      BR2=BR2*AMR
      BZ2=BZ2*AMR
C      MINUS BELOW FOR DIAMAGNETIC ANNULUS
      BRO=-(BRO+(BR1+BR2)*CN+(BZ1-BZ2)*SN)
      BZO=-(BZO+(BZ1+BZ2)*CN+(BR2-BR1)*SN)
      RETURN
C
C      ERROR RETURNS:
100      IERR=-1
      RETURN
200      IERR=1
      RETURN
      END

      FUNCTION ZERFUN(X)
      COMMON/CWPERB/RR,XR,BZ,AMC
      ZERFUN=BZ-PAT(X)
      RETURN
      END

C      FUNCTION PAT(X)
C      COLESTOCK FIT TO MIDPLANE FIELD IN EBT-I/S RESTRICTED TO ZERO
C      ANGLE.
      T2=0.
      R=X
      IF(X.GE.0.)GO TO 10
      T2=3.14159**2
      R=-X
10      PT=T2*(1.-3.724E-2*T2)
      C1=(PT+20.81)*1.046E-4
      C2=C1-2.04158E-3
      C3=(PT+12.43)*.5966
      AL=C1+C2*SIN((R-13.8)/C3)
      PAT=EXP(-AL*((X+2.90281)**2))
      RETURN
      END
:READ SOLF FORTRAN A1 EBT1 07/28/81 15:22:16
C      SUBROUTINE SOLF(NG,NSUB)
C      K.H.CARPENTER 28JUL81
C      COPIED FROM VERSION OF 07JUL81 ON PDP-10
C      USES GAUSSIAN INTEGRATION TO PERFORM (NORMALIZED) INTEGRAL
C      OF EQ(26), ORNL/TM-7076.
C      NG IS ORDER OF GAUSSIAN INTEGRATION; NSUB IS NUMBER OF
C      SUBDIVISIONS OF THE CIRCLE OVER WHICH GAUSSIAN INTEGRATION IS
C      APPLIED.
C      RETURNS NORMALIZED FLUX LINKAGE IN A CIRCULAR LOOP DUE TO A
C      CYLINDRICAL CURRENT SHEET.
C      ARGUMENTS PASSED IN COMMONS /CSOLF/ AND /CISOL/.
C      CALLING PROGRAM MUST SET CURRENT SHEET PARAMETERS IN /CISOL/:
C      RADIUS RSD, LENGTH SLD
C      CALLING PROGRAM MUST SET LOOP PARAMETERS IN /CSOLF/:
C      RADIUS BL, CENTER IN SHEET COORDINATES XB,ZB,
C      ANGLE IN DEGREES OF LOOP NORMAL TO SHEET AXIS, ADEG
C      NORMALIZED FLUX LINKAGE IS RETURNED AS FL IN /CSOLF/.
C      FL=FLUX*2*PI/MU0/BL/SLD/CURDEN

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C      DOUBLE PRECISION DPI
      EXTERNAL SOFUN
      COMMON/CSOLF/FL,BL,XB,ZB,ADEG,CX,SX,XBR,BSX,BCX
      DATA GPI/3.141592653589793D0/
      ANX=DPI*ADEG/180.
      CX=COS(ANX)
      SX=SIN(ANX)
      XBR=SB/BL
      BSX=BL*SX
      BCX=BL*CX
C      IF INTEGRATION NOT REQUIRED DUE TO SYMMETRY, SKIP IT.
      IF((ADEG.EQ.0..OR.ADEG.EQ.180.).AND.(XB.EQ.0.))GO TO 10
      CALL SGAUS8(0.00,DPI,NSUB,ANSWER,SOFUN,NG)
      FL=ANSWER
      RETURN
10     FL=DPI*SOFUN(0.)
      RETURN
      END
      FUNCTION SOFUN(ALP)
      DOUBLE PRECISION RSD,SLD,RFD,ZFD,BRD,BZD,APD
      COMMON/CISOL/RSD,SLD,RFD,ZFD,BRD,BZD,APD
      COMMON/CSOLF/FL,BL,XB,ZB,ADEG,CX,SX,XBR,BSX,BCX
      A=ALP
      SA=SIN(A)
      CA=COS(A)
      ZFD=ZB-BSX*CA
      RFD=SQRT((BL*SA)**2+(XB+BCX*CA)**2)
      CALL SOLBA
      SOFUN=APD*(BCX+XB*CA)/RFD
      RETURN
      END
:READ SOLBA      FORTRAN    A1 EBT1    10/13/80 08:50:07
      SUBROUTINE SOLBA
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/CISOL/RS,SL,RF,ZF,BR,BZ,AP
C      K.H.CARPENTER 29SEP80    UMR DEPT. OF EE.
C      ****
C      CALCULATES THE B-FIELD AND A-FIELD COMPONENTS FOR AN IDEAL
C      SOLENOID USING THE METHOD OF M.W.GARRETT, JAP VOL.34 P2567 (1963).
C      THIS VERSION IS AN ADAPTION OF THE BIDSOL SUBROUTINE WRITTEN BY
C      TOMMY TUCKER OF OAK RIDGE NAT. LAB., COMPUTER SCIENCES DIV.
C      (BIDSOL CONVERTED TO DOUBLE PRECISION, NORMALIZATION CHANGED, AND
C      CALCULATION OF VECTOR POTENTIAL ADDED.)
C      ****
C      INPUT VALUES:
C      RS - RADIUS OF SOLENOID CURRENT SHEET
C      SL - LENGTH OF SOLENOID CURRENT SHEET
C      RF - FIELD POINT RADIAL DISTANCE FROM SOLENOID AXIS
C      ZF - FIELD POINT AXIAL DISTANCE FROM CENTER OF SOLENOID
C      (INPUT VALUES CAN BE IN ANY UNIT OF LENGTH, BUT ALL FOUR MUST
C      BE IN THE SAME UNITS.)
C      OUTPUT VALUES:
C      BR - NORMALIZED RADIAL FIELD COMPONENT
C      BZ - NORMALIZED AXIAL FIELD COMPONENT

