NSTX-CALC-11-04

NSTX PFC Stress Analysis

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Reviewed by B. Nelson (ORNL)

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NSTX

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Subject: **PFC STRESS ANALYSIS AND TESTING**

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ABSTRACT

A design was proposed for mounting graphite tiles to the NSTX Center Stack which utilized drift[shear] pins and inconel brackets. Analysis of the mounting structure was performed and pull tests were performed on assemblies which simulated the attachment geometry in an attempt to determine the ultimate strength of the configuration and the mechanism of failure.

Analyses were also performed to determine the forces on the PFC components. These are attached as a memo at the end of this document entitled, "Tile and Component Force Summary for NSTX PFC Design."

Preliminary hand calculations of the CS tile configuration were performed as well as 2-D analysis using FRAME MAC[1]. Subsequent analyses were performed on completed drawings of the assemblies using MECHANICA[2]. Two candidate composite graphites were used in the test program. The other variables in the test program were the mounting pin diameter, the number of pins, and the direction of the pin relative to the grain direction of the specimens. The pin centerline distance from the edge of the tile was constrained by the design, therefore, that value was held constant in all the tests.

The results indicated that the short edge distance of the pin was the initiating factor in all the tile failures. The material and its orientation determined the failure mode and the ultimate load value. The failure load was affected to a lesser extent by the pin diameter and number of pins.

Only the Allied Signal (AS) material was able to meet the design criteria with any margin of safety. It was shown to be highly oriented, however and had the prerequisite strength only if loaded in the correct plane.

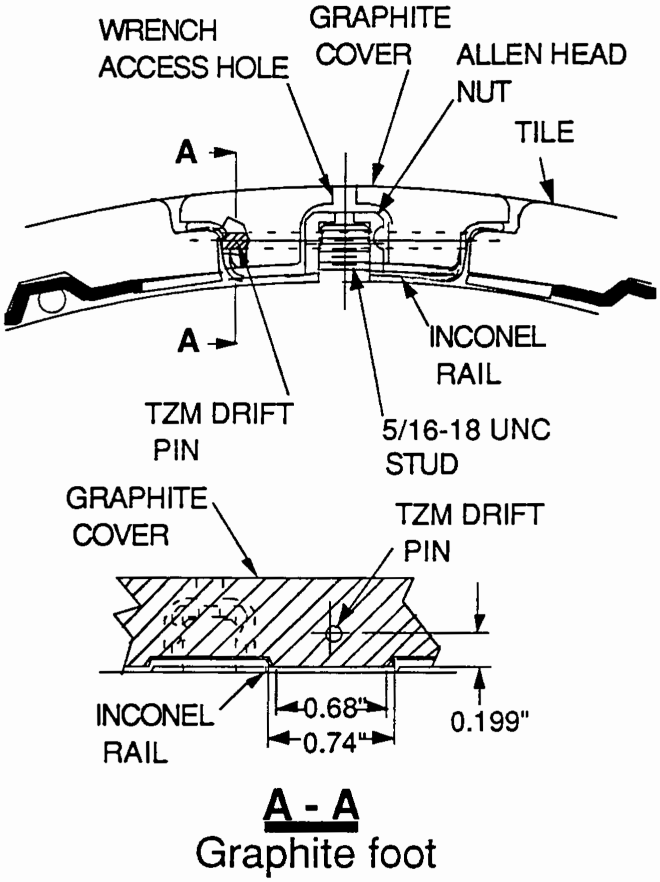
DISCUSSION

The baseline rail tile design is shown in figure 1. The rail tile assembly is attached to the Center Stack [CS] by studs. A step in the rail tile permits lapping adjacent tiles and serves to retain them, thereby halving the number of mounting studs required. The design utilizes four, 0.093 inch diameter, TZM alloy drift pins to retain the graphite tile onto the inconel rail. During disruption events a distributed load of approximately 100 psi was assumed to be applied to the graphite, in a direction radially away from the central column. This load is transmitted as a shear load through the drift pins into the rail bracket. With a nominal 2" x 6" tile this equates to 300 lbs per pin.

The entire rail tile structural is required to fall within an envelope of 0.55 inches from the CS. The pin diameter and edge distance are highly constrained by the necessity to clear the tile offset and the rail return leg. Thermal gradient considerations and size tradeoff studies result in a compromise design with a pin centerline to graphite edge distance of 0.199 inches. Using a 0.094 inch diameter pin results in a centerline to edge distance of 2.14

diameters, well within the criteria of two diameters set by strength of material handbooks for fasteners in pure shear. Using this criteria, tear out of the material should not occur, failure should be by tensile failure of the part or shear of the fastener itself. There is a problem with these failure criteria, however; they assume isotropic material, short

FIGURE 1 BASELINE CS TILE ASSY



fasteners and plates composed of the same modulus. This is not the case for the tile geometry where the pins are very long, the graphite anisotropic, and the modulus anywhere from 2 to 10 times less than the fastener, depending on grain direction. Nonlinear effects occur, such as pin bending and stress concentrations at the edge of the tile. For this reason the material properties supplied by the manufacturer are useful as guides in designing tile mounts and determining limiting loads for the configurations, but actual failure loads and failure modes can not be accurately predicted without testing.

TESTING PROGRAM

The two materials tested were:

1. FMI's Coarse Weave 4D carbon-carbon composite. The grain of the material had the appearance of a cloth weave, the pattern varying in all three planes.
2. Product 865-19-4, a carbon-carbon composite developed by Allied Signal for use in aircraft brakes. The grain in this material appeared as multi-directional individual fibers, with much the look of a felt. There was a definite impression of layers; fibers appear to be orientated primarily in a plane perpendicular to the "Z" direction.

The pin stock used in the testing was steel drill rod. The modulus of the steel approximates the modulus of the TZM pin material when it is at its maximum projected operating temperature of 700 C.

TEST DESCRIPTION

Specimens in Test Series 1 & 2 duplicated actual dimensions of the tile width, lower radius, pin length, and tile step dimension. The specimen thickness represented a section of the full tile containing one pin. (It equaled the width of the full depth foot section of the tile between stud fasteners shown in figure 1.)

The overall height of the specimen was increased to accommodate the 0.25" diameter pull pin used in the test fixture. This had no bearing on the test results since the section being tested was below the step of the tile. The pull fixture is shown in figure 2.

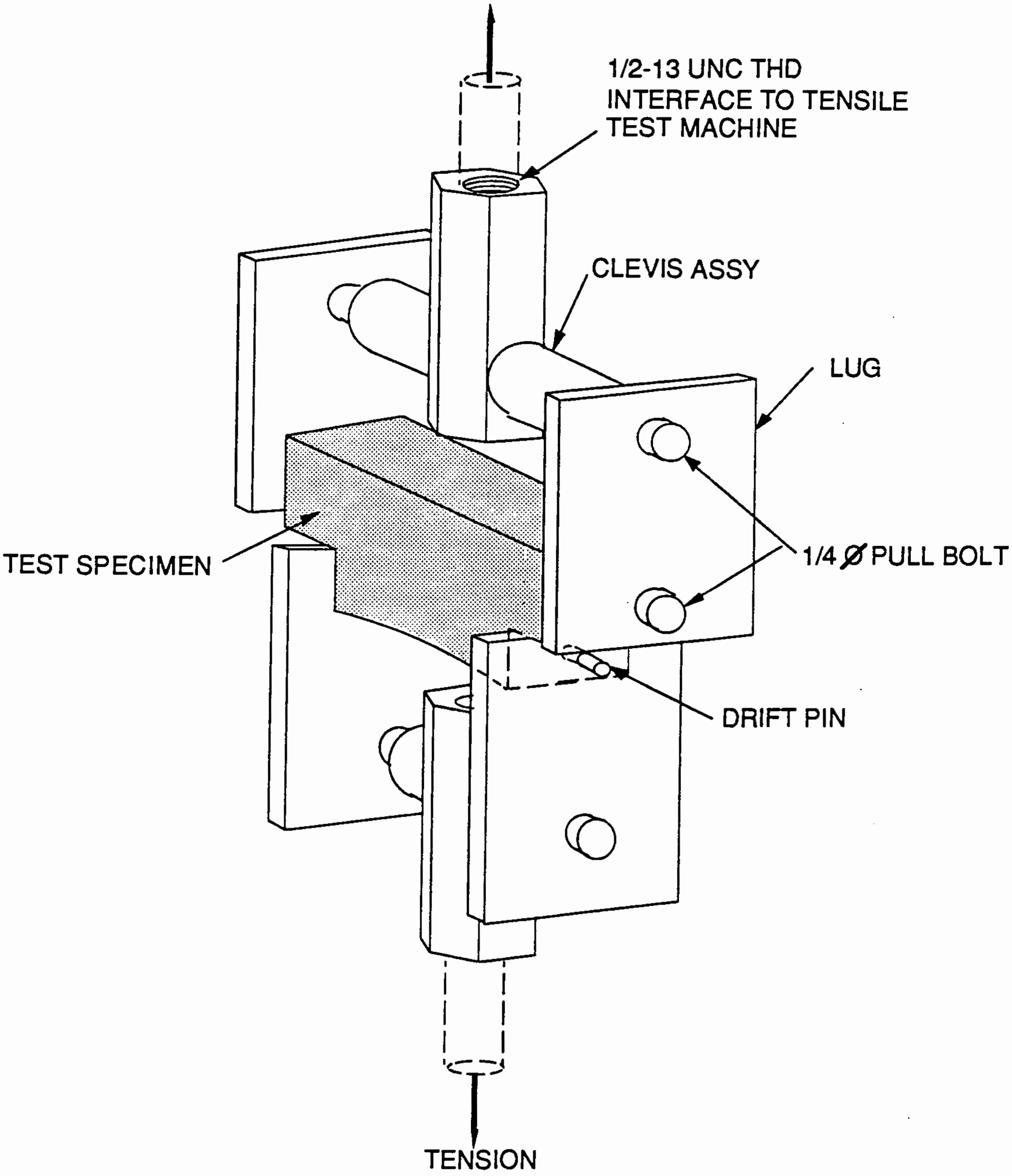
Test Series 2 had a three fold purpose:

- to determine the suitability of AS , a more economical and more readily available material than FMI.
- to quantify the effect of using two pins instead of one; it seemed reasonable to assume that the strength would double, thereby giving the safety margin required.
- to study the effect of using larger diameter pins with the same centerline

Test Series 3 was added to the original testing after disappointing results in Series 2 indicated that there may be a strong orientation in the grain structure of the Allied Signal material. The available material was too small to accommodate the prototypic dimensions of the tiles in a plane perpendicular to the stock. As a result, specimens were machined as reduced size, simple rectangular blocks, without the stepped feature or the lower radius and with a narrower width than the actual tiles. Thickness of the specimens was increased slightly. To make the results meaningful, specimens were made in two perpendicular planes of the Allied Signal material and another specimen was machined out of FMI material in identical orientation to the previous testing. This permitted testing to give comparative results which show the effect of grain orientation and relative strength of two different geometry's; the results do not necessarily represent the actual ultimate strength of the baseline tile configuration.

All specimens were pulled in a tensile test machine at a constant rate of 0.001 inches per second. Lugs were used on a pulling fixture to simulate the rail bracket. They applied the load in shear through the drift pins. A similar set of lugs applied shear to the quarter inch pull bolt at the the end, simulating the disruption load. Load and displacement were continuously plotted. In several runs the specimens were cycled by releasing the load before failure and then reapplying the load to a higher level.

FIGURE 2. PULL FIXTURE



Test Series 1 Parameters - Reference figure 3.

- FMI material
- 4 specimens in test
- Single pin, .094 inch in diameter, drilled in plane perpendicular to Z axis.

FIGURE 3 - Test Series 1 & 2 Test Specimen
Single Hole Configuration
All dimensions are in inches.

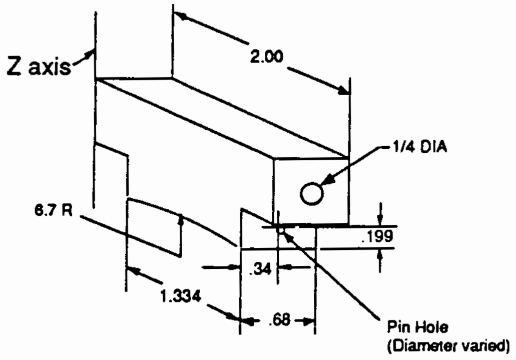


FIGURE 5 - Test Series 3 Test Specimen
All dimensions are in inches.

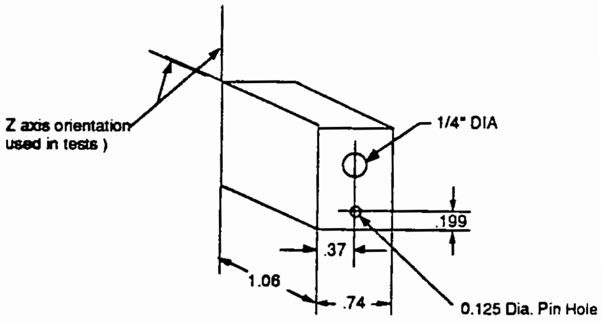
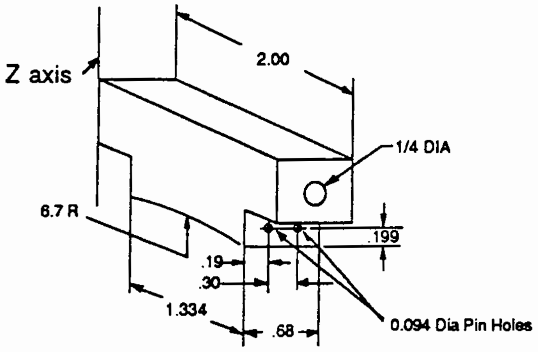


FIGURE 4 - Test Series 2 Test Specimen
Double Hole Configuration
All dimensions are in inches.



Test Series 2 Parameters - Reference figure 3, figure 4

- Allied Signal Material
- pins perpendicular to Z axis
- 3 specimens with double, 0. 094" dia pins
- 2 specimens with single 0.125" dia pin
- 1 specimen with single 0.1875" dia pin
- 1 specimen with single 0.25" dia pin

Test Series 3 Parameters - Reference figure 5

- 1 specimen of FMI material, same orientation as Test Series 1, with single 0.125" dia pin
- 2 specimens of Allied Signal material, orientated same as previous tests with single 0.125"dia pin perpendicular to Z axis.
- 2 specimens of Allied Signal material, orientated perpendicular to previous tests with single 0.125" dia pin parallel to Z axis.

TEST RESULTS

Test Series 1

Key

AS	Allied Signal
FMI	FMI material
T	Tensile failure, top split off
TO	Shear failure, tear-out of material

Run No.	Matl	Pin Dia (inch)	Fail. Load (lbs)	Fail. Mode	Pin Orientation to Z axis	Note
BN-1	FMI	0.094	375	TO	Perpendicular	1
BN-2	FMI	0.094	290	TO	Perpendicular	2
BN-3	FMI	0.094	315	TO	Perpendicular	3
BN-4	FMI	0.094	-	TO	Perpendicular	4
		Average	327			

Notes

1. Value is approximated ; specimen was inadvertently loaded at high rate of speed. The load reached approximately 475 lbs before starting down.
2. Ductile fracture, load continued to climb and leveled out at 320 lbs as fibers continued to fail across surface.
3. Specimen cycled to 250 lbs and back to zero twice before loading to failure. Some permanent strain was evident at unload.
4. The specimen was cycled to peaks of 226, 229, and 267 lbs respectively rather than loading to total failure. There was permanent strain in the specimen and cracks were evident on visual inspection.

Test Series 2

Key

AS	Allied Signal
FMI	FMI material
T	Tensile failure, top split off
TO	Shear failure, tear-out of material

Run No.	Matl	No. Pins/ Pin Dia (inch)	Fail. Load (lbs)	Fail. Mode	Pin Orientation to Z axis	Note
BN-5	AS	2,.094	308	T	Perpendicular	1
BN-6	AS	2,.094	240	T	Perpendicular	2
BN-7	AS	2,.094	315	T	Perpendicular	3
BN-8	AS	1,.125	335	T	Perpendicular	4
BN-9	AS	1,.1875	360	T	Perpendicular	5
BN-10	AS	1,.125	375	T	Perpendicular	6
BN-11	AS	1,.25	380	T	Perpendicular	7

Notes
1. Brittle failure.
2. Brittle failure.
3. Brittle failure.
4. Brittle failure.
5. Brittle failure.
6. Chamfered edges. Transition not as sharp.
7. Chamfered edges. Load continued up to 400 lbs after indication of initial failure.

Test Series 3

Key

AS	Allied Signal
FMI	FMI material
T	Tensile failure, top split off
TO	Shear failure, tear-out of material

Run No.	Matl	Pin Dia (inch)	Fail. Load (lbs)	Fail. Mode	Pin Orientation to Z axis	Note
BN-12	AS	0.125	350	T	Perpendicular	1
BN-13	AS	0.125	410	T	Perpendicular	2
BN-14	AS	0.125	668	TO	Parallel	3
BN-15	AS	0.125	570	TO	Parallel	4
BN-16	FMI	0.125	375	TO	Perpendicular	5

Notes

1. Brittle fracture

2. Brittle fracture

3. Ductile fracture, load maintained above 500 lbs for over 0.07 in of displacement. Progressed to total failure.

4. Ductile failure. Load was cycled once before failure. Maintained over 500 lbs for over .045 in of displacement. Load was released before failure of entire section.

5. Ductile failure. Load released after edges split. Initial failure hard to establish, probably exceeded elastic limit much earlier, somewhere around 320 - 350 lbs.

TEST SUMMARY

A typical readout from the testing[BN8] is included in the attachments.

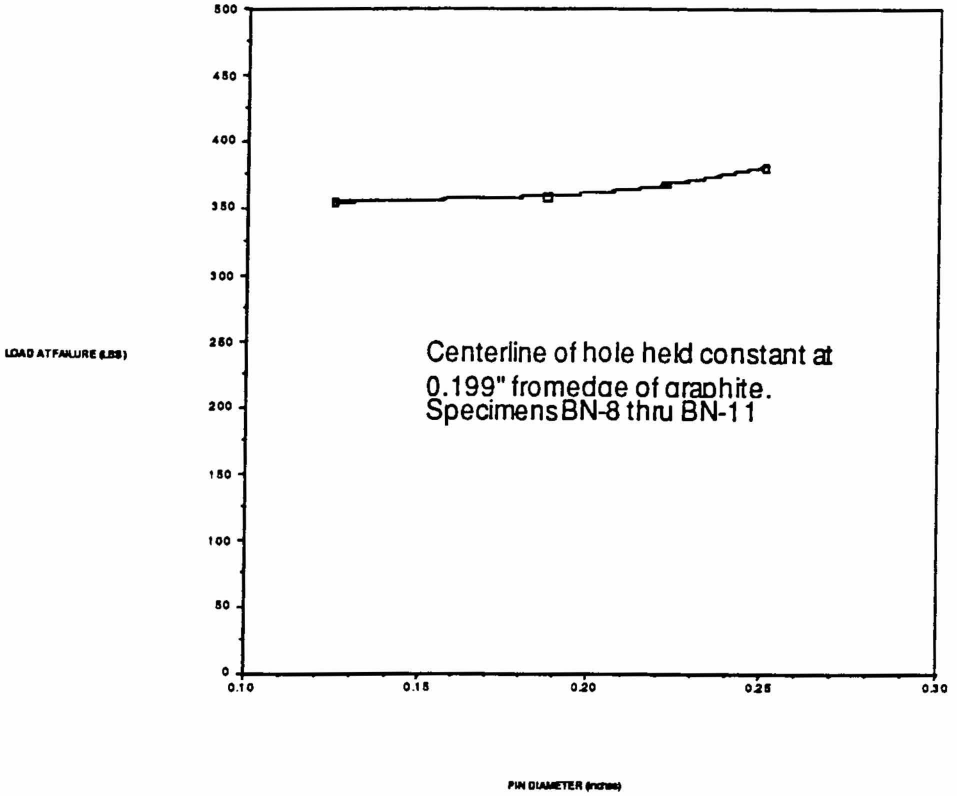
Test Series 1

- The FMI material failed at an average value of approximately 327 lbs, nowhere near the theoretical strength [970 lbs] of the grometry if the pins were in pure shear. In addition, the DN-4 showed evidence of fatigue failure after being loaded to levels never exceeding 267 lbs. This gave little or no margin of safety, as the expected maximum disruption load is right at 300 lb per pin.
- the failure mode in all the runs appeared to be classical tear out, despite the fact that theory for isotropic materials predicted this would not happen. Failure initiated as two cracks at each of the extreme outer edges, under the pin, and progressed inward until the cracks met, resulting in total tear out of the section. The low modulus of the material appeared to be allowing it to compress at the ends, thus allowing the pin to go into bending and transferring more load over to the edges, compounding the effect. In other words, the configuration involved a bearing load interaction between elastic bodies, not a simple fastener shear problem.
- The FMI generally machined well but great care had to be taken in some planes when the tool emerged, as long fibers had a tendency to 'pop out' of the part. These fibers were visible in the material and ran longitudinally in a plane perpendicular to the Z axis. There was also a pronounced tendency for small drill bits to wander in the part. This was reduced by using high speeds (>4000 rpm) and self-centering bits. Two hard inclusions were encountered and resulted in the loss of one drill bit and one scrapped part. (due to deflected bit)

Test Series 2

- Failure in all samples was by apparent tensile failure instead of tear out, with the bottom of the material splitting off through the pin hole. Failure was of a brittle nature as seen by the very sharp transition in the strain/load curves. By stopping the test before total failure it could be seen that the cracks first appeared at the ends and progressed inward just as in the first series, indicating that the pin was deflecting and transferring the load over to the edge of the part.
- Edge effects were further substantiated by the fact that slightly chamfering the edges of the holes changed the failure mode from sharp brittle failure to a more gradual ductile failure. The failure load in the .125 inch pin climbed from 335 lbs to 375 lbs when it was chamfered. Chamfering was done on all specimens starting with BN10.
- The failure load in the double pin configuration was not twice as high as for the single pin configuration as expected but <u>fell</u>, on the average, by 39 lbs.
- Increasing the diameter of the pins had the effect of slightly increasing the load capability, (see figure 6) but not by any factor approaching the increase in the bending modulus of the pin. The increase in stiffnesses appeared to be negated by the decrease in edge distances resulting from the larger diameters.

FIGURE 6. FAILURE LOAD AS A FUNCTION OF PIN DIAMETER



- It was very interesting to note that the specimen with the 1/4 inch pin still failed in the identical manner. The failure might have been expected to occur at the pull end (1/4 inch dia bolt) of the specimen. It had the same tensile area remaining but used a longer pin and therefore incured more bending and higher edge loads.(proportional to the square of the length) The fact that failure did not occur there indicated that the greater edge distance at the pull end was, in fact, affecting the results. The initial failure must start as a tear out crack but then progress along the weakest plane.
- All these results were indicative that the material was far from being a 3-D material. It appeared to be very weak in the X-Y plane and failure was premature, allowing failure along fault planes between layers in the substrate.
- The AS material machined well with conventional tooling[non carbide] and had no problems with breakouts or fiber separation. No inclusions were encountered. Under 10 power magnification the material did have significant numbers of voids, some exceeding .06 inches in length. There was less problem with drill wandering than with the FMI material but the use of self centering drills and speeds above 4000 rpm was still required. Speeds of 6000 rpm and above, however, resulted in excessive heating and shortened drill life.

Test Series 3

- Failure in the specimens machined in the same orientation as in Series 2 again failed by tensile splitting of the bottom. The average failure load was 380 lbs, slightly higher than the larger (longer pin) specimens used in Series 2 (1/8 inch pin) which failed at an average of 355 lbs. A shorter pin length did not reduce the load capability; it did in fact go up slightly. This is another indication of the strong involvement of end effects and pin flexibility in the failure mechanism.

- Failure in the specimens oriented 90 degrees to the previous plane failed in ductile tear out, reminiscent of the FMI material.
- More significantly, the average load capability increased dramatically, to an average of 619 lbs.
- Double pin tests were not conducted when it became evident that a single 0.125 inch pin could meet the design criteria.
- The FMI sample failed at a slightly higher (375 vs 327) load than the average for the samples in Series 1. This was another indication that shorter pins do not result in reduced strength. It may also indicate the positive effect of chamfering the hole edges.

TEST CONCLUSIONS

This test program was by necessity an abbreviated one, due to time and budgetary constraints. It's goal was to determine whether the proposed attachment scheme was viable and whether or not the Allied Signal material could be successfully substituted for the FMI material. The testing did not use sufficient numbers of samples to give statistically meaningful results nor did it explore some avenues which would be very interesting. The FMI material, for example, could have been machined in its other two planes to determine if significant load improvements would be possible. The fact that the AS material with its greater availability and lower cost met the criteria was deemed sufficient reason to conclude the testing. The actual elastic limits and fatigue limits of the samples were never determined. These could be established by cycling the specimens, slowly increasing the maximum load until permanent strain was detected. Again this would be costly and the approximate limits of the materials can be inferred from the strain curves. This is sufficient if very conservative design is utilized. The failure mechanism is not well understood and it would be informative to develop codes and benchmark them with additional testing, varying the pin diameters and edge distances. To make the results useful an additional set of experiments would be necessary to establish[baseline] the tensile and shear properties of the graphite material. Obviously this would be an extensive program.