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C      AP - NORMALIZED ANGULAR VECTOR POTENTIAL COMPONENT
C      TO OBTAIN DIMENSIONAL VALUES FOR COMPONENTS:
C      MULTIPLY ALL COMPONENTS BY SURFACE CURRENT DENSITY AND
C      MULTIPLY ALL COMPONENTS BY PERMEABILITY DIVIDED BY 4 TIMES PI.
C      IN ADDITION, MULTIPLY AP BY THE DIMENSIONAL LENGTH OF THE
C      SOLENOID CURRENT SHEET.
C****
      DATA PI/3.14159 265389 793238 DO/
      DATA IOL/1.0=12/, CUT/5.0-4/, CUTSQ/25.0-8/
      RSMRF=RS-RF
      RSPRF=RF+RS
      RSPFSQ=RSPRF**2
      DZ1=ZF-0.5DO*SL
      DZ2=DZ1+SL
      DZ1SQ=DZ1*DZ1
      R1SQ=RSPFSQ+DZ1SQ
      R1=DSQRT(R1SQ)
      DZ2SQ=DZ2*DZ2
      R2SQ=RSPFSQ+DZ2SQ
      R2=DSQRT(R2SQ)
      IF(RF.GT.1.00-6)GO TO 20
C  ON  AXIS THE CALCULATION SIMPLIFIES TO
      BZ=2.DO*PI*(DZ2/R2-DZ1/R1)
      BR=0.DO
      AP=0.DO
      RETURN
20    CONTINUE
      RSRFT4=RS*RF*4.DO
      PAR1=RSRFT4/R1SQ
      CMOD1=DSQRT(1.DO-PAR1)
      A1=1.DO
      B1=CMOD1
      CPRIME=RSMRF/RSPRF
      CCHAR=CPRIME**2
      IF(CCHAR.GE.CUTSQ)GO TO 30
C  TO CALCULATE BZ AT OR NEAR THE RADIUS OF THE CURRENT SHEET,
C  MODIFY CCHAR TO ALLOW THE ITERATION TO PROCEED WITHOUT
C  ZERO DIVIDED OR OVERFLOW. THE BZ CALCULATION IS CORRECTED
C  FOR THE SMALL ERROR INTRODUCED AT THE END OF THE ROUTINE.
      CPRIMA=CUT
      IF(RSMRF.LT.0.DO)CPRIMA=-CPRIMA
      CCHAR=CUTSQ
30    CONTINUE
      D1=CCHAR/CMOD1
      CHAR=1.DO-CCHAR
      E1=CHAR/CCHAR
      F1=0.DO
      S1=0.DO
      PAR2=RSRFT4/R2SQ
      CMOD2=DSQRT(1.DO-PAR2)
      A2=1.DO
      B2=CMOD2
      D2=CCHAR/CMOD2
      E2=E1
      F2=0.DO