Despite of the limitations of the program the test results were very consistent and several conclusions were reached:

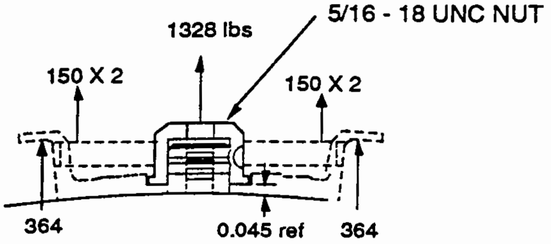
- The baseline design using FMI material with a single 0.094 inch pin did not have adequate strength.
- The Allied Signal material was not adequate when oriented with the pin perpendicular to the Z axis; even with two 0.094 inch pins or single pins of larger diameter.
- The Allied Signal material was much stronger than the FMI material when loaded in a plane with the pin parallel to the Z axis. The use of this material in the correct orientation using a single 0.125 inch pin will result in a design with a safety factor approaching 2
- Edge distance is very important and significant increase in load capability could be gained by moving the pin away from the edge of the graphite. Since this is not an option in the design it is recommended that the ends of the pin holes should be chamfered to reduce stress concentrations. It would also be prudent to slightly taper the outer 0.125 inches of the hole [a few thousands] to distribute the load as the pin deflects.
- Little would be gained by going to pins larger than 0.125 inch diameter and there is no need for double pins and the resulting increase in complexity and cost; sufficient safety margin is achievable with one pin.

ANALYSIS OF CS MOUNTING STRUCTURE

HAND CALCULATIONS

Hand calculations were performed to check the shear in the thread roots of the Allen head nut and the tensile stress in the stud body. All values were well within allowables with a safety factor of better than two, based on ultimate tensile strength. Results are shown in Figure 7.

FIGURE 7 CS TILE STUD LOADING



Reactions shown are for one-half tile
(one stud and two pins)

ASSUMPTIONS:

100 psi distributed load from disruption
5/16" inconel stud, 0.145 bore
A286 nut

RESULTS

Shear Stress in Nut threads - 10450 psi

Tensile Stress in Stud - 43250 psi

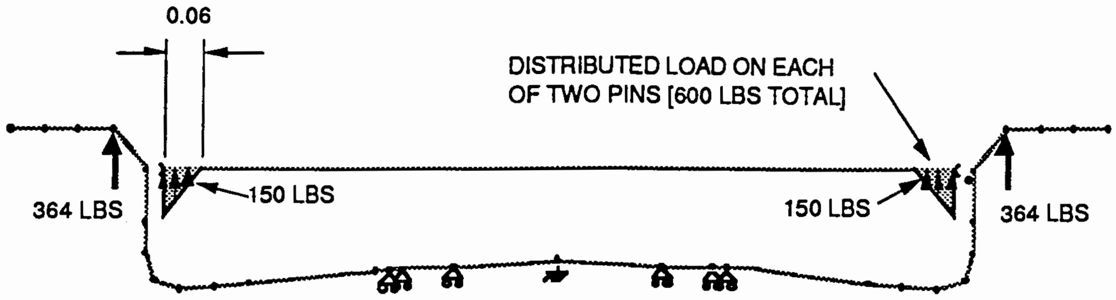
Shear Stress in Channel - 18800 psi

2-D MODELING

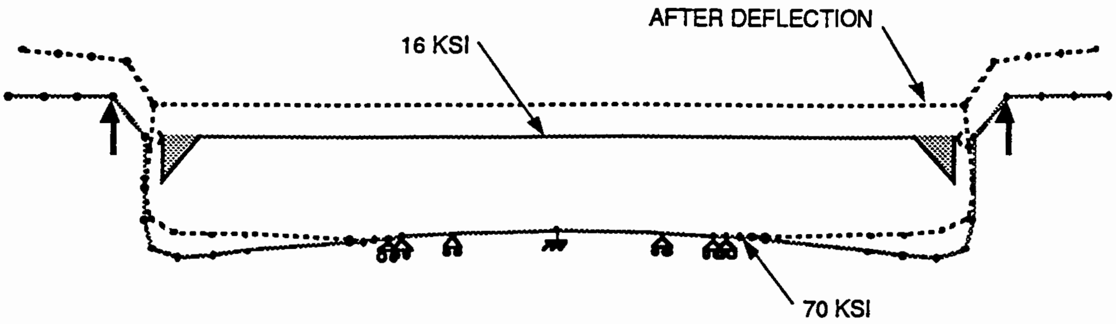
A finite element model was constructed of a representative cross section [1/2 of the bracket and two pins], with loads applied to simulate the reactions of the adjoining tiles and the rail tile. The stud and nut were simulated as a fixed restraint at the bottom center of the bracket. See figure 8. A load of 100 psi was assumed distributed over both the rail tile and the adjacent tiles. This resulted in a load of 300 lbs per pin and a load of 364 lbs on each lip of the half-bracket. The pin load was applied as small triangular loads at the ends of the pin and the lip load was assumed to be concentrated near the vertical leg of the bracket.

FIGURE 8 - 2D MODEL OF CS BRACKET

ALL DIMENSIONS IN INCHES
0.125 DIA PIN
0.09 THICK BRACKET



1/2 BRACKET
MODEL



1/2 BRACKET
MODE SHAPE AFTER LOADIND

The results of the analysis showed the bottom web of the bracket to be beyond yield. The pin diameter was increased to 0.125 inches to stiffen the structure, the result being that the stress dropped to about 100% of yield for TZM at 500 C.[70ksi] This was considered to be acceptable for an extreme case load, at least as a preliminary design. The results could not be considered conservative, however, in that the bottom was assumed by the model to be fixed along its length. In reality it is restrained locally by two fasteners and the result would likely to be additional stress due to three dimensional bending effects.

3-D ANALYSIS

A model of one-half of the rail bracket and its two pins constructed in ProE[3] were used to perform finite analyses in MECHANICA. The model and results are shown in the attached figures .

Very high stresses, above ultimate, were evident around the mounting hole and at the bottom corner of the bracket. These loads were highly localized and dropped off very quickly, indicating they were most likely stress concentrations. A more substantial portion was in the 70 ksi yield range and was more likely to be actual bending stress. This value, although higher than desired, would not lead to significant permanent deformation since it was in the outer fibers only and the section would be capable of 50% greater load before plastic failure of the section. The time spans invoved will be short, in the order of 1-3 miliseconds, and the loads are the extreme case.

POSTSCRIPT

Calculations done after the Peer Review [4] determined that the magnetic loading on the CS will not be as high as expected and, in fact, the higher loads never manifest as tensile loads,i.e., radially away from the center column. As a result, the bracket and tile configuration discussed in this document is overly conservative and will be redesigned for economic considerations, using 0.062 inconel material, a 0.125 inch inconel pin, and eliminating the stepped feature in the bracket. A further test series is planned to confirm the strength of the new design.

REFERENCES

[1] FRAME MAC is a trademark of Erez Anzel Software, Ontario, Canada.

[2] MECHANICA is a trademark of Parametric Technology Corporation.

[3] Pro/Engineer is a trademark of Parametric Technology Corporation.

[4] PPPL memorandum, 3/17/98, *Estimated Forces in NSTX Centerstack Tiles*.

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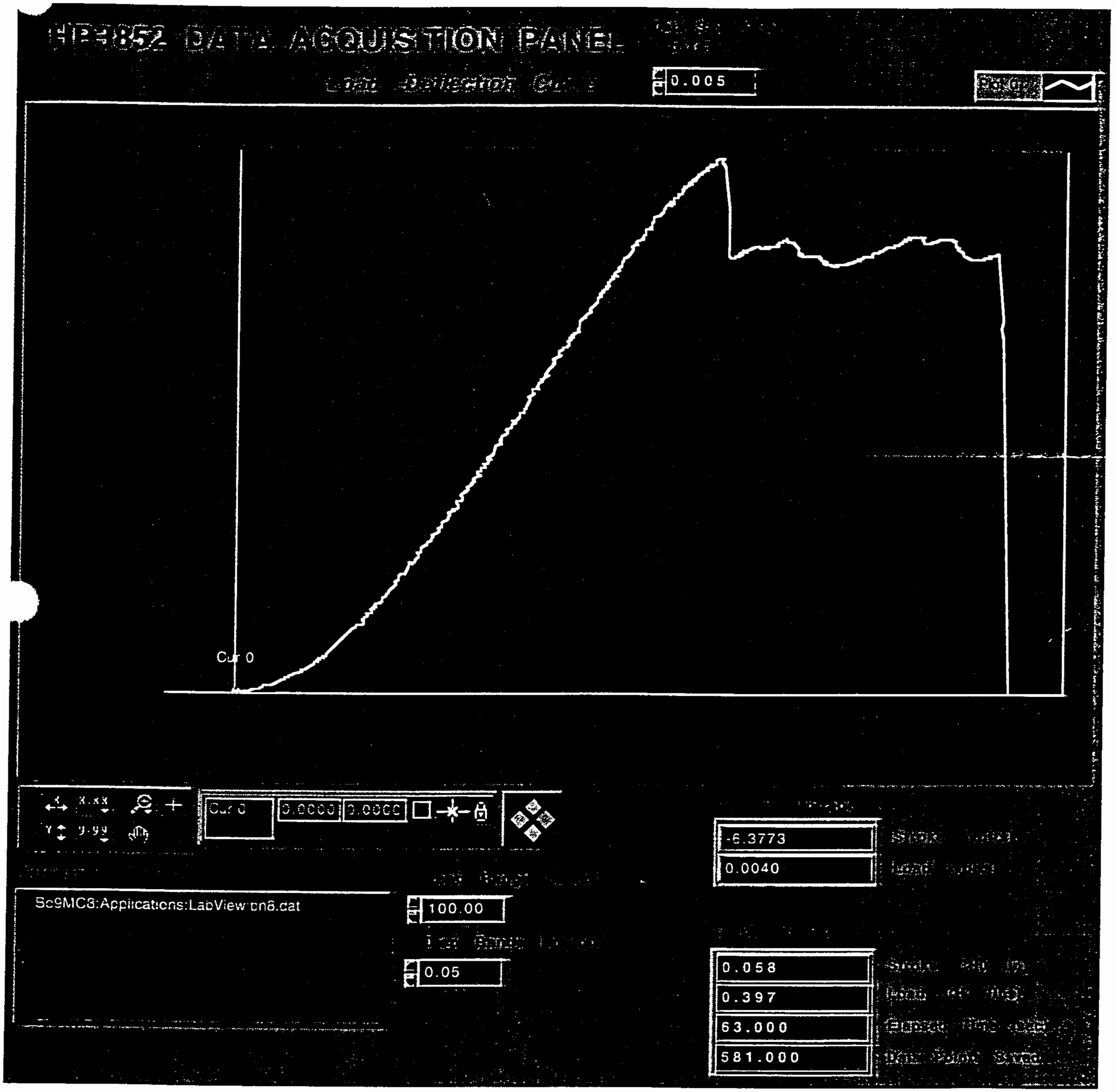

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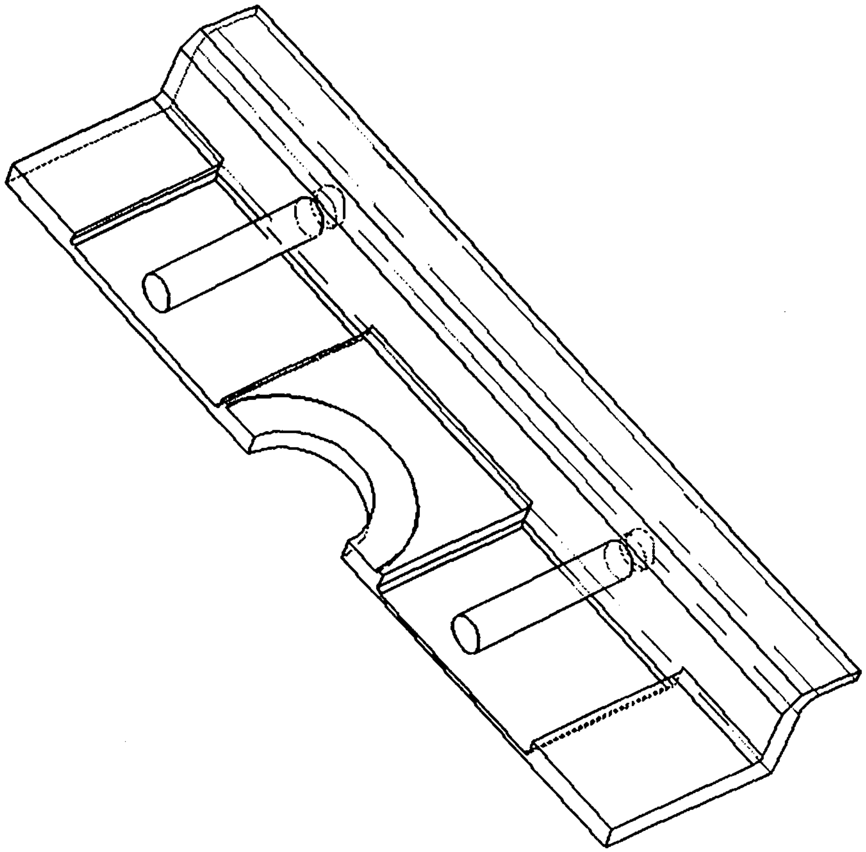
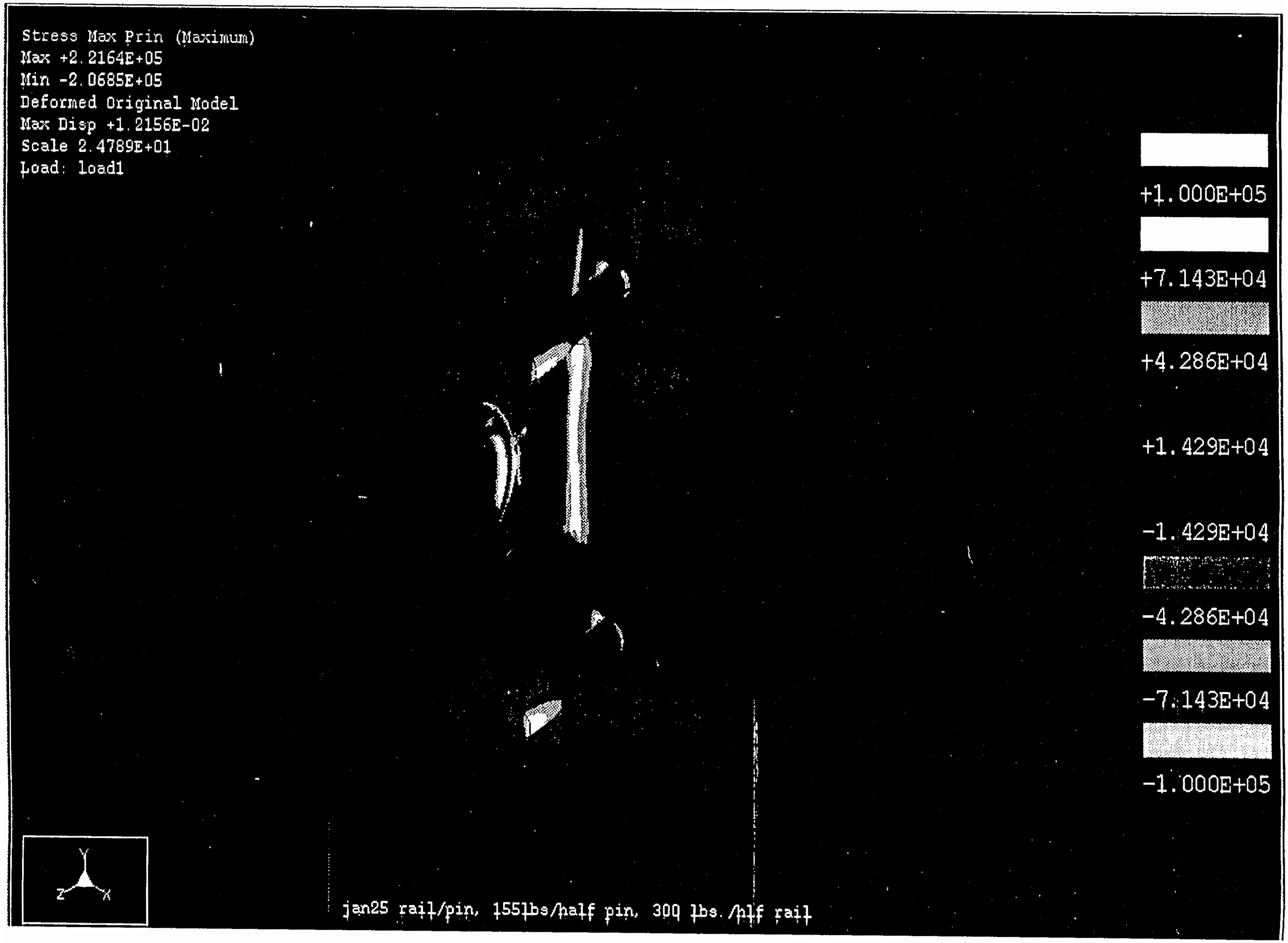
SINGLE PIN @ .125" ⌀

Rail model

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+7.143E+04
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+1.429E+04
-1.429E+04
-4.286E+04
-7.143E+04
-1.000E+05
Y
Z
X
jan25 rail/pin, 155lbs/half pin, 300 lbs./hlf rail

Tile and Component Force Summary for NSTX PFC Design

B. Nelson (ORNL)

Rev. 0

April 29, 1998

Tile and Component Force Summary for NSTX PFC Design

B. Nelson (ORNL)

The plasma facing components (PFCs) of the NSTX device consist of passive stability structure, divertor structures, and tiles. These structures experience thermal and electromagnetic loads due to plasma disruptions. The purpose of this memo is to document the forces on the tiles based on disruption conditions provided by the project.

The approach was to calculate the forces and moments based on current flowing in the individual tiles and components and the assumed background fields in the tiles and components. An excel spreadsheet format was used to sum these forces for the various conditions in an attempt to determine the worst case conditions.

The forces in the tiles are extreme for the halo currents, if the currents are assumed to flow in a direction that pulls the tiles from the wall. This assumption was used for the force conditions listed and is included in the summaries. However, more recent calculations have indicated that it is not necesary to design for a tension load due to halo currents. A compression loading is much more benign.

The attached files are arranged in the following fashion:

1. Force summary for PFCs, based on C. Neumeyer memo from February of 1998, entitled "Forces on Internal Hardware" 11-980223-CLN-01, but with updated dimensions.

2. A series of excel sptreadsheet printouts for the forces, intitled "Estimated Forces on NSTX ...""

   - Centerstack Tiles

   - Centerstack Rail Tiles
   - IB Divertor Cylindrical Tiles
   - IB Divetor Horizontal Tiles
   - OB Divertor Tiles
   - Secondary Passive Plate Tiles
   - Primary Passive Plate Tiles

3. An excel spreadsheet listing the fields at various component locations due to a nominal plasma current of 1 MA.

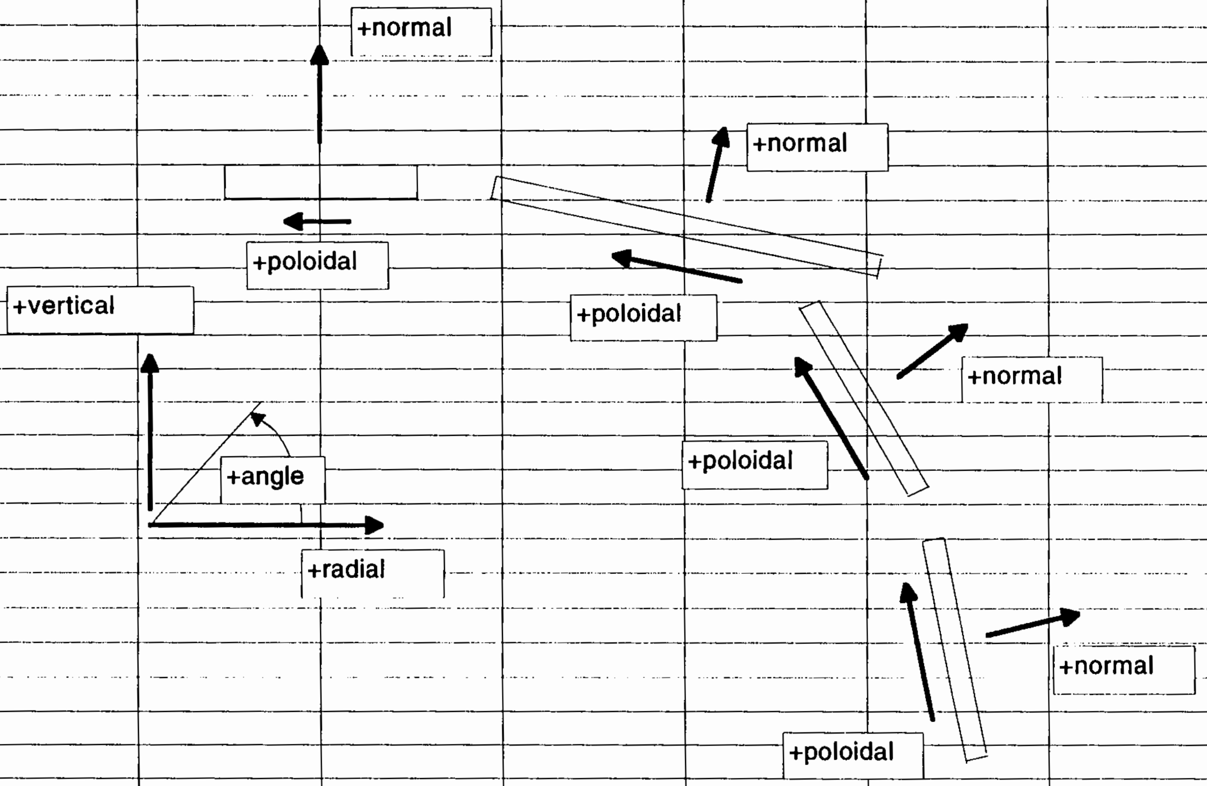
Force summary for NSTX PFCs

	Inner Wall	IBD, Cyl	IBD, Horiz.	OBD	Sec Plate	Pri Plate	
Halo...							
Ip	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	Amp
k	0.08	0.10	0.10	0.10	0.10	0.10	
peaking	2.00	2.00	2.00	2.00	2.00	2.00	
#segment,tor	24	24	32	48	12	12	
#tiles/seg, tor	1	1	1	2	8	8	
#tiles/seg, pol	1	4	4	5	4	4	
Ipoloidal	6666.67	8333.33	6250.00	4166.67	16666.67	16666.67	Amp
R1	0.178	0.267	0.267	0.622	1.113	1.360	m
Z1	0.152	1.167	1.629	1.640	1.375	1.006	m
R2	0.178	0.267	0.572	1.199	1.340	1.509	m
Z2	0.000	1.591	1.629	1.412	1.054	0.553	m
Theta (deg)	-90.000	-90.000	0.000	-21.497	-54.749	-71.741	degrees
theta (rad)	-1.571	-1.571	0.000	-0.375	-0.956	-1.252	
Ravg	0.178	0.267	0.420	0.910	1.227	1.435	m
R0	0.854	0.854	0.854	0.854	0.854	0.854	m
Bt(R0)	0.600	0.600	0.600	0.600	0.600	0.600	T
Bt(Ravg)	2.879	1.919	1.221	0.563	0.418	0.357	T
L poloidal	0.152	0.423	0.305	0.621	0.393	0.477	m
	6.000	16.664	12.008	24.432	15.471	18.762	in
Fnormal/segment	2925	6769	2328	1455	2736	2837	N
	657	1522	523	327	615	638	lbs
ΣFnormal	7890	18260	8375	7852	3690	3826	lbs
Fradial/segment	-657	-1522	0	-120	-502	-606	lbs
Fvertical/segment	0	0	-523	-304	-355	-200	lbs
Ftoroidal/plate	274	2399	1068	1737	4470	3053	N
	62	539	240	391	1005	686	lbs
Ftor/tile, avg	62	135	60	39	31	21	lbs

Force summary for NSTX PFCs

	Inner Wall	IBD, Cyl	IBD, Horiz.	OBD	Sec Plate	Pri Plate	
Disruption...							
Itoroidal	35000.00	44100.00	44100.00	44100.00	44100.00	105700.00	Amp
Br	0.27	0.68	0.50	0.31	0.44	0.22	T
Bv	0.37	0.52	0.56	0.60	0.56	0.56	T
Bnormal	0.27	0.68	0.56	0.67	0.68	0.38	T
Bpoloidal	0.37	0.52	-0.50	-0.07	0.20	0.46	T
L toroidal	0.05	0.07	0.08	0.12	0.64	0.75	m
k	1.50	1.50	1.50	1.50	1.50	1.50	
Fradial	-905.21	-2404.44	-3051.26	-4729.90	-23789.43	-66690.92	N
	-203.49	-540.52	-685.92	-1063.28	-5347.86	-14992.12	lbs
Fvertical	-440.37	-2096.17	-1798.07	-1629.19	-12461.13	-17466.67	N
	-99.00	-471.22	-404.21	-366.24	-2801.26	-3926.51	lbs
Fnormal	-203	-541	-404	-730	-5984	-15467	lbs
plate area	11	46	39	115	391	555	in^2
Press, normal	-18	-12	-10	-6	-15	-28	psi
Fpoloidal	-99	-471	686	855	799	969	lbs
Check magnitudes							
Fr,Fv mag.	226	717	796	1125	6037	15498	lbs
Fn.Fp mag.	226	717	796	1125	6037	15498	lbs
Br,Bv mag.	0.458	0.856	0.747	0.675	0.712	0.602	T
Bn, Bp mag	0.458	0.856	0.747	0.675	0.712	0.602	T

Force summary for NSTX PFCs



Estimated Forces in NSTX Centerstack tiles

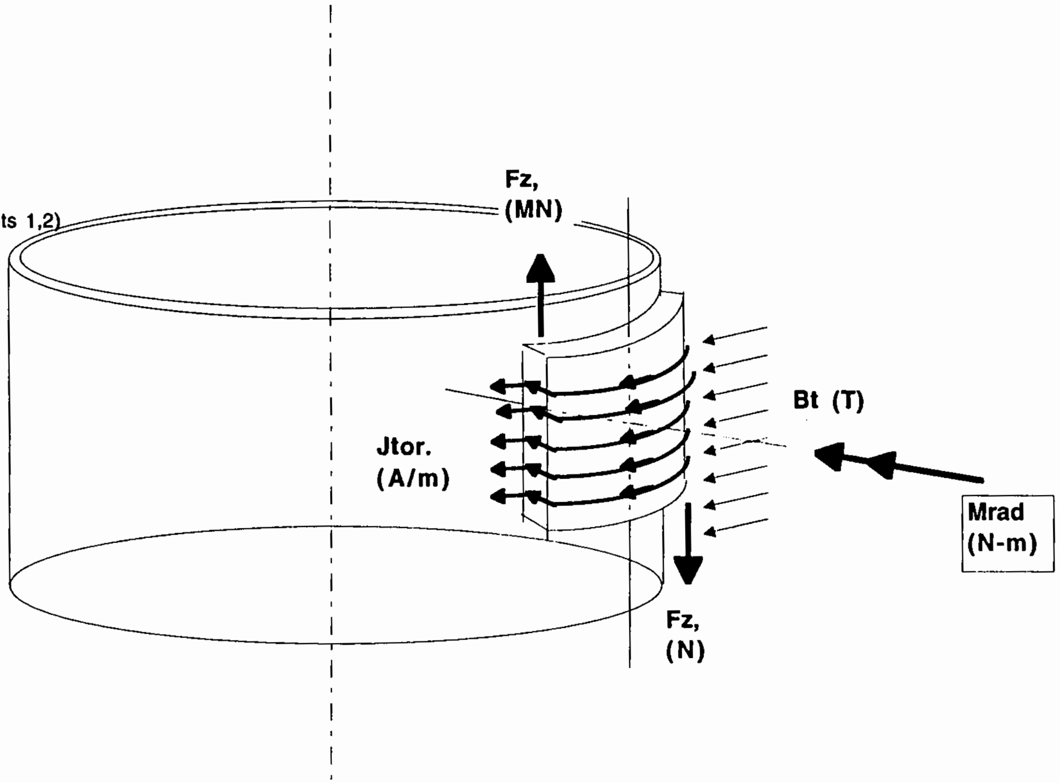
3/17/98 B. Nelson

Case no.	Description		Forces			Moments		Comments	
		Frad N	Ftor. N	Fver N	Mrad N-m	Mtor N-m	Mver N-m		
1	Forces due to radial current and toroidal field				2.330E+00				
2	Forces due to toroidal current and vertical field	2.157E+01	0 (net)					plus toroidal tension/comp	6.475E+00 N
3	Forces due to toroidal current and radial field			1.574E+01					
4	Forces due to loop current and radial field							plus toroidal tension/comp	7.890E-01
								plus vertical tension/comp	1.774E-01
5	Forces due to loop current and toroidal field						7.890E-01		
6	Forces due to loop current and vertical field					3.669E-02			
	TOTAL w/o Halo	2.157E+01	0.000E+00	1.574E+01	2.330E+00	3.669E-02	7.890E-01		
7	Forces due to Halo current and toroidal field	1.813E+03							
8	Forces due to Halo current and radial field		1.710E+02						
	TOTAL Halo only	1.813E+03	1.710E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00		
	Assumptions:	**Iplasma** **(Amps)**	**Halo fraction**	**toroidal peak**	**Btor @ R0** **(T)**	**Bradial, max** **(T)**	**Bpol, max** **(T)**		
		1.00E+06	0.1	2	0.6	0.27	0.37		

Case 1, force due to radial current, toroidal field

Let

t (thickness)=	1.400E-02 m	
r tile =	1.781E-01 m	
no of tiles =	24	
width of tile =	4.650E-02 m	
	1.83 in	
Btor @ tile =	2.863E+00 Tesla	
I tile, toroidal	1.250E+03 amps	(see sheets 1,2)
L tile =	7.620E-02 m	
J tile =	1.640E+04 A/m	
Fz = LxJxtxBt =	5.010E+01 N	
	1.126E+01 lbs	
Mrad = F*w=	2.329892531 N-m	
	2.062E+01 in-lbs	



Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

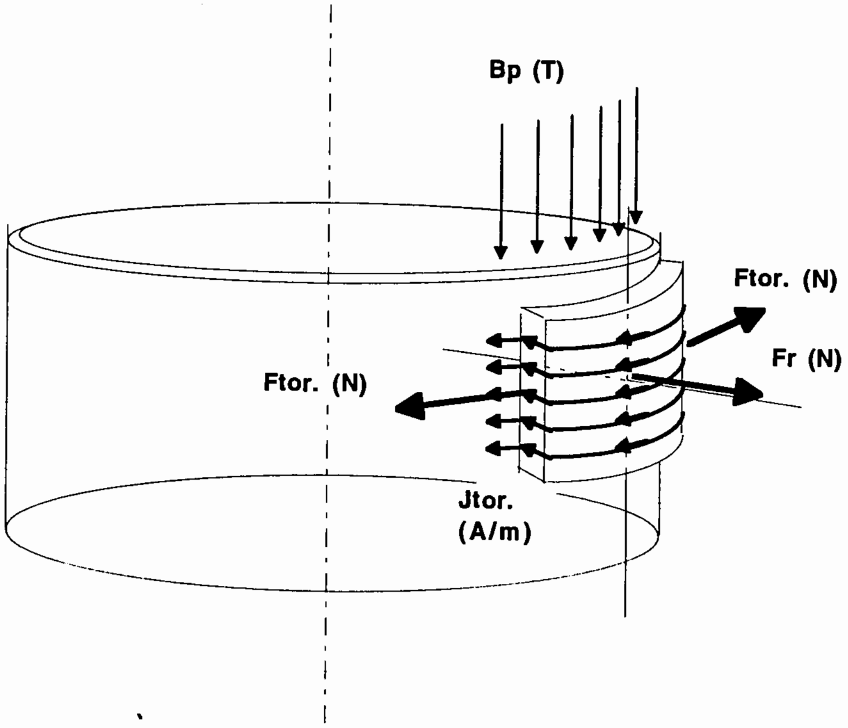
Case 2, Forces due to toroidal current , vertical field

Let:

no.tiles circum	24
Bpol =	0.37 Tesla, max
Jtor =	1.640E+04 A/m
P =JxB =	6.070E+03 Pa
rad pressure =	0.88 psi
Area,front =	
L*2*pi*r/n=	3.554E-03 m^2
Frad = P*A	2.157E+01 N
	4.849E+00 lbs
Area, side =	1.067E-03 m^2
Ftor =	6.475E+00 N
	1.456E+00 lbs

Note

Calculation assumes induced toroidal current as if tiles form continuous toroidal ring.

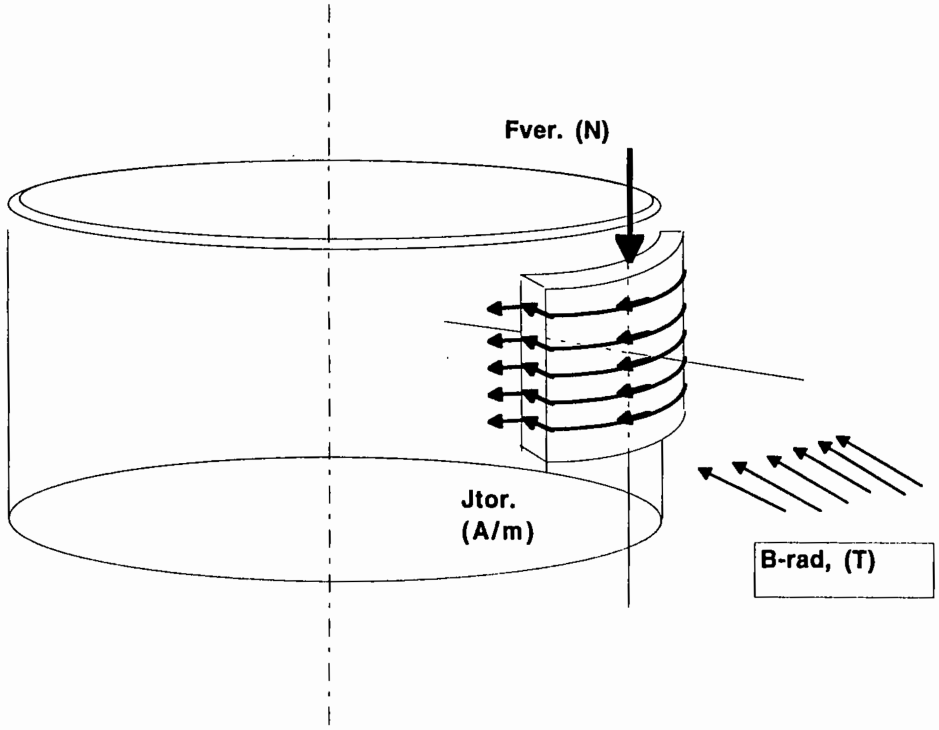


Case 3, Forces due to toroidal current , radial field

Let:

no.tiles circum	24
B-rad =	0.27 Tesla, max
Jtor =	1.640E+04 A/m
P =JxB =	4.429E+03 Pa
vert shear =	0.64 psi
Area,front =	
L*2*pi*r/n=	3.554E-03 m^2
Fver = P*A	1.574E+01 N
	3.539E+00 lbs

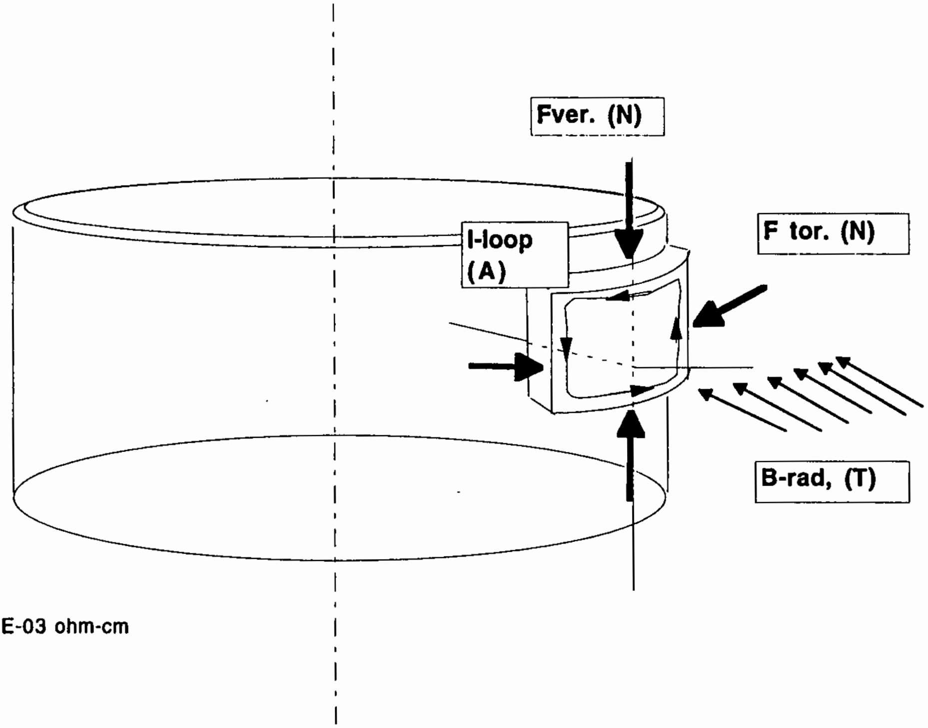
Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 4, Forces due to loop current , radial field

Let:	
no.tiles circum	24
B-rad =	0.27 Tesla, max
delta B-rad. =	0.037 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.227E-01 m
Apath = t*(L+w)/4	4.295E-04 m^2
R loop =	3.429E-03 ohms
dB/dt*A loop	1.315E-01 Volts
Iloop =	3.835E+01 A
Area,front =	3.554E-03 m^2
F/l =	1.035E+01 N/m
F tor = f/l*L =	7.890E-01 N
	1.774E-01 lbs
Fver = f/l*w =	4.816E-01 N
	1.083E-01 lbs

Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

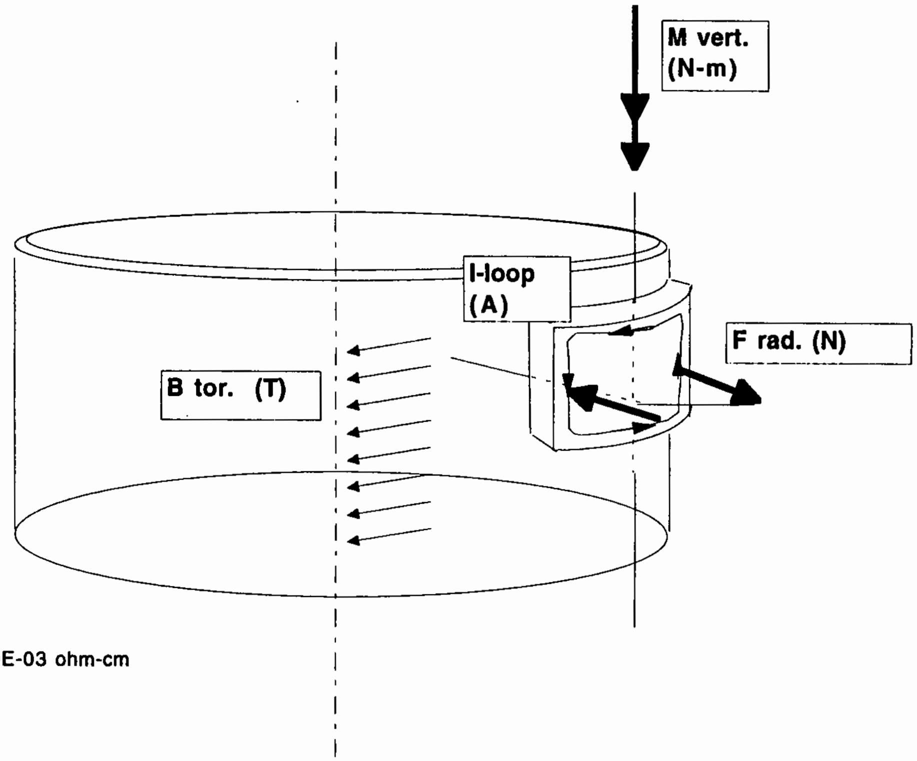


Case 5, Forces due to loop current , toroidal field

Let:

no.tiles circum	24
B-rad =	0.27 Tesla, max
delta B-rad. =	0.037 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.227E-01 m
Apath = t*(L+w)/4	4.295E-04 m^2
R loop =	3.429E-03 ohms
dB/dt*A loop	1.315E-01 Volts
Iloop =	3.835E+01 A
Area,front =	3.554E-03 m^2
F/l =	1.035E+01 N/m
F rad = f/l*L =	7.890E-01 N
	1.774E-01 lbs
M vert. = Fr*w	7.890E-01 N-m
	5.387E+00 in-lbs

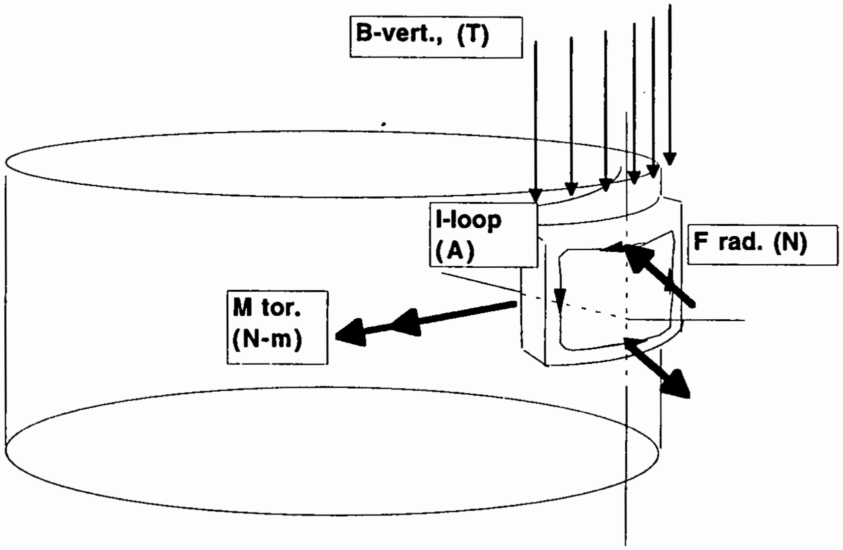
Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm



Case 6, Forces due to loop current , vertical field

Let:

no.tiles circum	24
B-rad =	0.27 Tesla, max
delta B-rad. =	0.037 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.227E-01 m
Apath = t*(L+w)/4	4.295E-04 m^2
R loop =	3.429E-03 ohms
dB/dt*A loop	1.315E-01 Volts
Iloop =	3.835E+01 A
Area,front =	3.554E-03 m^2
F/l =	1.035E+01 N/m
F rad = f/l*w =	4.816E-01 N 1.083E-01 lbs
M toroidal =	3.669E-02 N-m 2.505E-01 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

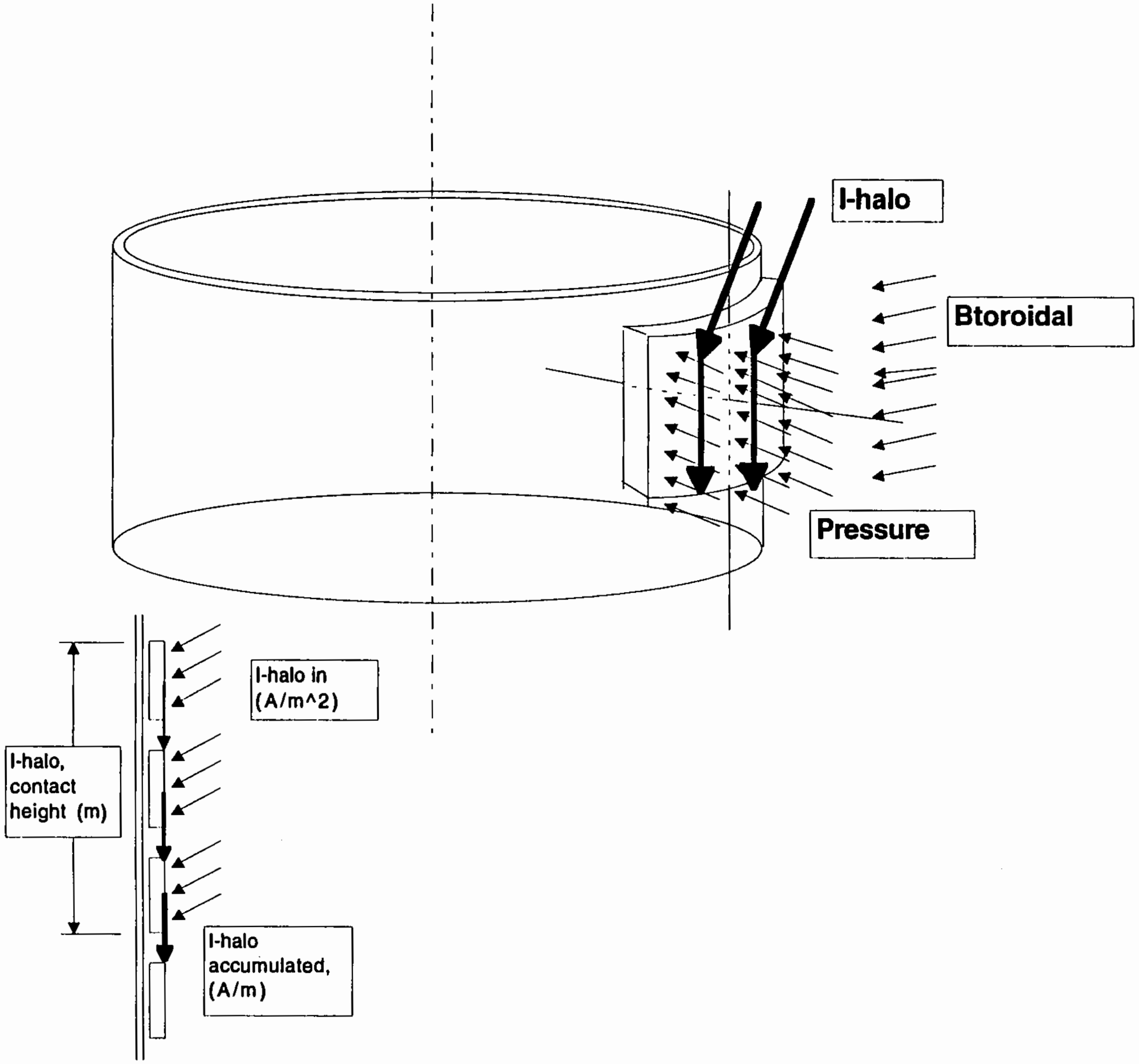
Case 7, halo currents and toroidal field

tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	178682 A/m
Ihalo/tile	8333 A
Btor =	2.86 Tesla
Phalo, max =	0.51 MPa 74 psi
height, L =	7.620E-02 m
width, w =	4.650E-02 m
Frad =	1.8E+3 N

Note:

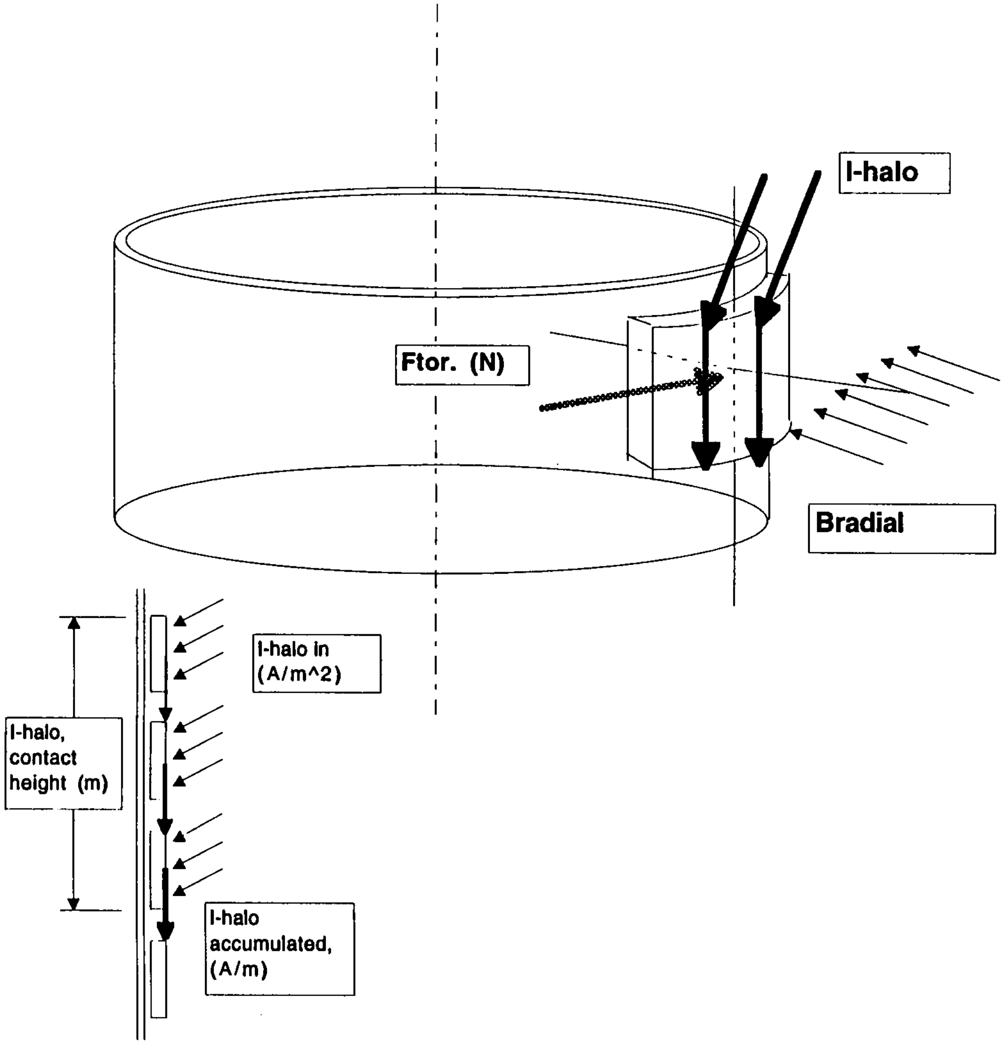
Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Case 8, halo currents and radial field

tor. peak fact=	2	
I plasma =	1.000E+06	A
I halo	1.000E+05	A
Jhalo, est. =	1.787E+05	A/m
Ihalo/tile	8.310E+03	A
Brad =	2.700E-01	Tesla
Phalo, max =	4.824E-02	MPa
	6.998E+00	psi
Height, L =	7.620E-02	m
width, w =	4.650E-02	m
Ftoroidal =	1.710E+02	N
	3.843E+01	lbs