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```

S2=0.00
TWOP=1.00
100 CONTINUE
TWOP=TWOP*2.00
C=A1
A1=(A1+B1)*0.500
B1=DSQRT(C*B1)
CSQ1=(C-A1)**2
S1=S1+CSQ1*TWOP
C=A2
A2=(A2+B2)*0.500
B2=DSQRT(C*B2)
CSQ2=(C-A2)**2
S2=S2+CSQ2*TWOP
C=F1
F1=(E1+F1)*0.500
DPONE=D1+1.00
E1=(D1*E1+C)/DPONE
D1=B1*0.2500*DPONE*DPONE/(A1*D1)
C=F2
F2=(E2+F2)*0.500
DPONE=D2+1.00
E2=(D2*E2+C)/DPONE
D2=B2*0.2500*DPONE*DPONE/(A2*D2)
IF((CSQ1.GT.TOL).OR.(CSQ2.GT.TOL))GO TO 100
C ONE ADDITIONAL 'A' STEP WILL HALVE THE ERROR
A1=(A1+B1)*0.500
A2=(A2+B2)*0.500
C BR CAN NOW BE CALCULATED FROM ELLIPTIC INTEGRAL VALUES
BR=0.500*PI*(R2*S2/A2-R1*S1/A1)/RF
C CONTINUE ITERATIONS TO IMPROVE ACCURACY OF 3RD COMPLETE ELL. INTEGRAL
200 CONTINUE
C=F1
F1=(E1+F1)*0.500
DPONE=D1+1.00
E1=(D1*E1+C)/DPONE
D1=0.2500*DPONE*DPONE/D1
C=F2
F2=(E2+F2)*0.500
DPONE=D2+1.00
E2=(D2*E2+C)/DPONE
D2=0.2500*DPONE*DPONE/D2
IF((D1*D2-1.00).GT.TOL)GO TO 200
F1=(E1+F1)*0.500
F2=(E2+F2)*0.500
C BZ AND AP CAN NOW BE CALCULATED
BZ=PI*(DZ2*(RS+RS+RSMRF*F2)/(RSPRF*R2*A2)-
> DZ1*(RS+RS+RSMRF*F1)/(RSPRF*R1*A1))
IF((CCHAR.EQ.CUTSQ).AND.(CPRIME.NE.0.00))BZ=BZ+PI*
> DABS(CPRIMA-CPRIME)/CPRIMA*(DZ2/(R2*CMOD2)-DZ1/(R1*CMOD1))
RSMRFS=RSMRF**2
AP=(DZ2*(R2*0.500*(PAR2+S2)-RSMRFS*F2/R2)/A2 -
> DZ1*(R1*0.500*(PAR1+S1)-RSMRFS*F1/R1)/A1)*0.500*PI/(RF*SL)
RETURN
END

```

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:READ SGAUS8 FORTRAN A1 TEMP 07/29/81 18:02:10
SUBROUTINE SGAUS8(XL,XU,NFOLD2,ANSW,FUN,NPT2)
MODIFIED 1MAY79 BY KHC TO HAVE MAX NPT2=8

CC THIS IS A SINGLE PRECISION VERSION TO RUN ON THE 7600.

C.....
C PROGRAM AUTHOR E. B. HARRIS
C GASEOUS DIFFUSION DEVELOPMENT DIVISION, UNION CARBIDE CORP.,
C NUCLEAR DIV.,
C OAK RIDGE, TENN.

C XL=LOWER LIMIT OF INTEGRAL
C XU=UPPER LIMIT OF INTEGRAL
C NFOLD2=NUMBER OF EQUAL SUBINTERVALS THAT (XL,XU) IS TO BE
C SUBDIVIDED INTO
C ANSW=APPROXIMATE VALUE OF THE INTEGRAL AS EVALUATED BY THIS
C SUBROUTINE
C FUN=THE NAME OF THE SINGLE PRECISION FUNCTION SUBPROGRAM THAT
C DEFINES THE INTEGRAND FUNCTION. FUN HAS ONE SINGLE PRECISION
C VARIABLE, SAY X, AS AN ARGUMENT AND RETURNS THE VALUE OF THE
C INTEGRAND AT X (WHERE X IS THE VARIABLE OF INTEGRATION). THE
C NAME PASSED TO FUN MUST BE DECLARED EXTERNAL IN THE CALLING
C PROGRAM.
C NPT2=NUMBER OF POINTS (ORDER) AT WHICH THE INTEGRAND IS TO BE
C EVALUATED IN EACH SUBINTERVAL, I.E., TOTAL NUMBER OF
C EVALUATIONS = NPT2*NFOLD2. PERMISSABLE VALUES OF NPT2 ARE
C 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 16, 20, 24, 32, 40, 48, 64,
C 80, AND 96. IF NPT2 IS .LT. 2, 2 POINTS ARE USED. IF NPT2 IS
C .GT. 96, 96 POINTS ARE USED. WITHIN THE RANGE OF 2-96, IF NPT2
C IS NOT ONE OF THE PERMISSABLE VALUES, THE NEXT HIGHER
C PERMISSABLE VALUE IS USED.

C THE DATA STATEMENTS BEGINNING WITH AN2 AND ENDING WITH AN96D
C ARE THE ABSCISSAS AND WEIGHT FACTORS FOR THE GAUSSIAN INTEGRATION
C AND ARE TAKEN FROM THE HANDBOOK OF MATHEMATICAL FUNCTIONS EDITED
C BY MILTON ABRAMOWITZ AND IRENE A. STEGUN, APPLIED MATHEMATICS
C SERIES 55, U. S. DEPARTMENT OF COMMERCE, NATIONAL BUREAU OF
C STANDARDS, 1964, PAGES 916-919.

C.....
C LOGICAL EVEN,READY
C DIMENSION AN2(2),AN3(4),AN4(4),AN5(6),AN6(6),AN7(8),AN8(8)
C DIMENSION CONST(38),JSTART(7)
C EQUIVALENCE (CONST(1),AN2(1)),(CONST(3),AN3(1)),(CONST(7),AN4(1))
> ,(CONST(11),AN5(1)),(CONST(17),AN6(1)),(CONST(23),AN7(1)),
> (CONST(31),AN8(1))
C DATA JSTART/4,8,12,18,24,32,40/
> ,READY/.FALSE./
C DATA AN2/ 0.577350269189626, 1.000000000000000/
C DATA AN3/ 0.000000000000000, 0.888888888888889, 0.774596669241483,
> 0.555555555555556/
C DATA AN4/ 0.339981043584856, 0.652145154862546, 0.861136311594053,
> 0.347854845137454/
C DATA AN5/ 0.000000000000000, 0.568888888888889, 0.538469310105683,
> 0.478628670499366, 0.906179845938664, 0.236926885056189/
C DATA AN6/ 0.238619186093197, 0.467913934572691, 0.661209386466265,

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```

> 0.360761573048139, 0.932469514203152, 0.171324492379170/
DATA AN7/ 0.000000000000000, 0.417959183673469, 0.405845151377397,
> 0.381830050505119, 0.741531185599394, 0.279705391489277,
> 0.949107912342759, 0.129484966168870/
DATA AN8/ 0.183434642495650, 0.362683783378362, 0.525532409916329,
> 0.313706645877887, 0.796666477413627, 0.222381034453374,
> 0.960289856497536, 0.101228536290376/