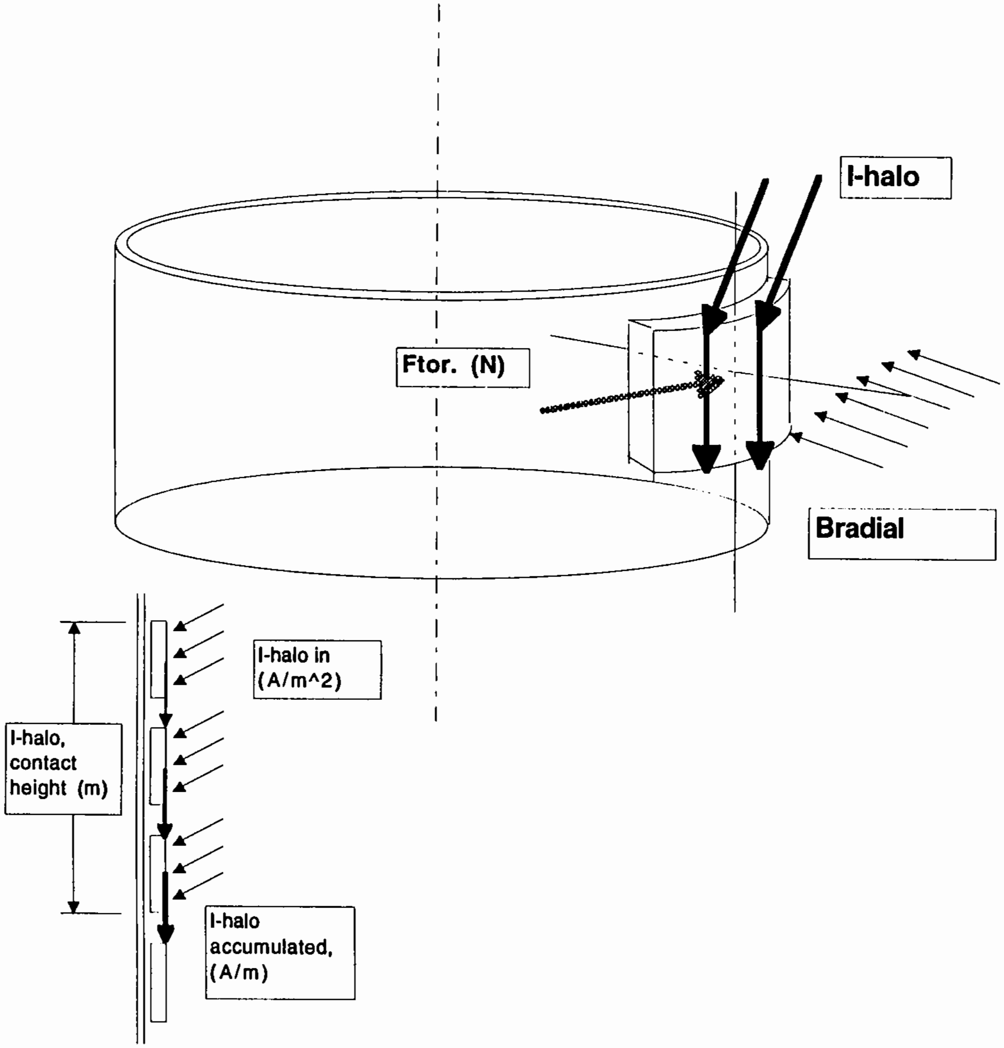
Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower

Case 8, halo currents and radial field

tor. peak fact=	2
I plasma =	1.000E+06 A
I halo	1.000E+05 A
Jhalo, est. =	1.787E+05 A/m
Ihalo/tile	8.310E+03 A
Brad =	2.700E-01 Tesla
Phalo, max =	4.824E-02 MPa
	6.998E+00 psi
Height, L =	1.524E-01 m
width, w =	4.650E-02 m
Ftoroidal =	3.419E+02 N
	7.687E+01 lbs



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower

Estimated Forces in NSTX IB divertor cylindrical tiles

3/17/98 B. Nelson

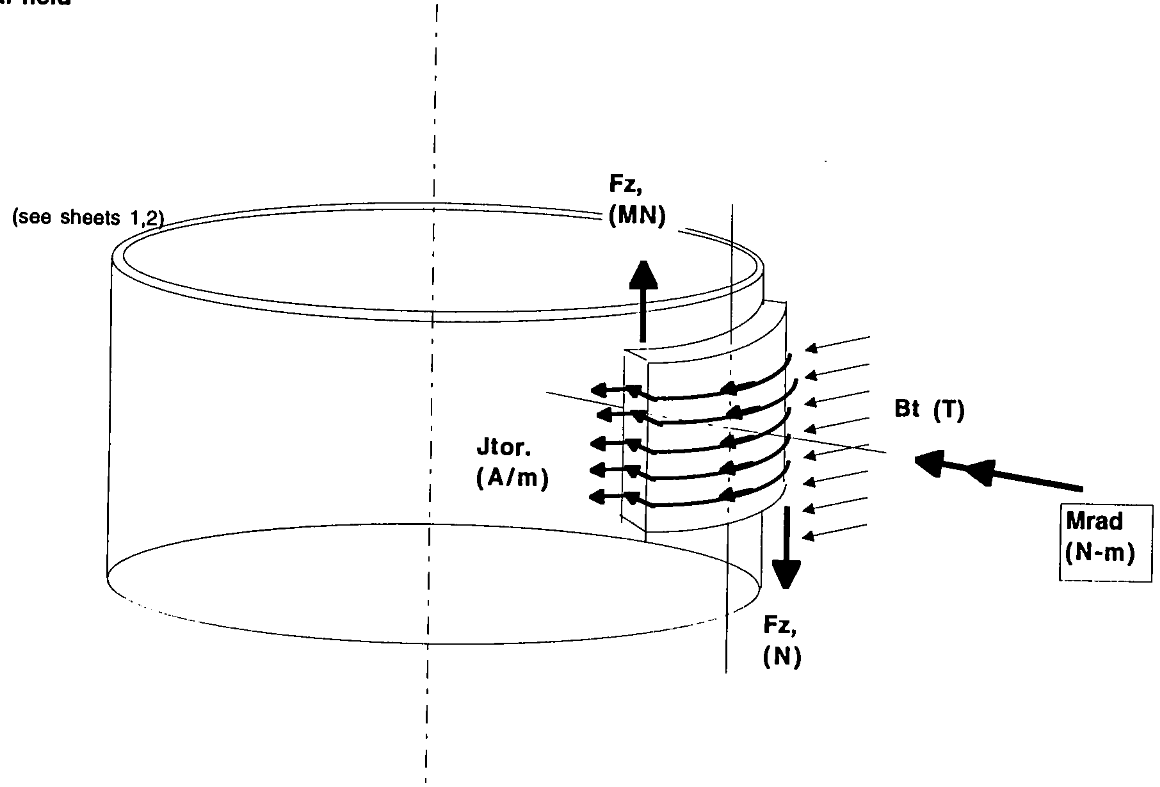
			Forces			Moments			
Case no.	**Description**	**Frad** **N**	**Ftor.** **N**	**Fver** **N**	**Mrad** **N-m**	**Mtor** **N-m**	**Mver** **N-m**	**Comments**	
1	Forces due to radial current and toroidal field				6.116E+00				
2	Forces due to toroidal current and vertical field	6.671E+01	0 (net)					plus toroidal tension/comp	2.389E+01 N
3	Forces due to toroidal current and radial field			8.724E+01					
4	Forces due to loop current and radial field							plus toroidal tension/comp plus vertical tension/comp	1.051E+01 2.362E+00
5	Forces due to loop current and toroidal field						1.051E+01		
6	Forces due to loop current and vertical field					7.316E-01			
	TOTAL w/o Halo	6.671E+01	0.000E+00	8.724E+01	6.116E+00	7.316E-01	1.051E+01		
7	Forces due to Halo current and toroidal field	1.680E+03							
8	Forces due to Halo current and radial field		5.975E+02						
	TOTAL Halo only	1.680E+03	5.975E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00		
	Assumptions:	**Iplasma (Amps)**	**Halo fraction**	**toroidal peak**	**Btor @ R0 (T)**	**Bradial, max (T)**	**Bpol, max (T)**		
		1.00E+06	0.1	2	0.6	0.68	0.52		

Case 1, force due to radial current, toroidal field

Let

t (thickness)=	2.500E-02 m
r tile =	2.667E-01 m
no of tiles =	24
width of tile =	6.962E-02 m
	2.74 in
Btor @ tile =	1.912E+00 Tesla
I tile, toroidal	1.838E+03 amps
L tile =	1.058E-01 m
J tile =	1.738E+04 A/m
Fz = LxJxtxBt =	8.784E+01 N
	1.975E+01 lbs
Mrad = F*w=	6.115967894 N-m
	5.413E+01 in-lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



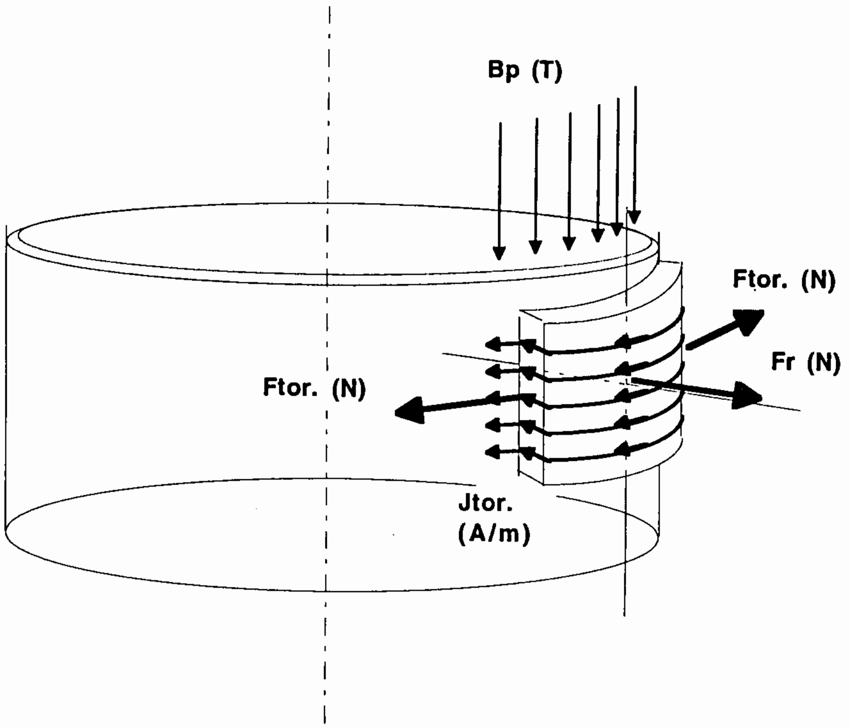
Case 2, Forces due to toroidal current , vertical field

Let:

no.tiles circum	24
Bpol =	0.52 Tesla, max
Jtor =	1.738E+04 A/m
P =JxB =	9.035E+03 Pa
rad pressure =	1.31 psi
Area,front =	
L*2*pi*r/n=	7.384E-03 m^2
Frad = P*A	6.671E+01 N
	1.500E+01 lbs
Area, side =	2.644E-03 m^2
Ftor =	2.389E+01 N
	5.370E+00 lbs

Note

Calculation assumes induced toroidal current as if tiles form continuous toroidal ring.

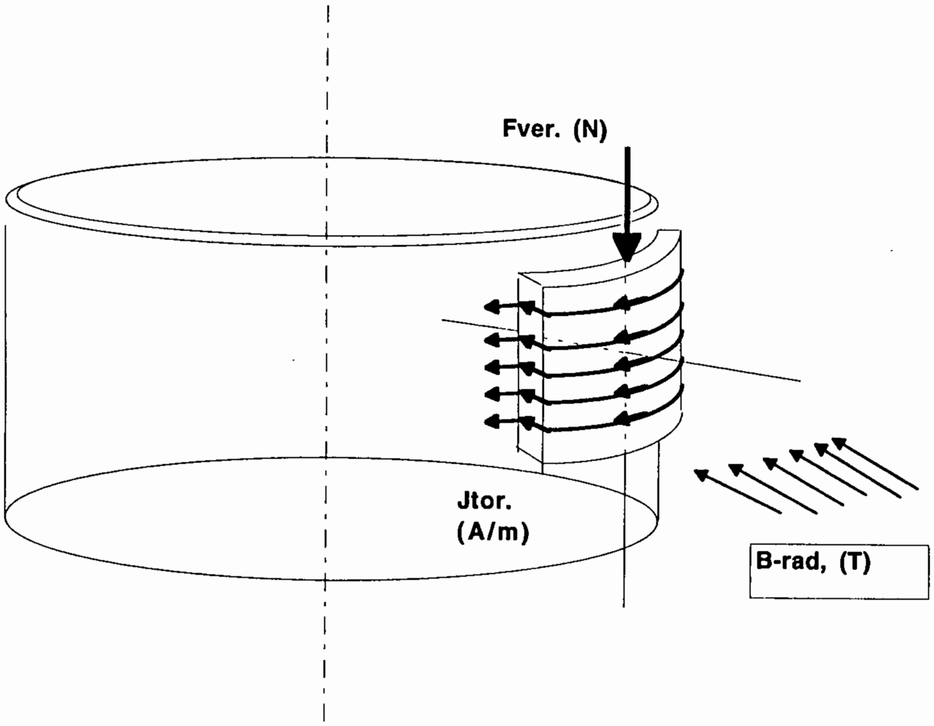


Case 3, Forces due to toroidal current , radial field

Let:

no.tiles circum	24
B-rad =	0.68 Tesla, max
Jtor =	1.738E+04 A/m
P =JxB =	1.182E+04 Pa
vert shear =	1.71 psi
Area,front =	
L*2*pi*r/n=	7.384E-03 m^2
Fver = P*A	8.724E+01 N
	1.961E+01 lbs

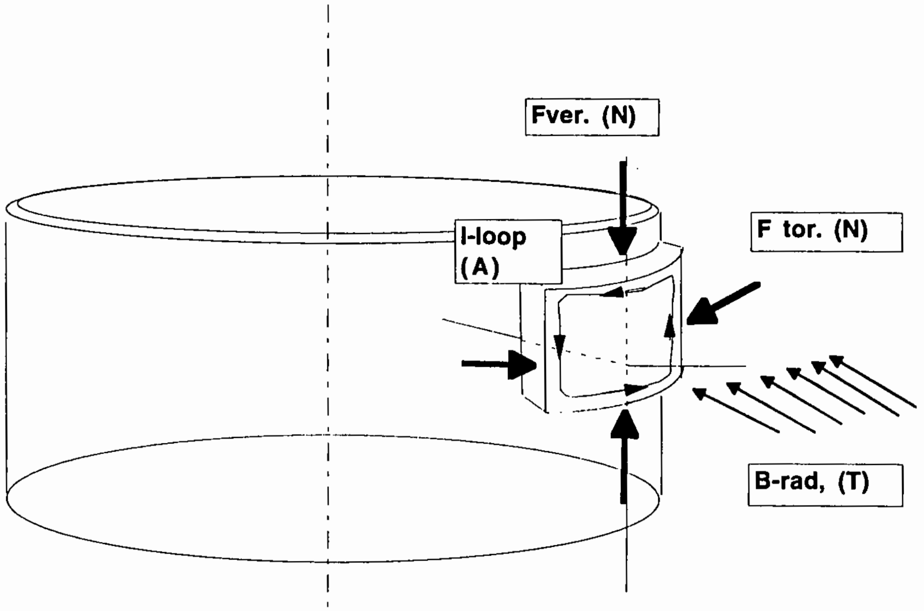
Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 4, Forces due to loop current , radial field

Let:

no.tiles circum	24
B-rad =	0.68 Tesla, max
delta B-rad. =	0.038 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.754E-01 m
Apath = t*(L+w)/4	1.096E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	2.806E-01 Volts
Iloop =	1.461E+02 A
Area,front =	7.384E-03 m^2
F/l =	9.937E+01 N/m
F tor = f/l*L =	1.051E+01 N
	2.362E+00 lbs
Fver = f/l*w =	6.919E+00 N
	1.555E+00 lbs



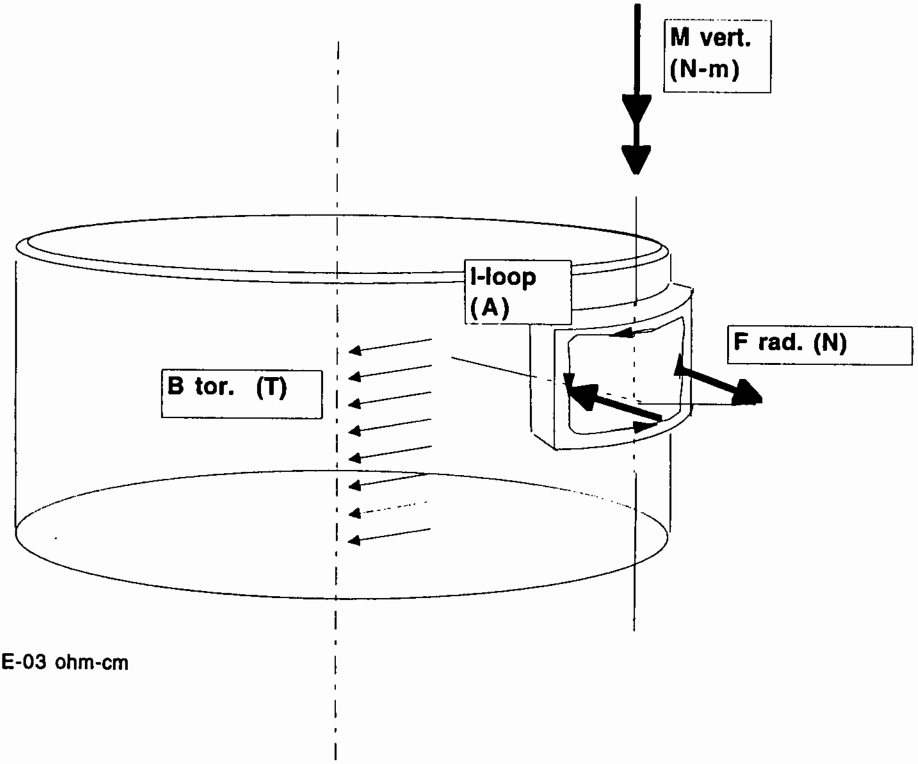
Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 5, Forces due to loop current , toroidal field

Let:

no.tiles circum	24
B-rad =	0.68 Tesla, max
delta B-rad. =	0.038 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.754E-01 m
Apath =	
t*(L+w)/4	1.096E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	2.806E-01 Volts
Iloop =	1.461E+02 A
Area,front =	7.384E-03 m^2
F/l =	9.937E+01 N/m
F rad = f/l*L =	1.051E+01 N
	2.362E+00 lbs
M vert. = Fr*w	1.051E+01 N-m
	7.175E+01 in-lbs

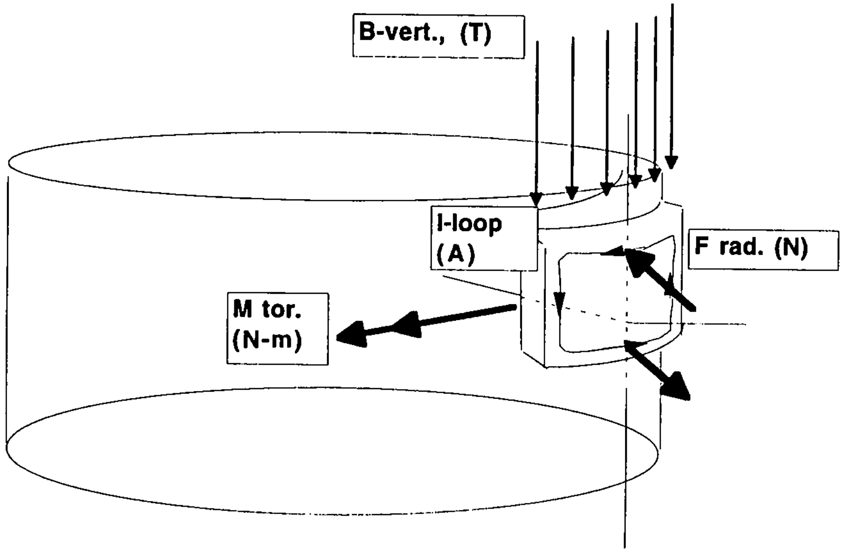
Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm



Case 6, Forces due to loop current , vertical field

Let:

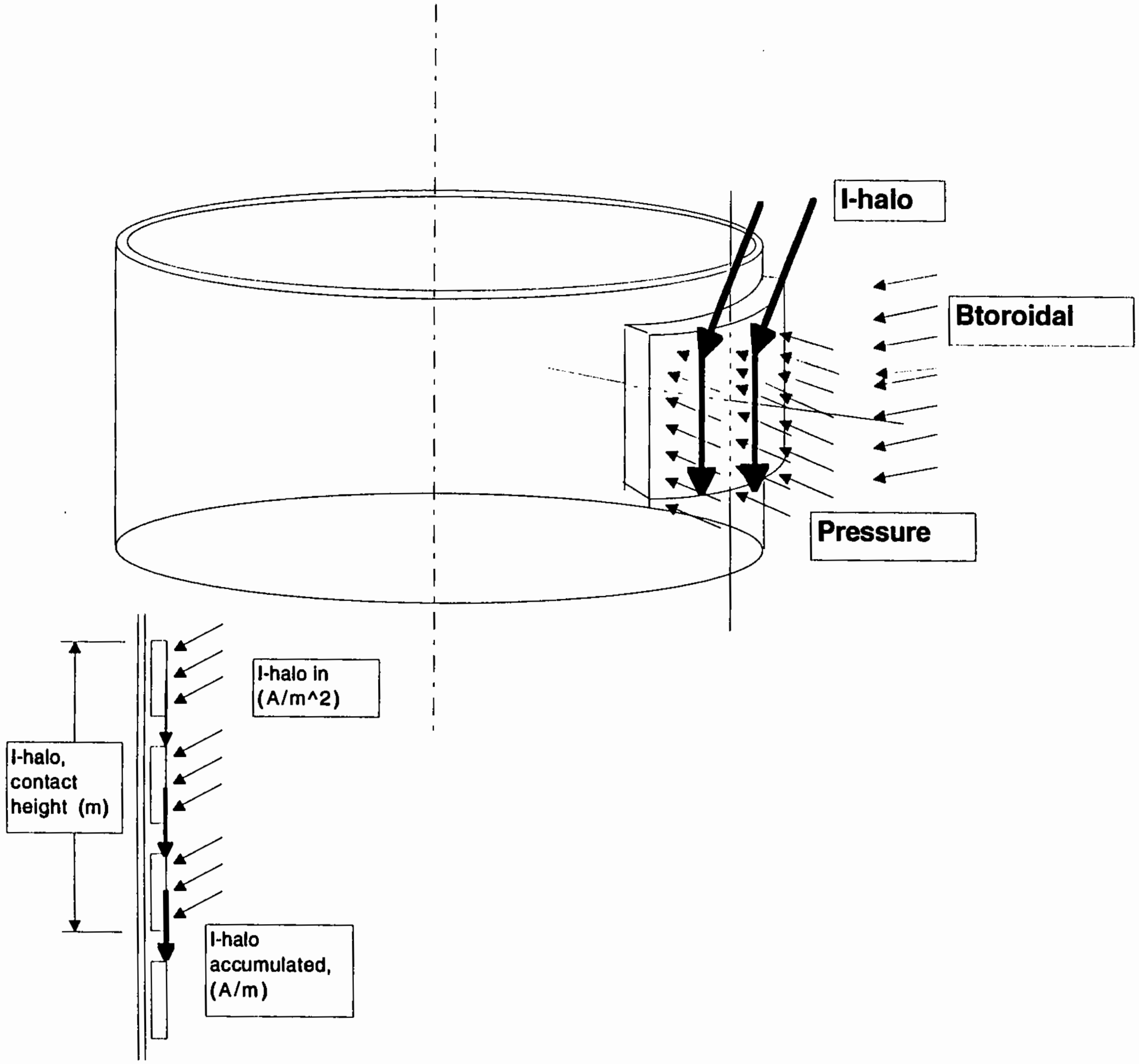
no.tiles circum	24
B-rad =	0.68 Tesla, max
delta B-rad. =	0.038 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.754E-01 m
Apath = t*(L+w)/4	1.096E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	2.806E-01 Volts
Iloop =	1.461E+02 A
Area,front =	7.384E-03 m^2
F/l =	9.937E+01 N/m
F rad = f/l*w =	6.919E+00 N 1.555E+00 lbs
M toroidal =	7.316E-01 N-m 4.995E+00 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 7, halo currents and toroidal field

tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	119351 A/m
Ihalo/tile	8333 A
Btor =	1.91 Tesla
Phalo, max =	0.23 MPa 33 psi
height, L =	1.058E-01 m
width, w =	6.962E-02 m
Frad =	1.7E+3 N



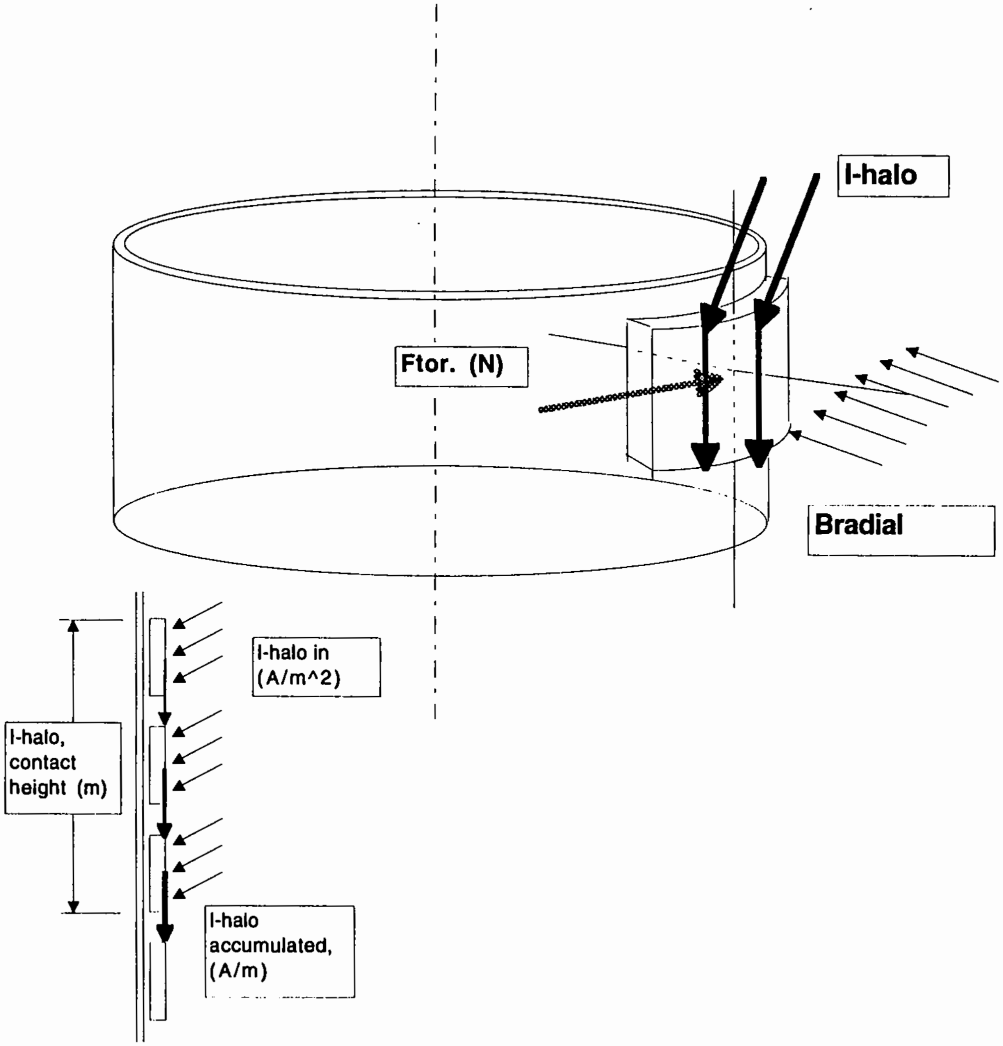
Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower

Case 8, halo currents and radial field

tor. peak fact=	2
I plasma =	1.000E+06 A
I halo	1.000E+05 A
Jhalo, est. =	1.194E+05 A/m
Ihalo/tile	8.310E+03 A
Brad =	6.800E-01 Tesla
Phalo, max =	8.116E-02 MPa
	1.177E+01 psi
Height, L =	1.058E-01 m
width, w =	6.962E-02 m
Ftoroidal =	5.975E+02 N
	1.343E+02 lbs



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower

Estimated Forces in NSTX IB divertor horizontal tiles

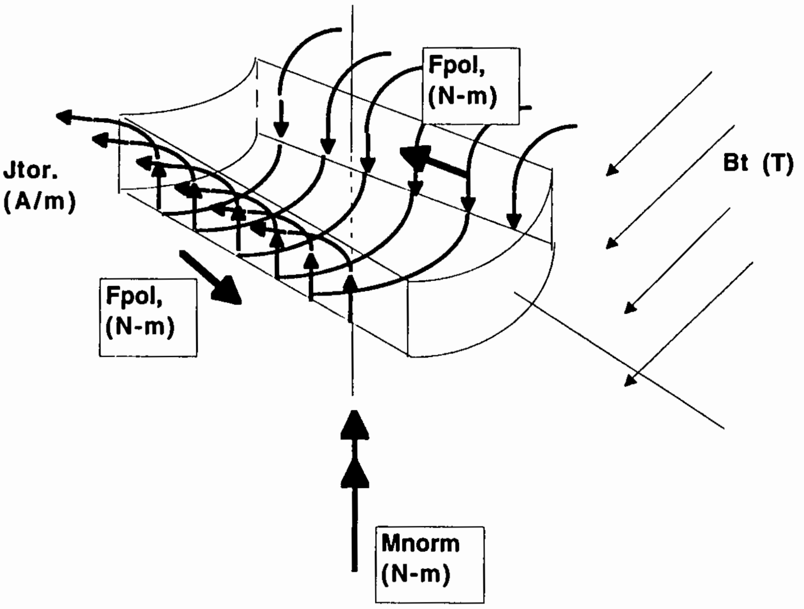
3/17/98 B. Nelson

Case no.	Description		Forces			Moments			Comments
		Fnorm N	Ftor. N	Fpol N	Mnorm N-m	Mtor N-m	Mpol N-m		
1	Forces due to normal current and toroidal field				9.998E+00				
2	Forces due to toroidal current and poloidal field	-8.237E+01	0 (net)					plus toroidal tension/comp	-5.000E+01 N
3	Forces due to toroidal current and normal field			9.225E+01					
4	Forces due to loop current and normal field							plus toroidal tension/comp plus vertical tension/comp	1.129E+02 2.537E+01
5	Forces due to loop current and toroidal field						1.129E+02		
6	Forces due to loop current and poloidal field					9.281E+00			
	TOTAL w/o Halo	-8.237E+01	0.000E+00	9.225E+01	9.998E+00	9.281E+00	1.129E+02		
7	Forces due to Halo current and toroidal field	1.157E+03							
8	Forces due to Halo current and normal field		5.329E+02						
	TOTAL Halo only	1.157E+03	5.329E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00		
	Assumptions:	**Iplasma (Amps)**	**Halo fraction**	**toroidal peak**	**Btor @ R0 (T)**	**Bradial, max (T)**	**Bpol, max (T)**		
		1.00E+06	0.1	2	0.6	0.56	-0.5		

Case 1, force due to normal current, toroidal field

Let

t (thickness)=	5.000E-02 m	
r tile =	4.195E-01 m	
no of tiles =	32	
width of tile =	8.224E-02 m	
	3.24 in	
Btor @ tile =	1.216E+00 Tesla	
I tile, toroidal	2.000E+03 amps	(see sheets 1,2)
L tile =	1.525E-01 m	
J tile =	1.311E+04 A/m	
Fpol = LxJxtxBt	1.216E+02 N	
	2.733E+01 lbs	
Mnorm = F*w=	9.998E+00 N-m	
	8.849E+01 in-lbs	



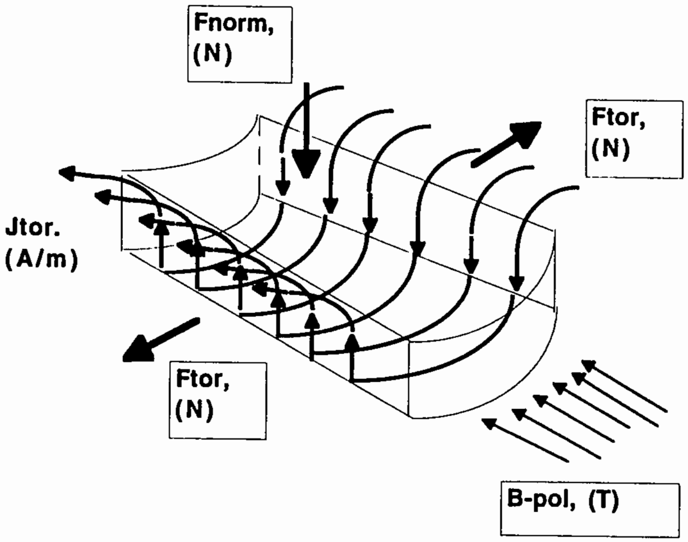
Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

innermost tile is used for calculation due to larger fields

Case 2, Forces due to toroidal current , normal field

Let:	
no.tiles circum	32
Bpol =	-0.5 Tesla, max
Jtor =	1.311E+04 A/m
P =JxB =	-6.557E+03 Pa
normal press =	-0.95 psi
Area,front =	
L*2*pi*r/n=	1.256E-02 m^2
Fnorm = P*A	-8.237E+01 N
	-1.852E+01 lbs
Area, side =	7.625E-03 m^2
Ftor =	-5.000E+01 N
	-1.124E+01 lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

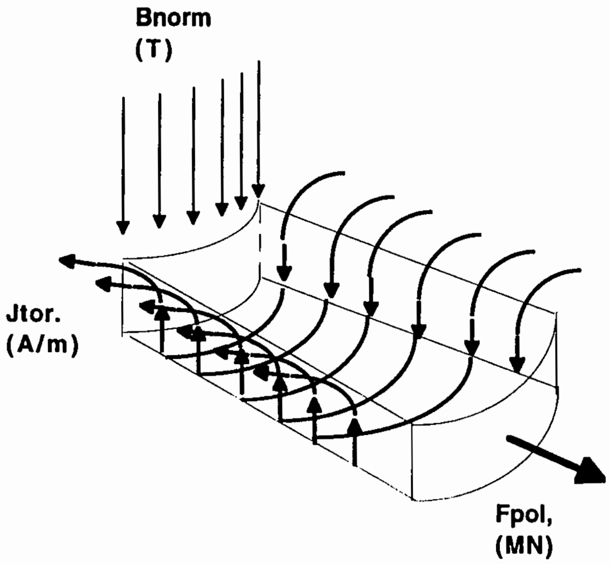


Case 3, Forces due to toroidal current , normal field

Let:

no.tiles circum	32
B-norm =	0.56 Tesla, max
Jtor =	1.311E+04 A/m
P =JxB =	7.344E+03 Pa
pol shear =	1.07 psi
Area,front =	
L*2*pi*r/n=	1.256E-02 m^2
Fpol = P*A	9.225E+01 N
	2.074E+01 lbs

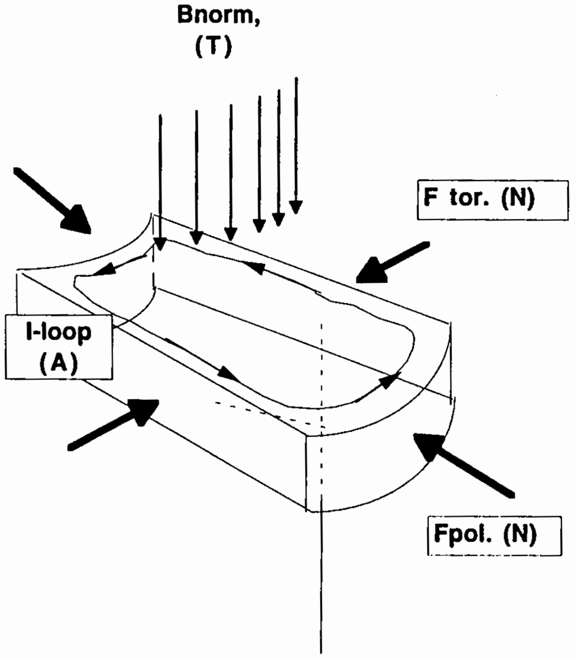
Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 4, Forces due to loop current , normal field

Let:

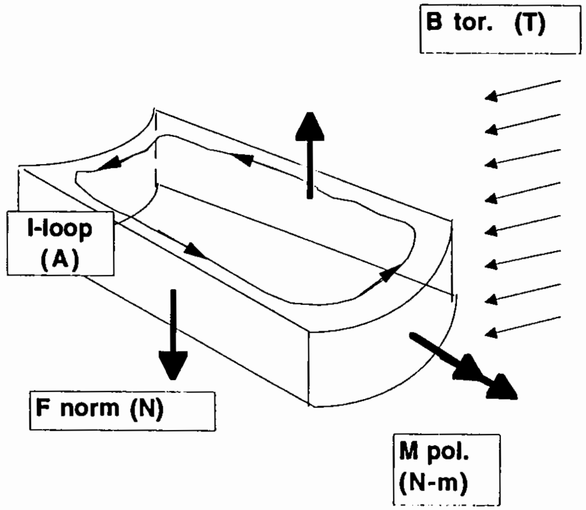
no.tiles circum	32
B-norm =	0.56 Tesla, max
delta B-norm. =	0.101 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	2.347E-01 m
Apath = t*(L+w)/4	2.934E-03 m^2
R loop =	9.600E-04 ohms
dB/dt*A loop	1.269E+00 Volts
Iloop =	1.322E+03 A
Area,front =	1.256E-02 m^2
F/l =	7.401E+02 N/m
F tor = f/l*L =	1.129E+02 N 2.537E+01 lbs
Fpol = f/l*w =	6.086E+01 N 1.368E+01 lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 5, Forces due to loop current , toroidal field

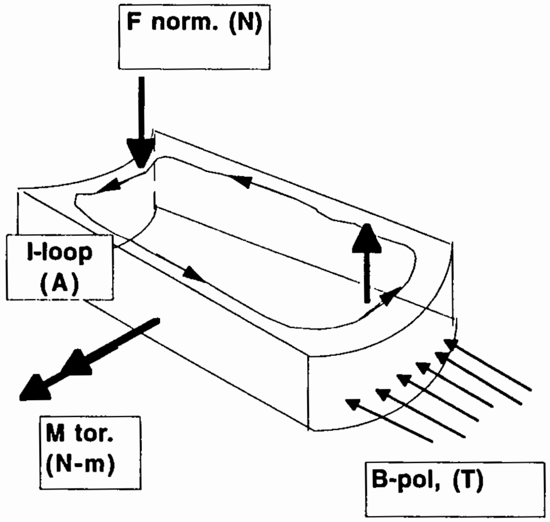
Let:	
no.tiles circum	32
B-norm =	0.56 Tesla, max
delta B-rad. =	0.101 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	2.347E-01 m
Apath =	
t*(L+w)/4	2.934E-03 m^2
R loop =	9.600E-04 ohms
dB/dt*A loop	1.269E+00 Volts
Iloop =	1.322E+03 A
Area,front =	1.256E-02 m^2
F/l =	7.401E+02 N/m
F norm = f/l*L =	1.129E+02 N
	2.537E+01 lbs
M pol.. = Fn*w	1.129E+02 N-m
	7.705E+02 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 6, Forces due to loop current , poloidal field

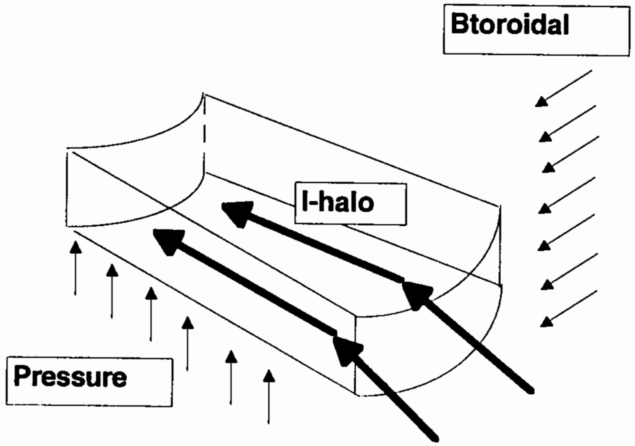
Let:	
no.tiles circum	32
B-norm =	0.56 Tesla, max
delta B-norm. =	0.101 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	2.347E-01 m
Apath = t*(L+w)/4	2.934E-03 m^2
R loop =	9.600E-04 ohms
dB/dt*A loop	1.269E+00 Volts
Iloop =	1.322E+03 A
Area,front =	1.256E-02 m^2
F/l =	7.401E+02 N/m
F norm = f/l*w =	6.086E+01 N
	1.368E+01 lbs
M toroidal =	9.281E+00 N-m
	8.215E+01 in-lbs

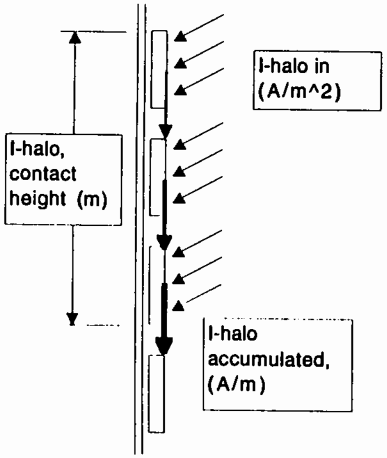


Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 7, halo currents and toroidal field

tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	75878 A/m
Ihalo/tile	6250 A
Btor =	1.22 Tesla
Phalo, max =	0.09 MPa 13 psi
height, L =	1.525E-01 m
width, w =	8.224E-02 m
Fnorm =	1.2E+3 N





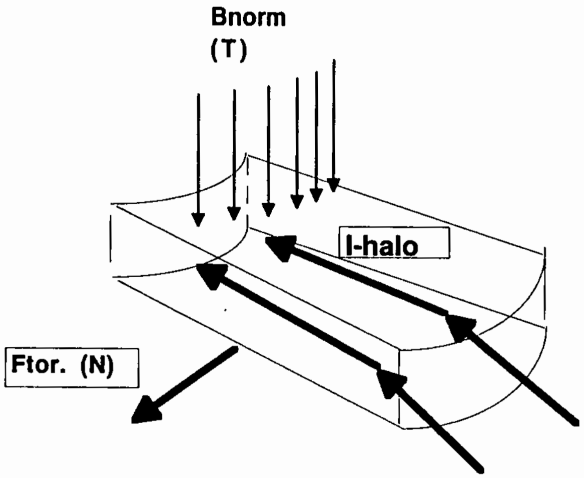
Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower

Case 8, halo currents and normal field

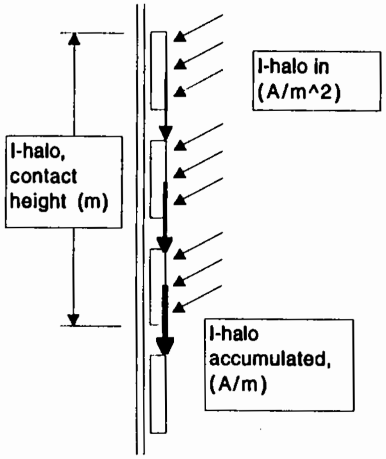
tor. peak fact=	2
I plasma =	1.000E+06 A
I halo	1.000E+05 A
Jhalo, est. =	7.588E+04 A/m
Ihalo/tile	6.240E+03 A
Bnorm=	5.600E-01 Tesla
Phalo, max =	4.249E-02 MPa
	6.164E+00 psi
Height, L =	1.525E-01 m
width, w =	8.224E-02 m
Ftoroidal =	5.329E+02 N
	1.198E+02 lbs



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Estimated Forces in NSTX Centerstack Rail Tiles

3/17/98 B. Nelson

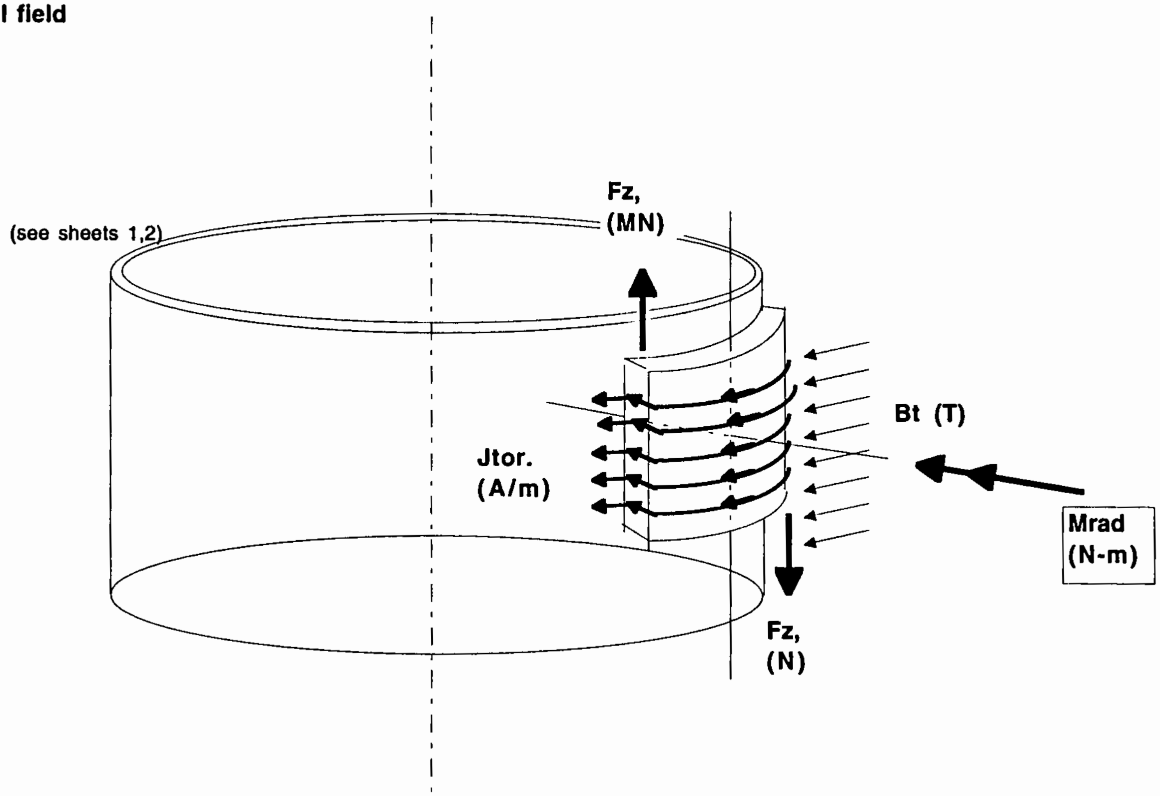
Case no.	Description	Forces Frad N	Ftor. N	Fver N	Moments Mrad N-m	Mtor N-m	Mver N-m	Comments	
1	Forces due to radial current and toroidal field				4.660E+00				
2	Forces due to toroidal current and vertical field	4.314E+01	0 (net)					plus toroidal tension/comp	1.295E+01 N
3	Forces due to toroidal current and radial field			3.148E+01					
4	Forces due to loop current and radial field							plus toroidal tension/comp plus vertical tension/comp	3.156E+00 7.095E-01
5	Forces due to loop current and toroidal field						3.156E+00		
6	Forces due to loop current and vertical field					1.468E-01			
	TOTAL w/o Halo	4.314E+01	0.000E+00	3.148E+01	4.660E+00	1.468E-01	3.156E+00		
7	Forces due to Halo current and toroidal field	3.625E+03							
8	Forces due to Halo current and radial field		3.419E+02						
	TOTAL Halo only	3.625E+03	3.419E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00		

Assumptions:	Iplasma (Amps)	Halo fraction	toroidal peak	Btor @ R0 (T)	Bradial, max (T)	Bpol, max (T)
	1.00E+06	0.1	2	0.6	0.27	0.37

Case 1, force due to radial current, toroidal field

Let

t (thickness)=	1.400E-02	m
r tile =	1.781E-01	m
no of tiles =	24	
width of tile =	4.650E-02	m
	1.83	in
Btor @ tile =	2.863E+00	Tesla
I tile, toroidal	2.500E+03	amps
L tile =	1.524E-01	m
J tile =	1.640E+04	A/m
Fz = LxJxtxBt =	1.002E+02	N
	2.253E+01	lbs
Mrad = F*w=	4.659785062	N-m
	4.124E+01	in-lbs



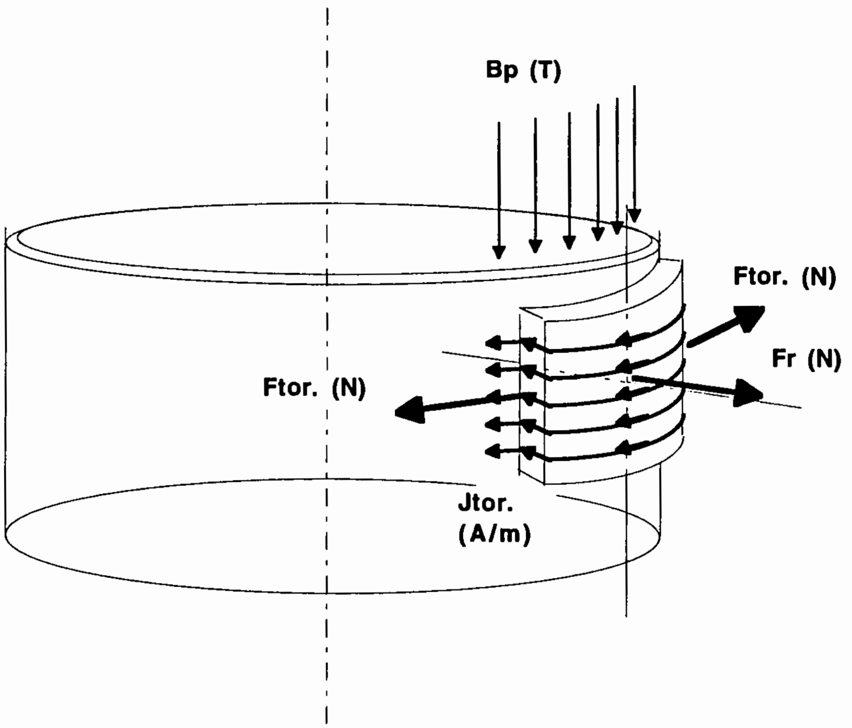
Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

Case 2, Forces due to toroidal current , vertical field

Let:	
no.tiles circum	24
Bpol =	0.37 Tesla, max
Jtor =	1.640E+04 A/m
P =JxB =	6.070E+03 Pa
rad pressure =	0.88 psi
Area,front =	
L*2*pi*r/n=	7.108E-03 m^2
Frad = P*A	4.314E+01 N
	9.698E+00 lbs
Area, side =	2.134E-03 m^2
Ftor =	1.295E+01 N
	2.911E+00 lbs

Note

Calculation assumes induced toroidal current as if tiles form continuous toroidal ring.