```

```

C.....ON FIRST TIME PROGRAM IS INVOKED, TAKE ONE-HALF OF THE CONSTANTS
C      IN ARRAY CONST.
C.....

```

```

      IF (READY) GO TO 20
      DO 10 I=1,38
        CONST(I)=0.5D+00*CONST(I)
      10 CONTINUE
      READY=.TRUE.
      20 NPT=IABS(NPT2)
      NFOLDS=IABS(NFOLD2)

```

```

C.....DETERMINE THE PERMISSABLE NUMBER OF POINTS TO USE IN EACH
C      SUBINTERVAL AND THE STARTING POINT IN ARRAY CONST FOR THAT
C      NUMBER OF POINTS.
C.....

```

```

      IF (NPT.LT.2) NPT=2
      IF (NPT.GT.8) NPT=8

```

```

      JHOLD=JSTART(NPT-1)
      EVEN=.FALSE.
      IF (MOD(NPT,2).EQ.0) EVEN=.TRUE.
      H=(XU-XL)/DBLE(FLOAT(NFOLDS))
      A=XL-0.5D+00*H
      ANSW=C.D+00
      KSTOP=NPT/2

```

```

      DO 60 I=1,NFOLDS

```

```

        J=JHOLD

```

```

        A=A+H

```

```

        DO 50 K=1,KSTOP

```

```

          J=J-3

```

```

          C=CONST(J)*H

```

```

          J=J+1

```

```

          ANSW=ANSW+CONST(J)*((FUN(A+C)+FUN(A-C)))

```

```

      50 CONTINUE

```

```

        IF (EVEN) GO TO 60

```

```

        ANSW=ANSW+CONST(J-2)*FUN(A)

```

```

      60 CONTINUE

```

```

      ANSW=ANSW*H

```

```

      RETURN

```

```

      END

```

```

:READ ZERGIN    FORTRAN    A1 TEMP    07/29/81 18:02:48

```

```

      REAL FUNCTION ZERGIN(AX,BX,F,TOL)

```

```

      REAL AX,BX,F,TOL

```

```

C      A ZERO OF THE FUNCTION F(X) IS COMPUTED IN THE INTERVAL AX,BX.
C      INPUT..