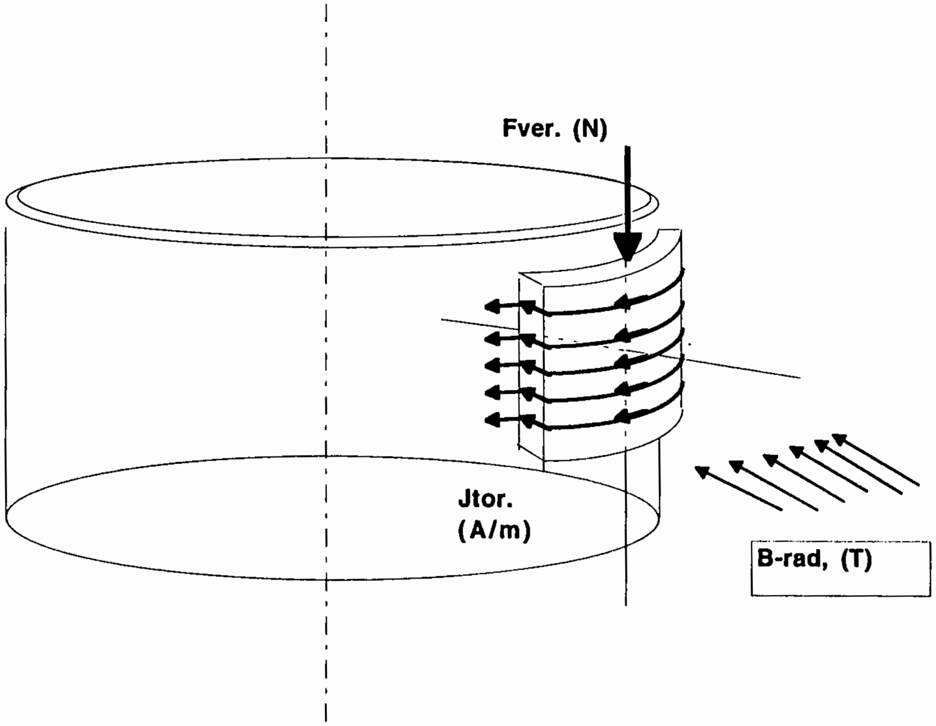


Case 3, Forces due to toroidal current , radial field

Let:

no.tiles circum	24	
B-rad =	0.27	Tesla, max
Jtor =	1.640E+04	A/m
P =JxB =	4.429E+03	Pa
vert shear =	0.64	psi
Area,front =		
L*2*pi*r/n=	7.108E-03	m^2
Fver = P*A	3.148E+01	N
	7.077E+00	lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 4, Forces due to loop current , radial field

Let:
no.tiles circum 24
B-rad = 0.27 Tesla, max
delta B-rad. = 0.037 Tesla
curr decay = 0.001 seconds

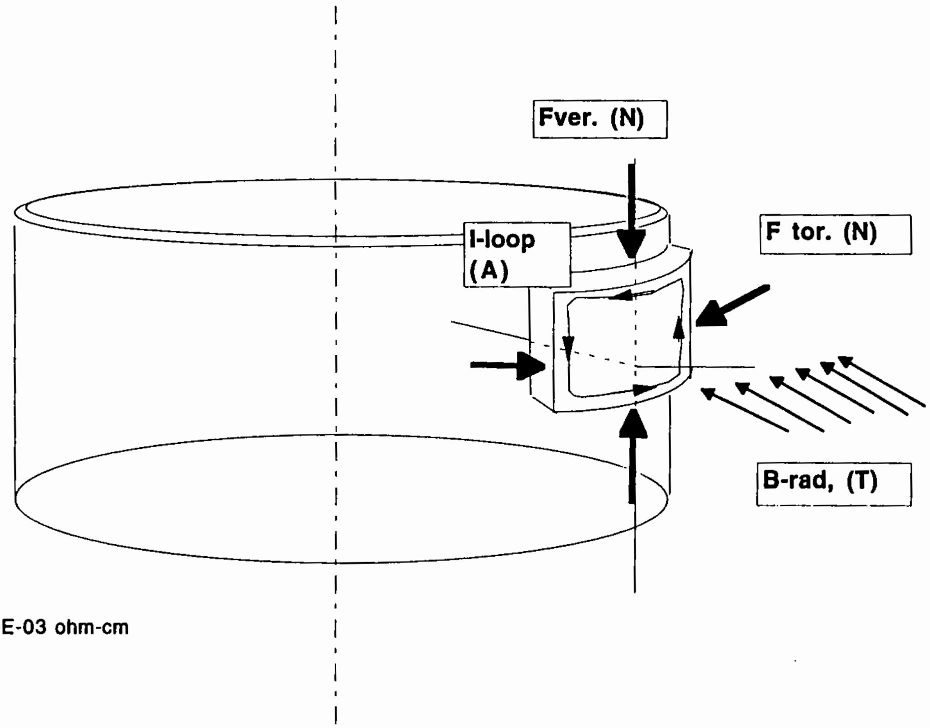
Lpath = L+w = 1.989E-01 m
Apath =
t*(L+w)/4 6.962E-04 m^2
R loop = 3.429E-03 ohms
dB/dt*A loop 2.630E-01 Volts
Iloop = 7.670E+01 A

Area,front = 7.108E-03 m^2

F/l = 2.071E+01 N/m

F tor = f/l*L = 3.156E+00 N
7.095E-01 lbs
Fver = f/l*w = 9.631E-01 N
2.165E-01 lbs

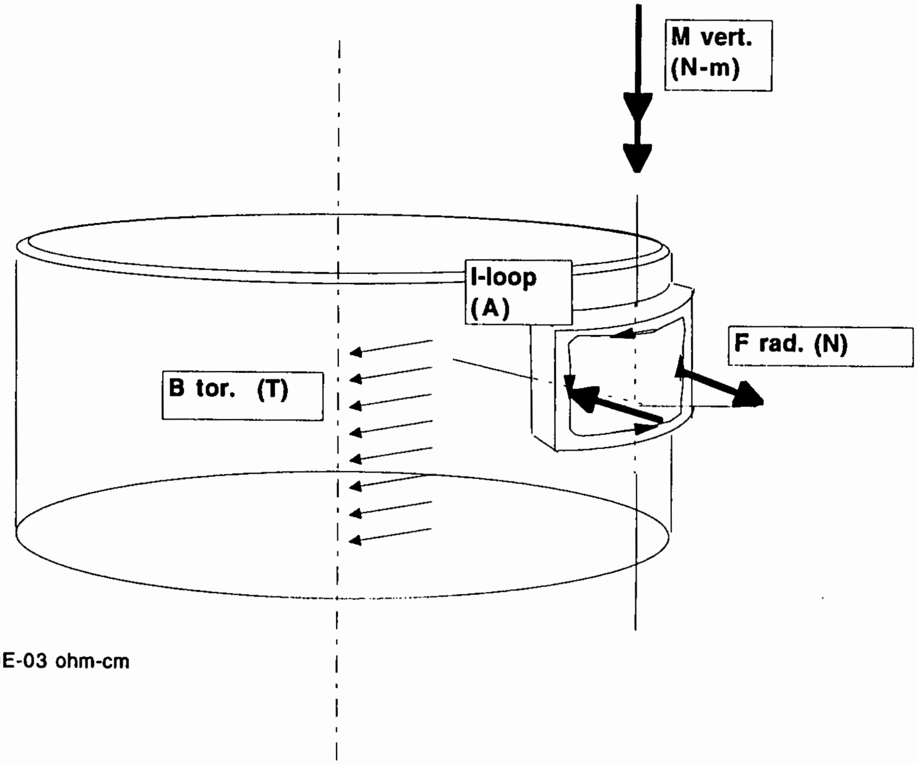
Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm



Case 5, Forces due to loop current , toroidal field

Let:

no.tiles circum	24
B-rad =	0.27 Tesla, max
delta B-rad. =	0.037 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.989E-01 m
Apath = t*(L+w)/4	6.962E-04 m^2
R loop =	3.429E-03 ohms
dB/dt*A loop	2.630E-01 Volts
Iloop =	7.670E+01 A
Area,front =	7.108E-03 m^2
F/l =	2.071E+01 N/m
F rad = f/l*L =	3.156E+00 N 7.095E-01 lbs
M vert. = Fr*w	3.156E+00 N-m 2.155E+01 in-lbs



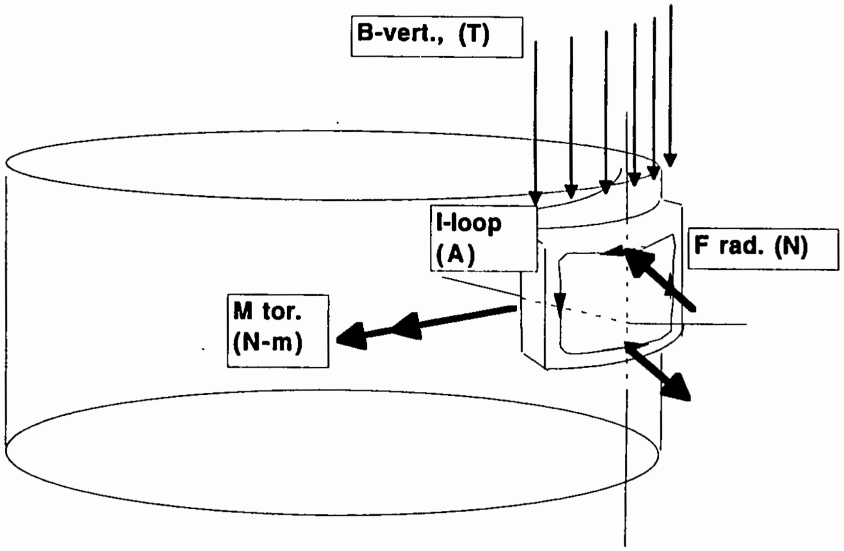
Note

Calculation assumes induced loop current due to change in radial field with resistivity of poco graphite 1.20E-03 ohm-cm

Case 6, Forces due to loop current , vertical field

Let:

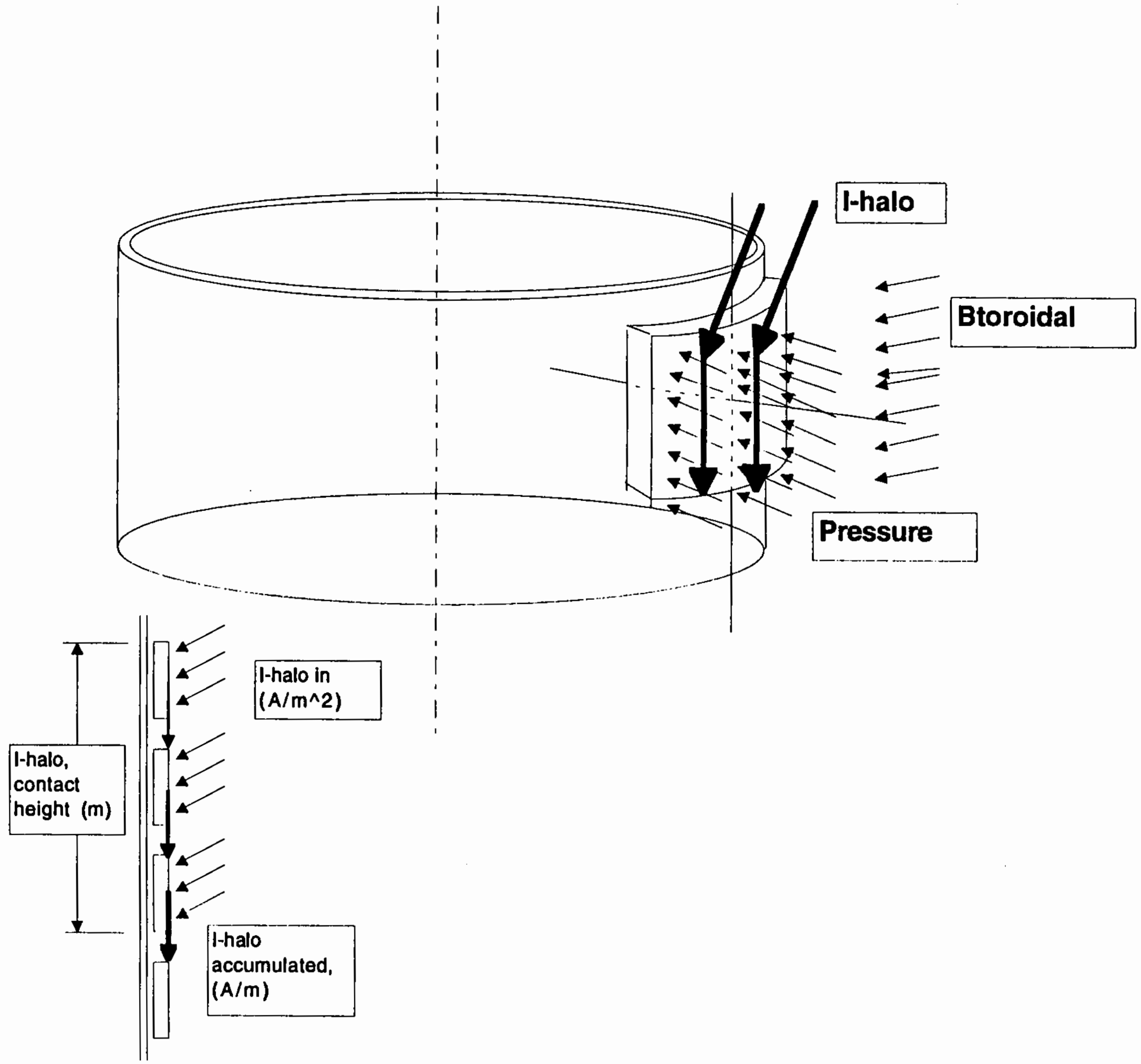
no.tiles circum	24
B-rad =	0.27 Tesla, max
delta B-rad. =	0.037 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.989E-01 m
Apath =	
t*(L+w)/4	6.962E-04 m^2
R loop =	3.429E-03 ohms
dB/dt*A loop	2.630E-01 Volts
Iloop =	7.670E+01 A
Area,front =	7.108E-03 m^2
F/l =	2.071E+01 N/m
F rad = f/l*w =	9.631E-01 N
	2.165E-01 lbs
M toroidal =	1.468E-01 N-m
	1.002E+00 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 7, halo currents and toroidal field

tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	178682 A/m
Ihalo/tile	8333 A
Btor =	2.86 Tesla
Phalo, max =	0.51 MPa 74 psi
height, L =	1.524E-01 m
width, w =	4.650E-02 m
Frad =	3.6E+3 N



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower

Estimated Forces in NSTX OB divertor tiles

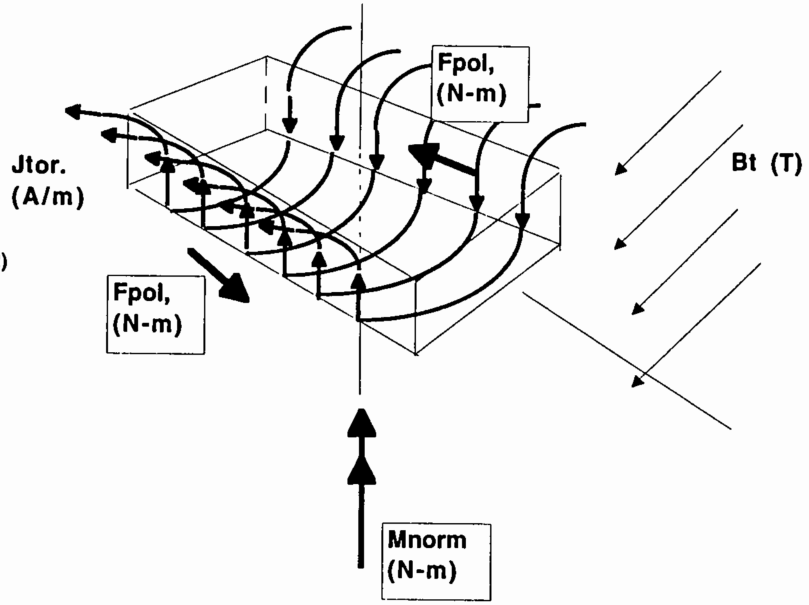
3/17/98 B. Nelson

Case no.	Description	Fnorm N	Forces Ftor. N	Fpol N	Mnorm N-m	Moments Mtor N-m	Mpol N-m	Comments	
1	Forces due to normal current and toroidal field				4.599E+00				
2	Forces due to toroidal current and vertical field	-2.298E+01	0 (net)					plus toroidal tension/comp	-9.647E+00 N
3	Forces due to toroidal current and radial field			2.200E+02					
4	Forces due to loop current and radial field							plus toroidal tension/comp	2.917E+01
								plus vertical tension/comp	6.559E+00
5	Forces due to loop current and toroidal field						2.917E+01		
6	Forces due to loop current and vertical field					1.737E+00			
	TOTAL w/o Halo	-2.298E+01	0.000E+00	2.200E+02	4.599E+00	1.737E+00	2.917E+01		
7	Forces due to Halo current and toroidal field	1.450E+02							
8	Forces due to Halo current and radial field		1.733E+02						
	TOTAL Halo only	1.450E+02	1.733E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00		
	Assumptions:	**Iplasma (Amps)**	**Halo fraction**	**toroidal peak**	**Btor @ R0 (T)**	**Bradial, max (T)**	**Bpol, max (T)**		
		1.00E+06	0.1	2	0.6	0.67	-0.07		

Case 1, force due to normal current, toroidal field

Let

t (thickness)=	2.500E-02 m	
r tile =	9.100E-01 m	
no of tiles =	96	
width of tile =	5.955E-02 m	
	2.34 in	
Btor @ tile =	5.604E-01 Tesla	
I tile, toroidal	5.513E+03 amps	(see sheets 1,2)
L tile =	1.242E-01 m	
J tile =	4.438E+04 A/m	
Fpol = LxJxtxBt	7.724E+01 N	
	1.736E+01 lbs	
Mnorm = F*w=	4.599E+00 N-m	
	4.071E+01 in-lbs	



Note

Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

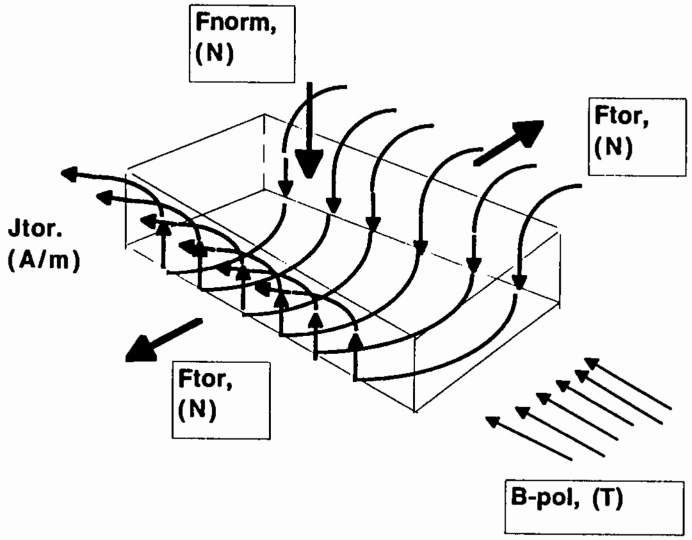
innermost tile is used for calculation due to larger fields

Case 2, Forces due to toroidal current , normal field

Let:

no.tiles circum	96	
Bpol =	-0.07	Tesla, max
Jtor =	4.438E+04	A/m
P =JxB =	-3.107E+03	Pa
normal press =	-0.45	psi
Area,front =		
L*2*pi*r/n=	7.397E-03	m^2
Fnorm = P*A	-2.298E+01	N
	-5.167E+00	lbs
Area, side =	3.105E-03	m^2
Ftor =	-9.647E+00	N
	-2.169E+00	lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

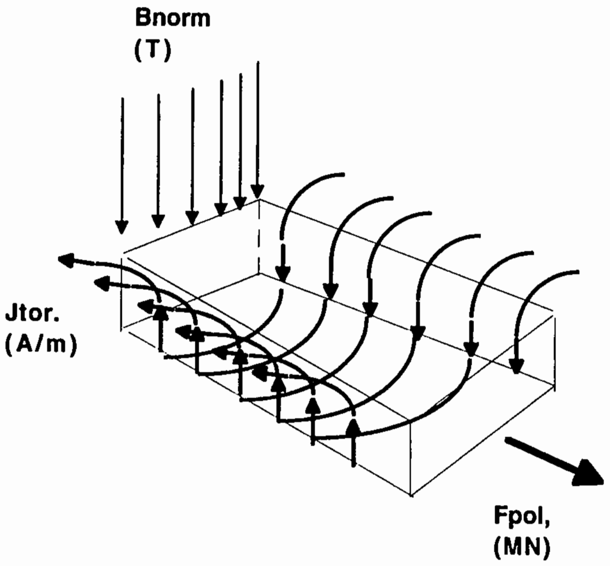


Case 3, Forces due to toroidal current , normal field

Let:

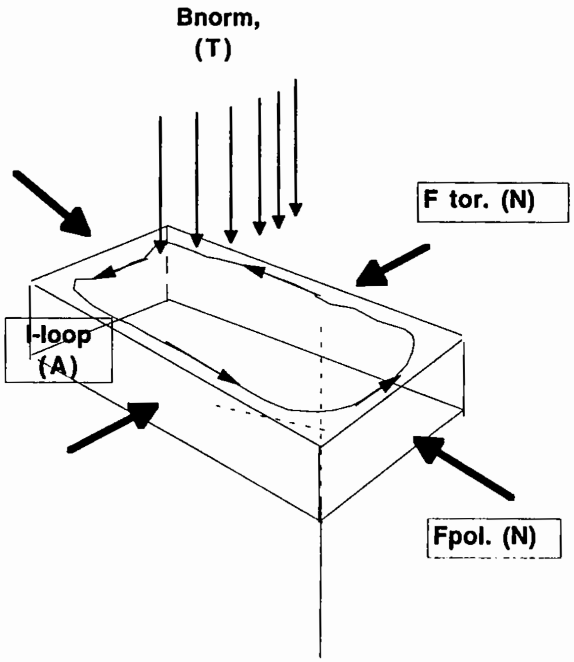
no.tiles circum	96
B-norm =	0.67 Tesla, max
Jtor =	4.438E+04 A/m
P =JxB =	2.974E+04 Pa
pol shear =	4.31 psi
Area,front =	
L*2*pi*r/n=	7.397E-03 m^2
Fpol = P*A	2.200E+02 N
	4.945E+01 lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 4, Forces due to loop current , normal field

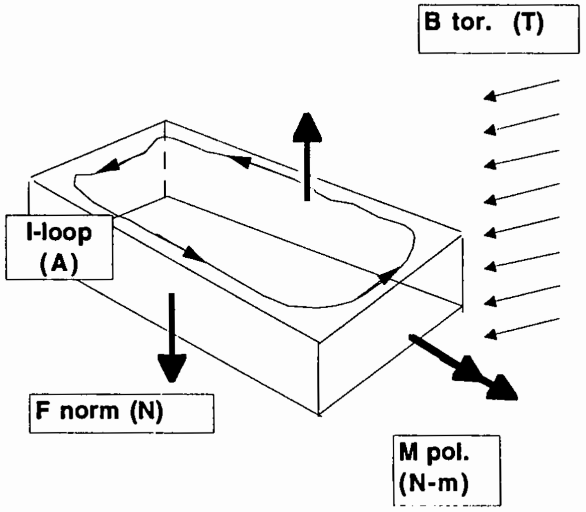
Let:	
no.tiles circum	96
B-norm =	0.67 Tesla, max
delta B-norm. =	0.091 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.837E-01 m
Apath = t*(L+w)/4	1.148E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	6.732E-01 Volts
Iloop =	3.506E+02 A
Area,front =	7.397E-03 m^2
F/l =	2.349E+02 N/m
F tor = f/l*L =	2.917E+01 N
	6.559E+00 lbs
Fpol = f/l*w =	1.399E+01 N
	3.145E+00 lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 5, Forces due to loop current , toroidal field

Let:	
no.tiles circum	96
B-norm =	0.67 Tesla, max
delta B-rad. =	0.091 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.837E-01 m
Apath =	
t*(L+w)/4	1.148E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	6.732E-01 Volts
Iloop =	3.506E+02 A
Area,front =	7.397E-03 m^2
F/l =	2.349E+02 N/m
F norm = f/l*L =	2.917E+01 N
	6.559E+00 lbs
M pol.. = Fn*w	2.917E+01 N-m
	1.992E+02 in-lbs

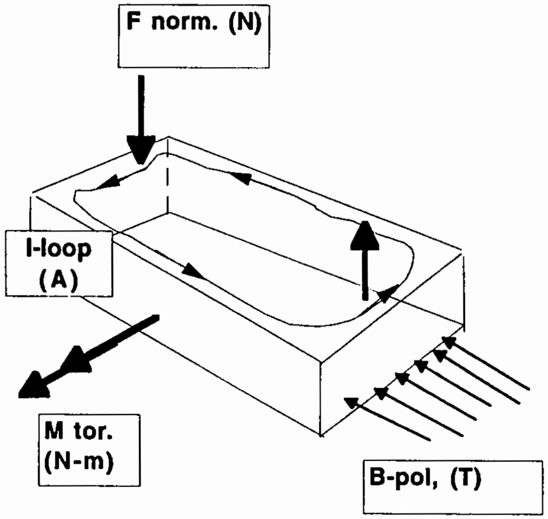


Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 6, Forces due to loop current , poloidal field

Let:

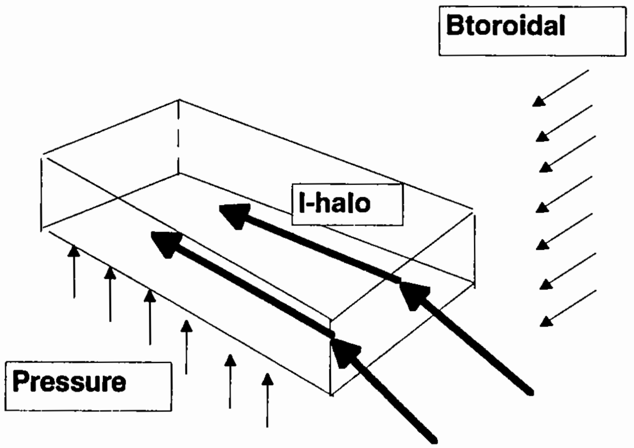
no.tiles circum	96
B-norm =	0.67 Tesla, max
delta B-norm. =	0.091 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.837E-01 m
Apath =	
t*(L+w)/4	1.148E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	6.732E-01 Volts
Iloop =	3.506E+02 A
Area,front =	7.397E-03 m^2
F/l =	2.349E+02 N/m
F norm = f/l*w =	1.399E+01 N
	3.145E+00 lbs
M toroidal =	1.737E+00 N-m
	1.538E+01 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 7, halo currents and toroidal field

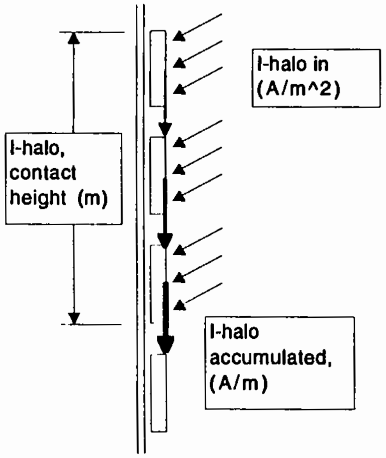
tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	34979 A/m
Ihalo/tile	2083 A
Btor =	0.56 Tesla
Phalo, max =	0.02 MPa
	3 psi
height, L =	1.242E-01 m
width, w =	5.955E-02 m
Fnorm =	145.0E+0 N



Note:

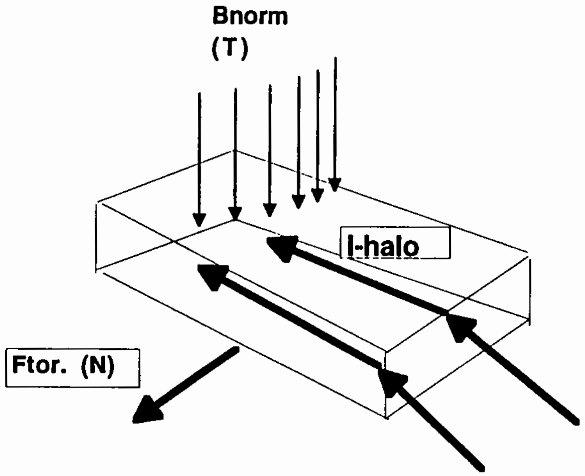
Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Case 8, halo currents and normal field

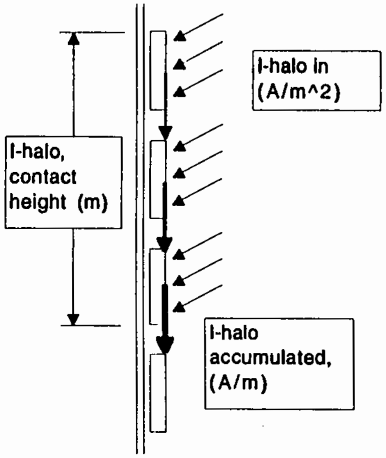
tor. peak fact=	2
I plasma =	1.000E+06 A
I halo	1.000E+05 A
Jhalo, est. =	3.498E+04 A/m
Ihalo/tile. =	2.083E+03 A
Bnorm=	6.700E-01 Tesla
Phalo, max =	2.344E-02 MPa
	3.399E+00 psi
Height, L =	1.242E-01 m
width, w =	5.955E-02 m
Ftoroidal =	1.733E+02 N
	3.897E+01 lbs



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Estimated Forces in NSTX secondary passive plate tiles

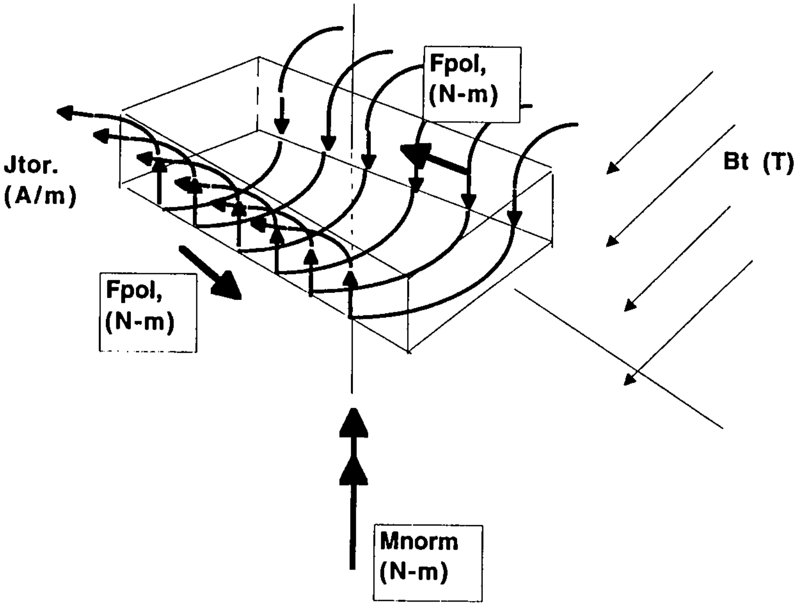
3/17/98 B. Nelson

			Forces			Moments			
Case no.	Description	Fnorm N	Ftor. N	Fpol N	Mnorm N-m	Mtor N-m	Mpol N-m	Comments	
1	Forces due to normal current and toroidal field				4.599E+00				
2	Forces due to toroidal current and vertical field	1.072E+02	0 (net)					plus toroidal tension/comp	3.445E+01 N
3	Forces due to toroidal current and radial field			2.872E+02					
4	Forces due to loop current and radial field							plus toroidal tension/comp	3.982E+01
								plus vertical tension/comp	8.952E+00
5	Forces due to loop current and toroidal field						3.982E+01		
6	Forces due to loop current and vertical field					3.096E+00			
	TOTAL w/o Halo	1.072E+02	0.000E+00	2.872E+02	4.599E+00	3.096E+00	3.982E+01		
7	Forces due to Halo current and toroidal field	9.613E+01							
8	Forces due to Halo current and radial field		1.500E+02						
	TOTAL Halo only	9.613E+01	1.500E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00		
	Assumptions:	**Iplasma (Amps)**	**Halo fraction**	**toroidal peak**	**Btor @ R0 (T)**	**Bnorm, max (T)**	**Bpol, max (T)**		
		1.00E+06	0.1	2	0.6	0.67	0.25		

Case 1, force due to normal current, toroidal field

Let

t (thickness)=	2.500E-02 m	
r tile =	1.188E+00 m	
no of tiles =	96	
width of tile =	7.774E-02 m	
	3.06 in	
Btor @ tile =	4.293E-01 Tesla	
I tile, toroidal	5.513E+03 amps	(see sheets 1,2)
L tile =	1.075E-01 m	
J tile =	5.128E+04 A/m	
Fpol = LxJxtxBt	5.916E+01 N	
	1.330E+01 lbs	
Mnorm = F*w=	4.599E+00 N-m	
	4.071E+01 in-lbs	



Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

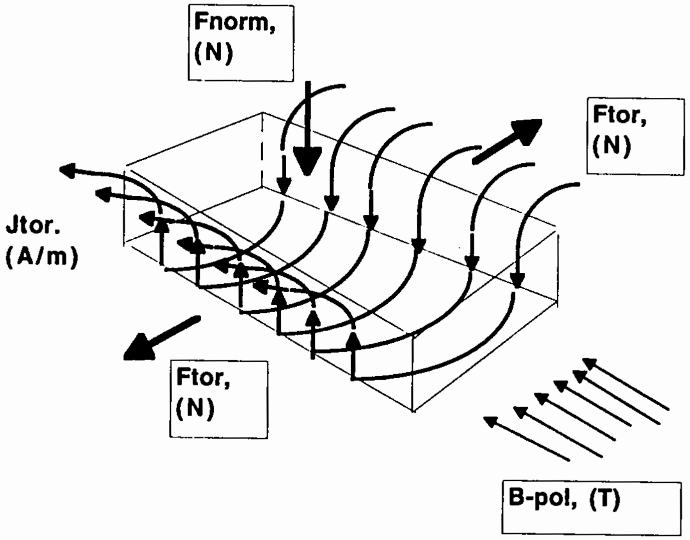
mean tile size and location is used for calculation

Case 2, Forces due to toroidal current , normal field

Let:
no.tiles circum 96
Bpol = 0.25 Tesla, max
Jtor = 5.128E+04 A/m
P =JxB = 1.282E+04 Pa
normal press = 1.86 psi
Area,front =
L*2*pi*r/n= 8.359E-03 m^2
Fnorm = P*A 1.072E+02 N
2.409E+01 lbs

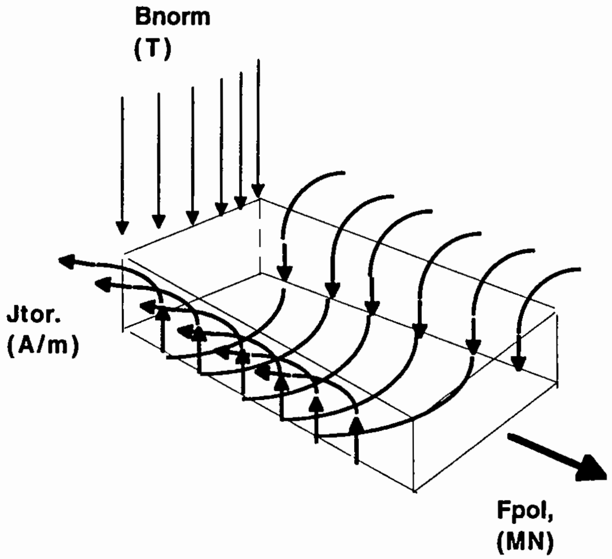
Area, side = 2.688E-03 m^2
Ftor = 3.445E+01 N
7.745E+00 lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 3, Forces due to toroidal current , normal field

Let:	
no.tiles circum	96
B-norm =	0.67 Tesla, max
Jtor =	5.128E+04 A/m
P =JxB =	3.436E+04 Pa
pol shear =	4.98 psi
Area,front =	
L*2*pi*r/n=	8.359E-03 m^2
Fpol = P*A	2.872E+02 N
	6.456E+01 lbs



Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

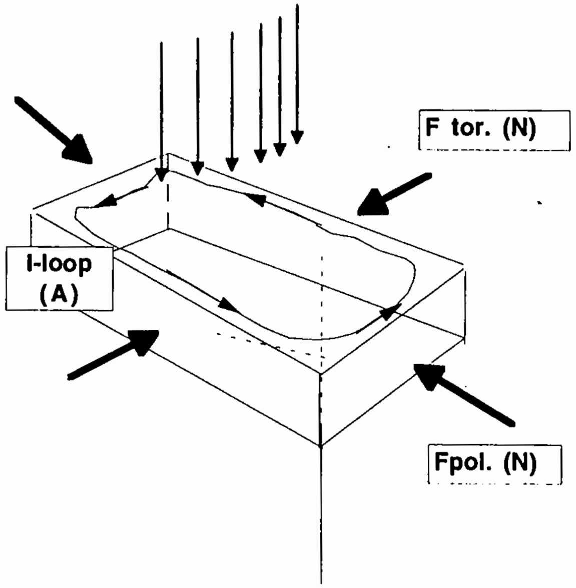
Case 4, Forces due to loop current , normal field

Let:

no.tiles circum	96
B-norm =	0.67 Tesla, max
delta B-norm. =	0.127 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.852E-01 m
Apath = t*(L+w)/4	1.158E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	1.062E+00 Volts
Iloop =	5.529E+02 A
Area,front =	8.359E-03 m^2
F/l =	3.704E+02 N/m
F tor = f/l*L =	3.982E+01 N
	8.952E+00 lbs
Fpol = f/l*w =	2.880E+01 N
	6.474E+00 lbs

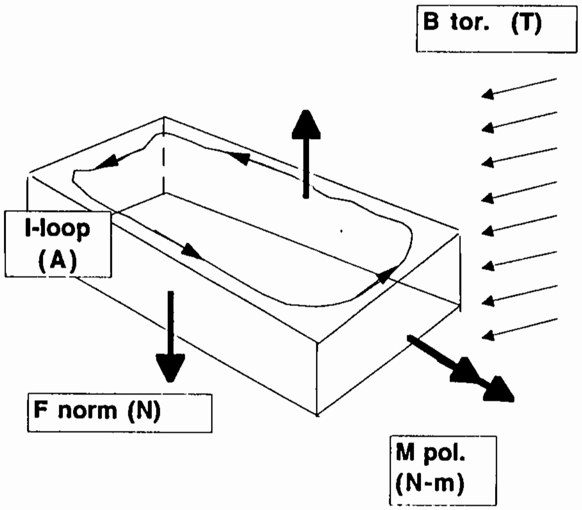
Note

Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm



Case 5, Forces due to loop current , toroidal field

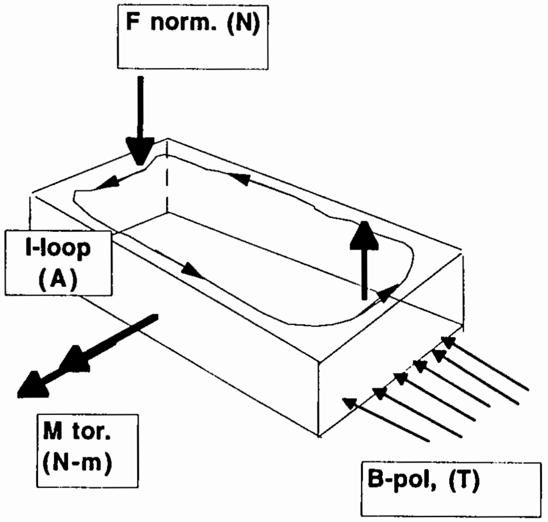
Let:	
no.tiles circum	96
B-norm =	0.67 Tesla, max
delta B-rad. =	0.127 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.852E-01 m
Apath =	
t*(L+w)/4	1.158E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	1.062E+00 Volts
Iloop =	5.529E+02 A
Area,front =	8.359E-03 m^2
F/l =	3.704E+02 N/m
F norm = f/l*L =	3.982E+01 N
	8.952E+00 lbs
M pol.. = Fn*w	3.982E+01 N-m
	2.719E+02 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 6, Forces due to loop current , poloidal field

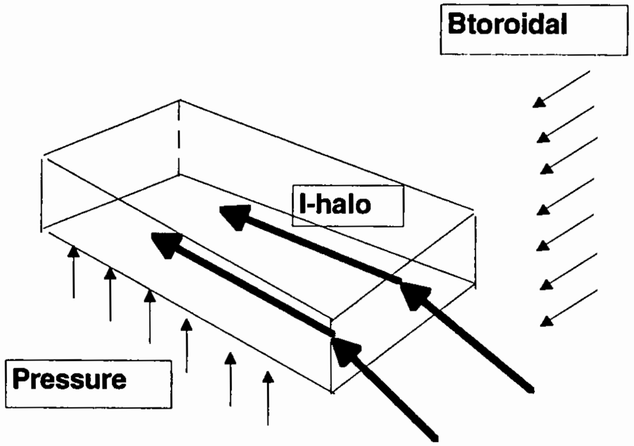
Let:	
no.tiles circum	96
B-norm =	0.67 Tesla, max
delta B-norm. =	0.127 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	1.852E-01 m
Apath = t*(L+w)/4	1.158E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	1.062E+00 Volts
Iloop =	5.529E+02 A
Area,front =	8.359E-03 m^2
F/l =	3.704E+02 N/m
F norm = f/l*w =	2.880E+01 N 6.474E+00 lbs
M toroidal =	3.096E+00 N-m 2.740E+01 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 7, halo currents and toroidal field

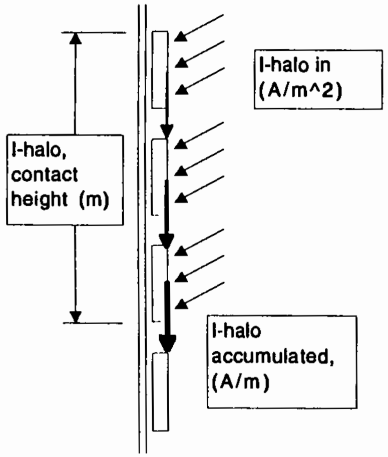
tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	26794 A/m
Ihalo/tile	2083 A
Btor =	0.43 Tesla
Phalo, max =	0.01 MPa 2 psi
height, L =	1.075E-01 m
width, w =	7.774E-02 m
Fnorm =	96.1E+0 N



Note:

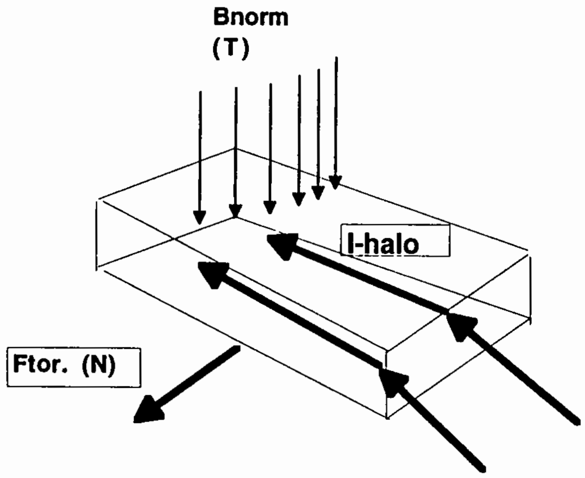
Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Case 8, halo currents and normal field

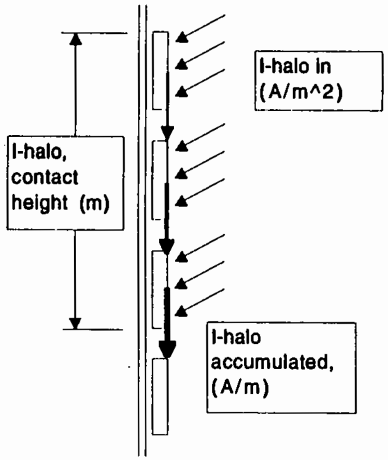
tor. peak fact=	2
I plasma =	1.000E+06 A
I halo	1.000E+05 A
Jhalo, est. =	2.679E+04 A/m
Ihalo/tile	2.083E+03 A
Bnorm=	6.700E-01 Tesla
Phalo, max =	1.795E-02 MPa 2.604E+00 psi
Height, L =	1.075E-01 m
width, w =	7.774E-02 m
Ftoroidal =	1.500E+02 N 3.373E+01 lbs



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Estimated Forces in NSTX primary passive plate tiles

3/17/98 B. Nelson

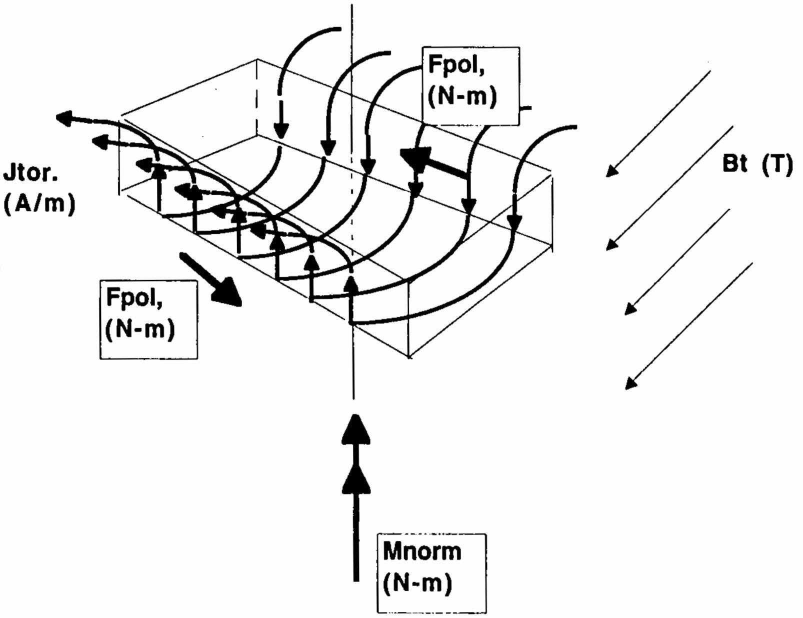
Case no.	Description	Forces Fnorm N	Ftor. N	Fpol N	Moments Mnorm N-m	Mtor N-m	Mpol N-m	Comments	
1	Forces due to normal current and toroidal field				1.764E+01				
2	Forces due to toroidal current and vertical field	9.119E+02	0 (net)					plus toroidal tension/comp	2.537E+02 N
3	Forces due to toroidal current and radial field			7.029E+02					
4	Forces due to loop current and radial field							plus toroidal tension/comp plus vertical tension/comp	3.940E+01 8.858E+00
5	Forces due to loop current and toroidal field						3.940E+01		
6	Forces due to loop current and vertical field					3.540E+00			
	TOTAL w/o Halo	9.119E+02	0.000E+00	7.029E+02	1.764E+01	3.540E+00	3.940E+01		
7	Forces due to Halo current and toroidal field	9.227E+01							
8	Forces due to Halo current and radial field		9.191E+01						
	TOTAL Halo only	9.227E+01	9.191E+01	0.000E+00	0.000E+00	0.000E+00	0.000E+00		

	Iplasma (Amps)	Halo fraction	toroidal peak	Btor @ R0 (T)	Bnorm, max (T)	Bpol, max (T)
Assumptions:	1.00E+06	0.1	2	0.6	0.37	0.48

Case 1, force due to normal current, toroidal field

Let

t (thickness)=	2.500E-02 m	
r tile =	1.373E+00 m	
no of tiles =	96	
width of tile =	8.985E-02 m	
	3.54 in	
Btor @ tile =	3.714E-01 Tesla	
I tile, toroidal	2.114E+04 amps	(see sheets 1,2)
L tile =	1.193E-01 m	
J tile =	1.773E+05 A/m	
Fpol = LxJxtxBt	1.963E+02 N	
	4.413E+01 lbs	
Mnorm = F*w=	1.764E+01 N-m	
	1.561E+02 in-lbs	



Note

Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

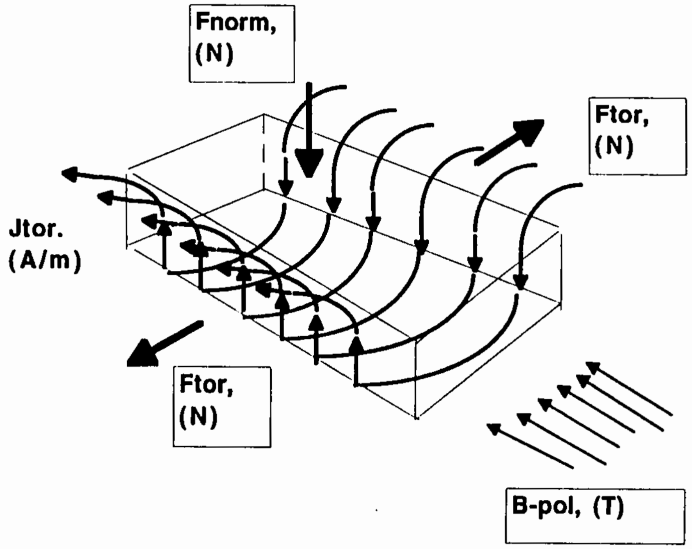
mean tile size and location is used for calculation

Case 2, Forces due to toroidal current , normal field

Let:
no.tiles circum 96
Bpol = 0.48 Tesla, max
Jtor = 1.773E+05 A/m
P =JxB = 8.509E+04 Pa
normal press = 12.34 psi
Area,front =
L*2*pi*r/n= 1.072E-02 m^2
Fnorm = P*A 9.119E+02 N
2.050E+02 lbs

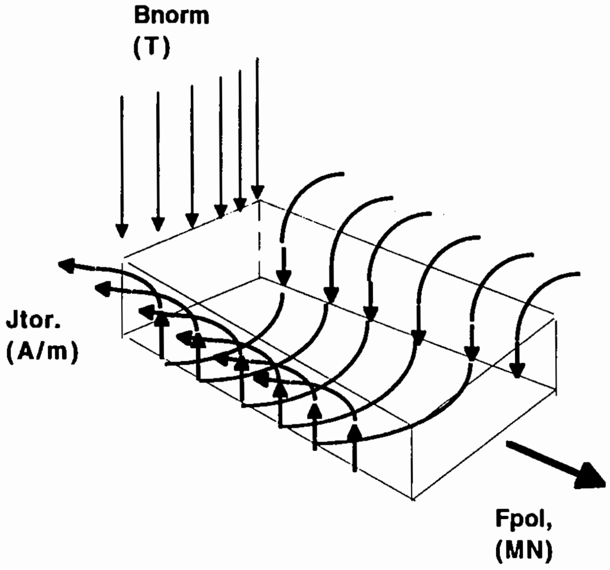
Area, side = 2.981E-03 m^2
Ftor = 2.537E+02 N
5.703E+01 lbs

Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.