```

FILE: WPERB CPR A UNIVERSITY OF MISSOURI COMPUTER NETWORK

```

C
C AX      LEFT ENDPOINT OF INITIAL INTERVAL
C BX      RIGHT ENDPOINT OF INITIAL INTERVAL
C F       FUNCTION SUBPROGRAM WHICH EVALUATES F(X) FOR ANY X IN
C         THE INTERVAL AX,BX
C TOL     DESIRED LENGTH OF THE INTERVAL OF UNCERTAINTY OF THE
C         FINAL RESULT ( .GE. 0.0)
C
C
C OUTPUT..
C
C ZEROIN ABCISSA APPROXIMATING A ZERO OF F IN THE INTERVAL AX,BX
C
C IT IS ASSUMED THAT F(AX) AND F(BX) HAVE OPPOSITE SIGNS
C WITHOUT A CHECK. ZEROIN RETURNS A ZERO X IN THE GIVEN INTERVAL
C AX,BX TO WITHIN A TOLERANCE  $4 * \text{MACHEPS} * \text{ABS}(X) + \text{TOL}$ , WHERE MACHEPS
C IS THE RELATIVE MACHINE PRECISION.
C THIS FUNCTION SUBPROGRAM IS A SLIGHTLY MODIFIED TRANSLATION OF
C THE ALGOL 60 PROCEDURE ZERO GIVEN IN RICHARD BRENT, ALGORITHMS FOR
C MINIMIZATION WITHOUT DERIVATIVES, PRENTICE - HALL, INC. (1973).
C
C REAL A,B,C,D,E,EPS,FA,FB,FC,TOL1,XM,P,Q,R,S
C
C COMPUTE EPS, THE RELATIVE MACHINE PRECISION
C
C EPS = 1.0
C 10 EPS = EPS/2.0
C TOL1 = 1.0 + EPS
C IF (TOL1 .GT. 1.0) GO TO 10
C
C INITIALIZATION
C
C A = AX
C B = BX
C FA = F(A)
C FB = F(B)
C
C BEGIN STEP
C
C 20 C = A
C FC = FA
C D = B - A
C E = D
C 30 IF (ABS(FC) .GE. ABS(FB)) GO TO 40
C A = B
C B = C
C C = A
C FA = FB
C FB = FC
C FC = FA
C
C CONVERGENCE TEST
C

```


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```

40 TOL1 = 2.0*EPS*ABS(B) + 0.5*TOL
   XM = .5*(C - B)
   IF (ABS(XM) .LE. TOL1) GO TO 90
   IF (FB .EQ. 0.0) GO TO 90
C
C IS BISECTION NECESSARY
C
   IF (ABS(E) .LT. TOL1) GO TO 70
   IF (ABS(FA) .LE. ABS(FB)) GO TO 70
C
C IS QUADRATIC INTERPOLATION POSSIBLE
C
   IF (A .NE. C) GO TO 50
C
C LINEAR INTERPOLATION
C
   S = FB/FA
   P = 2.0*XM*S
   Q = 1.0 - S
   GO TO 60
C
C INVERSE QUADRATIC INTERPOLATION
C
50 Q = FA/FC
   R = FB/FC
   S = FB/FA
   P = S*(2.0*XM*Q*(Q - R) - (B - A)*(R - 1.0))
   Q = (Q - 1.0)*(R - 1.0)*(S - 1.0)
C
C ADJUST SIGNS
C
60 IF (P .GT. 0.0) Q = -Q
   P = ABS(P)
C
C IS INTERPOLATION ACCEPTABLE
C
   IF ((2.0*P) .GE. (3.0*XM*Q - ABS(TOL1*Q))) GO TO 70
   IF (P .GE. ABS(0.5*E*Q)) GO TO 70
   E = D
   D = P/Q
   GO TO 80
C
C BISECTION
C
70 D = XM
   E = D
C
C COMPLETE STEP
C
80 A = B
   FA = FB
   IF (ABS(D) .GT. TOL1) B = B + D
   IF (ABS(D) .LE. TOL1) B = B + SIGN(TOL1, XM)
   FB = F(B)
   IF ((FB*(FC/ABS(FC))) .GT. 0.0) GO TO 20

```

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GO TO 30

C

C

C

DONE

90 ZERGIN = 8

RETURN

END