Case 3, Forces due to toroidal current , normal field

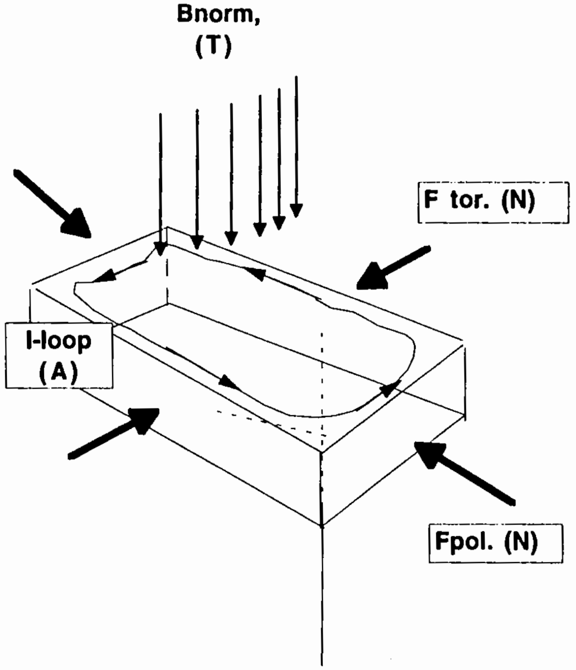
Let:	
no.tiles circum	96
B-norm =	0.37 Tesla, max
Jtor =	1.773E+05 A/m
P =JxB =	6.559E+04 Pa
pol shear =	9.51 psi
Area,front =	
L*2*pi*r/n=	1.072E-02 m^2
Fpol = P*A	7.029E+02 N
	1.580E+02 lbs



Note
Calculation assumes induced toroidal current
as if tiles form continuous toroidal ring.

Case 4, Forces due to loop current , normal field

Let:	
no.tiles circum	96
B-norm =	0.37 Tesla, max
delta B-norm. =	0.16 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	2.091E-01 m
Apath =	
t*(L+w)/4	1.307E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	1.715E+00 Volts
Iloop =	8.930E+02 A
Area,front =	1.072E-02 m^2
F/l =	3.304E+02 N/m
F tor = f/l*L =	3.940E+01 N
	8.858E+00 lbs
Fpol = f/l*w =	2.969E+01 N
	6.674E+00 lbs



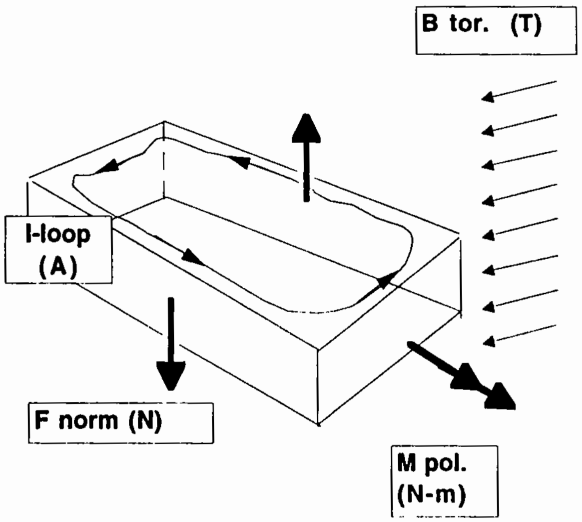
Note

Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 5, Forces due to loop current , toroidal field

Let:

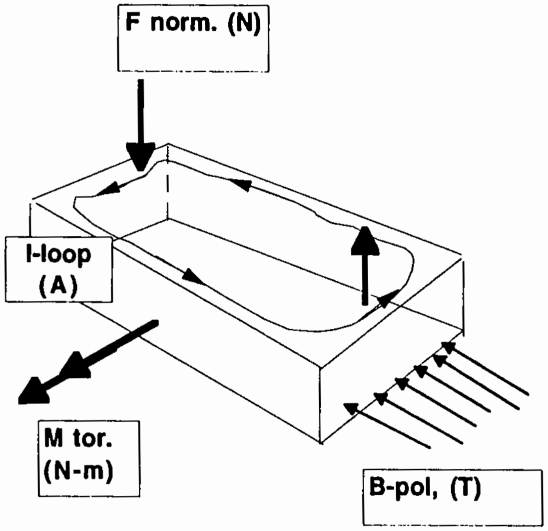
no.tiles circum	96
B-norm =	0.37 Tesla, max
delta B-rad. =	0.16 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	2.091E-01 m
Apath =	
t*(L+w)/4	1.307E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	1.715E+00 Volts
Iloop =	8.930E+02 A
Area,front =	1.072E-02 m^2
F/l =	3.304E+02 N/m
F norm = f/l*L =	3.940E+01 N
	8.858E+00 lbs
M pol.. = Fn*w	3.940E+01 N-m
	2.690E+02 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 6, Forces due to loop current , poloidal field

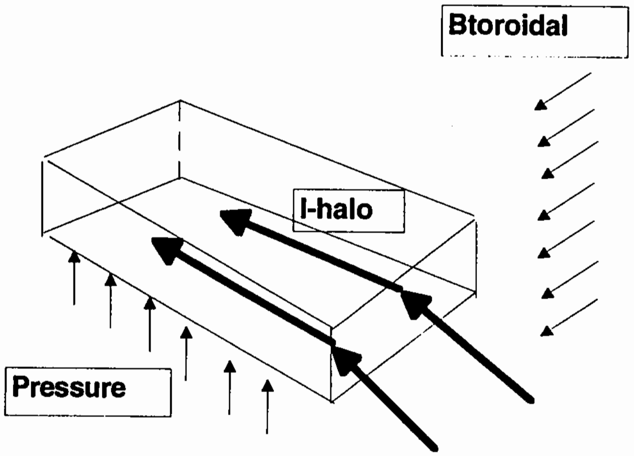
Let:	
no.tiles circum	96
B-norm =	0.37 Tesla, max
delta B-norm. =	0.16 Tesla
curr decay =	0.001 seconds
Lpath = L+w =	2.091E-01 m
Apath = t*(L+w)/4	1.307E-03 m^2
R loop =	1.920E-03 ohms
dB/dt*A loop	1.715E+00 Volts
Iloop =	8.930E+02 A
Area,front =	1.072E-02 m^2
F/l =	3.304E+02 N/m
F norm = f/l*w =	2.969E+01 N 6.674E+00 lbs
M toroidal =	3.540E+00 N-m 3.133E+01 in-lbs



Note
Calculation assumes induced loop current
due to change in radial field
with resistivity of poco graphite 1.20E-03 ohm-cm

Case 7, halo currents and toroidal field

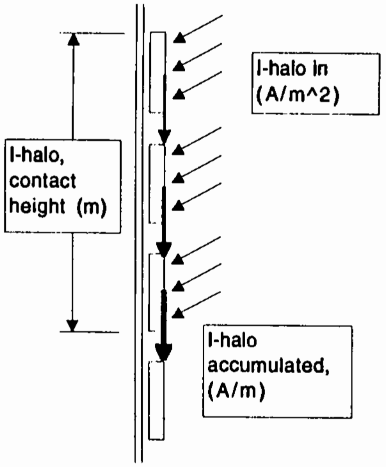
tor. peak fact=	2
I plasma =	1.00E+06 A
fract of I plasma in halo	0.1
I halo	100000 A
Jhalo, est. =	23184 A/m
Ihalo/tile	2083 A
Btor =	0.37 Tesla
Phalo, max =	0.01 MPa 1 psi
height, L =	1.193E-01 m
width, w =	8.985E-02 m
Fnorm =	92.3E+0 N



Note:

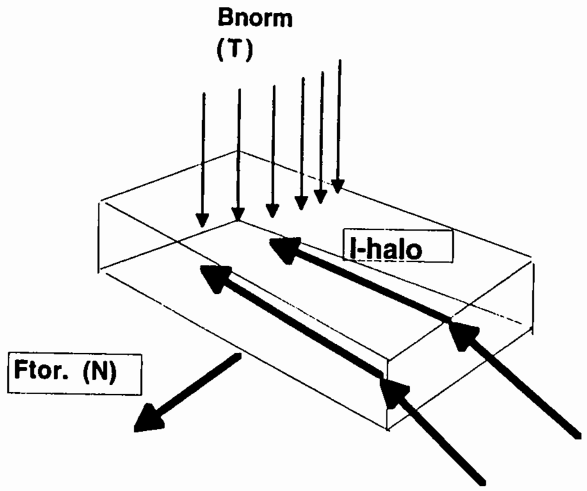
Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Case 8, halo currents and normal field

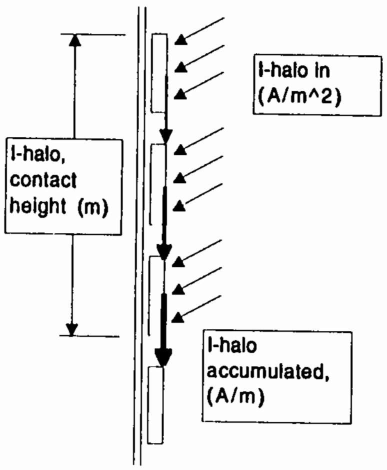
tor. peak fact=	2
I plasma =	1.000E+06 A
I halo	1.000E+05 A
Jhalo, est. =	2.318E+04 A/m
Ihalo/tile	2.083E+03 A
Bnorm=	3.700E-01 Tesla
Phalo, max =	8.578E-03 MPa
	1.244E+00 psi
Height, L =	1.193E-01 m
width, w =	8.985E-02 m
Ftoroidal =	9.191E+01 N
	2.066E+01 lbs



Note:

Calculaton assumes that the halo current transfers from tile to tile vertically and accumulates over halo contact "height"

If the current does not accumulate from tile to tile, the forces will be lower



Fields from 1 MA plasma at components

	Average		Peak (abs value)	
	Bnorm	Bpol	Bnorm	Bpol
Centerstack	5.07E-07	2.41E+03	1.29E+02	5.08E+03
IBD, cylinder	2.83E+02	1.47E+03	3.84E+02	1.92E+03
IBD, horizontal	9.44E+02	-2.71E+02	1.01E+03	3.55E+02
OB divertor	8.47E+02	-2.35E+02	9.13E+02	4.25E+02
Sec Pass Plate	1.10E+03	5.52E+01	1.27E+03	2.19E+02
Prim pass plate	1.25E+03	-2.58E+01	1.60E+03	1.84E+02

Centerstack

Angle =	90	deg	1.57079633	rad			
NCOORD	NCAL	NCOL	NLAY	NGEO	NX	NY	NZ
3	1	1	1	0	1	1	9
XST	XF	YST	YF	ZST	ZF		
0.178	0.178	0	0	-1.6	1.6		

R	THET	Z	BR	BTHET	BZ	BMOD	Bnorm	Bpoloidal	Bmod
1.78E-01	0.00E+00	-1.60E+00	-1.29E+02	2.56E-08	1.07E+03	1.08E+03	-1.29E+02	1.07E+03	1.08E+03
1.78E-01	0.00E+00	-1.20E+00	-2.45E+02	-6.58E-08	1.87E+03	1.89E+03	-2.45E+02	1.87E+03	1.89E+03
1.78E-01	0.00E+00	-8.00E-01	-3.66E+02	-4.96E-07	3.33E+03	3.35E+03	-3.66E+02	3.33E+03	3.35E+03
1.78E-01	0.00E+00	-4.00E-01	-1.92E+02	-1.25E-06	4.66E+03	4.67E+03	-1.92E+02	4.66E+03	4.67E+03
1.78E-01	0.00E+00	-1.11E-16	1.52E-06	-1.50E-06	5.08E+03	5.08E+03	1.52E-06	5.08E+03	5.08E+03
1.78E-01	0.00E+00	4.00E-01	1.92E+02	-1.25E-06	4.66E+03	4.67E+03	1.92E+02	4.66E+03	4.67E+03
1.78E-01	0.00E+00	8.00E-01	3.66E+02	-4.96E-07	3.33E+03	3.35E+03	3.66E+02	3.33E+03	3.35E+03
1.78E-01	0.00E+00	1.20E+00	2.45E+02	-6.58E-08	1.87E+03	1.89E+03	2.45E+02	1.87E+03	1.89E+03
1.78E-01	0.00E+00	1.60E+00	1.29E+02	2.56E-08	1.07E+03	1.08E+03	1.29E+02	1.07E+03	1.08E+03

IBD, cylinder

Angle =	90	deg	1.57079633	rad			
NCOORD	NCAL	NCOL	NLAY	NGEO	NX	NY	NZ
3	1	1	1	0	3	1	3
XST	XF	YST	YF	ZST	ZF		
0.267	0.267	0	0	1.167	1.591		

R	THET	Z	BR	BTHET	BZ	BMOD	Bnorm	Bpoloidal	Bmod

	2.67E-01	0.00E+00	1.17E+00	3.84E+02	-7.18E-08	1.92E+03	1.96E+03	3.84E+02	1.92E+03	1.96E+03
	2.67E-01	0.00E+00	1.38E+00	2.72E+02	-2.95E-09	1.42E+03	1.44E+03	2.72E+02	1.42E+03	1.44E+03
	2.67E-01	0.00E+00	1.59E+00	1.93E+02	2.69E-08	1.06E+03	1.08E+03	1.93E+02	1.06E+03	1.08E+03
	2.67E-01	0.00E+00	1.17E+00	3.84E+02	-7.18E-08	1.92E+03	1.96E+03	3.84E+02	1.92E+03	1.96E+03
	2.67E-01	0.00E+00	1.38E+00	2.72E+02	-2.95E-09	1.42E+03	1.44E+03	2.72E+02	1.42E+03	1.44E+03
	2.67E-01	0.00E+00	1.59E+00	1.93E+02	2.69E-08	1.06E+03	1.08E+03	1.93E+02	1.06E+03	1.08E+03
	2.67E-01	0.00E+00	1.17E+00	3.84E+02	-7.18E-08	1.92E+03	1.96E+03	3.84E+02	1.92E+03	1.96E+03
	2.67E-01	0.00E+00	1.38E+00	2.72E+02	-2.95E-09	1.42E+03	1.44E+03	2.72E+02	1.42E+03	1.44E+03
	2.67E-01	0.00E+00	1.59E+00	1.93E+02	2.69E-08	1.06E+03	1.08E+03	1.93E+02	1.06E+03	1.08E+03
IBD, horizontal										
	Angle =	0	deg	0	rad					
	NCOORD	NCAL	NCOL	NLAY	NGEO	NX	NY	NZ		
	3	1	1	1	0	3	1	3		
	XST	XF	YST	YF	ZST	ZF				
	0.267	0.572	0	0	1.629	1.629				
	R	THET	Z	BR	BTHET	BZ	BMOD	Bnorm	Bpoloidal	Bmod
	2.67E-01	0.00E+00	1.63E+00	1.82E+02	2.99E-08	1.01E+03	1.02E+03	1.01E+03	-1.82E+02	1.02E+03
	2.67E-01	0.00E+00	1.63E+00	1.82E+02	2.99E-08	1.01E+03	1.02E+03	1.01E+03	-1.82E+02	1.02E+03
	2.67E-01	0.00E+00	1.63E+00	1.82E+02	2.99E-08	1.01E+03	1.02E+03	1.01E+03	-1.82E+02	1.02E+03
	4.20E-01	0.00E+00	1.63E+00	2.75E+02	3.44E-08	9.51E+02	9.90E+02	9.51E+02	-2.75E+02	9.90E+02
	4.20E-01	0.00E+00	1.63E+00	2.75E+02	3.44E-08	9.51E+02	9.90E+02	9.51E+02	-2.75E+02	9.90E+02
	4.20E-01	0.00E+00	1.63E+00	2.75E+02	3.44E-08	9.51E+02	9.90E+02	9.51E+02	-2.75E+02	9.90E+02
	5.72E-01	0.00E+00	1.63E+00	3.55E+02	4.01E-08	8.75E+02	9.44E+02	8.75E+02	-3.55E+02	9.44E+02
	5.72E-01	0.00E+00	1.63E+00	3.55E+02	4.01E-08	8.75E+02	9.44E+02	8.75E+02	-3.55E+02	9.44E+02
	5.72E-01	0.00E+00	1.63E+00	3.55E+02	4.01E-08	8.75E+02	9.44E+02	8.75E+02	-3.55E+02	9.44E+02
OB divertor										
	Angle =	21.5	deg	0.37524579	rad					
	NCOORD	NCAL	NCOL	NLAY	NGEO	NX	NY	NZ		
	3	1	1	1	0	3	1	3		
	XST	XF	YST	YF	ZST	ZF				
	0.622	1.199	0	0	1.64	1.412				
	R	THET	Z	BR	BTHET	BZ	BMOD	Bnorm	Bpoloidal	Bmod
	6.22E-01	0.00E+00	1.64E+00	3.71E+02	4.25E-08	8.35E+02	9.14E+02	9.13E+02	-3.94E+01	9.14E+02

	6.22E-01	0.00E+00	1.53E+00	4.45E+02	3.78E-08	9.63E+02	1.06E+03	1.06E+03	-6.09E+01	1.06E+03
	6.22E-01	0.00E+00	1.41E+00	5.35E+02	2.91E-08	1.12E+03	1.24E+03	1.23E+03	-8.88E+01	1.24E+03
	9.11E-01	0.00E+00	1.64E+00	4.61E+02	5.39E-08	6.48E+02	7.96E+02	7.72E+02	-1.92E+02	7.96E+02
	9.11E-01	0.00E+00	1.53E+00	5.49E+02	5.48E-08	7.34E+02	9.17E+02	8.84E+02	-2.42E+02	9.16E+02
	9.11E-01	0.00E+00	1.41E+00	6.56E+02	5.38E-08	8.34E+02	1.06E+03	1.02E+03	-3.04E+02	1.06E+03
	1.20E+00	0.00E+00	1.64E+00	4.82E+02	6.22E-08	4.48E+02	6.58E+02	5.93E+02	-2.84E+02	6.58E+02
	1.20E+00	0.00E+00	1.53E+00	5.66E+02	6.79E-08	4.91E+02	7.49E+02	6.64E+02	-3.47E+02	7.49E+02
	1.20E+00	0.00E+00	1.41E+00	6.69E+02	7.38E-08	5.37E+02	8.58E+02	7.45E+02	-4.25E+02	8.58E+02
Sec Pass Plate										
	Angle =	59	deg	1.02974426	rad					
	NCOORD	NCAL	NCOL	NLAY	NGEO	NX	NY	NZ		
	3	1	1	1	0	3	1	3		
	XST	XF	YST	YF	ZST	ZF				
	1.077	1.299	0	0	1.401	1.032				
	R	THET	Z	BR	BTHET	BZ	BMOD	Bnorm	Bpoloidal	Bmod
	1.08E+00	0.00E+00	1.40E+00	6.88E+02	6.67E-08	6.68E+02	9.59E+02	9.33E+02	2.19E+02	9.59E+02
	1.08E+00	0.00E+00	1.22E+00	9.18E+02	6.92E-08	8.03E+02	1.22E+03	1.20E+03	2.15E+02	1.22E+03
	1.08E+00	0.00E+00	1.03E+00	1.24E+03	6.33E-08	9.74E+02	1.58E+03	1.56E+03	1.96E+02	1.58E+03
	1.19E+00	0.00E+00	1.40E+00	6.81E+02	7.38E-08	5.53E+02	8.77E+02	8.69E+02	1.23E+02	8.77E+02
	1.19E+00	0.00E+00	1.22E+00	9.03E+02	8.33E-08	6.42E+02	1.11E+03	1.10E+03	8.54E+01	1.11E+03
	1.19E+00	0.00E+00	1.03E+00	1.21E+03	9.02E-08	7.48E+02	1.43E+03	1.43E+03	1.62E+01	1.43E+03
	1.30E+00	0.00E+00	1.40E+00	6.60E+02	7.91E-08	4.44E+02	7.96E+02	7.95E+02	4.05E+01	7.96E+02
	1.30E+00	0.00E+00	1.22E+00	8.66E+02	9.45E-08	4.91E+02	9.95E+02	9.95E+02	-2.55E+01	9.95E+02
	1.30E+00	0.00E+00	1.03E+00	1.16E+03	1.14E-07	5.33E+02	1.27E+03	1.27E+03	-1.38E+02	1.27E+03
Prim pass plate										
	Angle =	74	deg	1.29154365	rad					
	NCOORD	NCAL	NCOL	NLAY	NGEO	NX	NY			
	3	1	1	1	0	3	1			
	XST	XF	YST	YF	ZST	ZF				
	1.307	1.438	0	0	1.004	0.546				
	R	THET	Z	BR	BTHET	BZ	BMOD	Bnorm	Bpoloidal	Bmod
	1.31E+00	0.00E+00	1.00E+00	1.21E+03	1.18E-07	5.24E+02	1.31E+03	1.30E+03	1.71E+02	1.31E+03
	1.31E+00	0.00E+00	7.75E-01	1.62E+03	1.11E-07	5.86E+02	1.72E+03	1.72E+03	1.16E+02	1.72E+03

	1.31E+00	0.00E+00	5.46E-01	9.78E+02	-6.49E-08	6.29E+02	1.16E+03	1.11E+03	3.35E+02	1.16E+03
	1.37E+00	0.00E+00	1.00E+00	1.15E+03	1.31E-07	3.97E+02	1.22E+03	1.22E+03	6.47E+01	1.22E+03
	1.37E+00	0.00E+00	7.75E-01	1.55E+03	1.47E-07	3.78E+02	1.60E+03	1.60E+03	-6.47E+01	1.60E+03
	1.37E+00	0.00E+00	5.46E-01	9.31E+02	6.47E-09	3.49E+02	9.95E+02	9.91E+02	7.84E+01	9.94E+02
	1.44E+00	0.00E+00	1.00E+00	1.08E+03	1.41E-07	2.80E+02	1.12E+03	1.12E+03	-2.95E+01	1.12E+03
	1.44E+00	0.00E+00	7.75E-01	1.46E+03	1.83E-07	1.68E+02	1.47E+03	1.45E+03	-2.42E+02	1.47E+03
	1.44E+00	0.00E+00	5.46E-01	8.75E+02	8.04E-08	5.95E+01	8.77E+02	8.58E+02	-1.84E+02	8.77E+02