<u>NSTX CALCULATION</u>

TITLE Forces on Passive Plates Due To Non-Axisymmetric Current

CALC. NO. NSTX-CALC-11-09 DATE 12/13/00

ORIGINATOR C Neumeyer CHECKER R. Hatcher Rev. 0

PURPOSE:

This calculation estimates the forces on the primary and secondary passive plates due to non-axisymmetric current flow resulting from plasma disruption. In the original NSTX design this was not an issue because of the presence of copper jumpers between plates. However, since these jumpers were not installed, the non-axisymmetric current is anticipated.

REFERENCES:

1) NSTX-CALC-11-04, "NSTX PFC Stress Analysis"
2) "Inductance Calculations", F. W. Grover, p. 60, eq. 58
3) NSTX-CALC-11-02, "Forces on Internal Hardware"
4) NSTX-CALC-11-08, "Plasma Disruption Calculation"

ASSUMPTIONS:

1) Field at plates due to plasma estimated via spreadsheet "nstx plasma fields.xls supplied by ORNL in ref. 1.
2) Field at plates decays at a rate corresponding to 1.0MA/6mS.
3) Current driven in plate simulated by rectangular loop of rectangular copper cross section, dimensions of loop corresponding to periphery of plate, dimensions of conductor assumed square with sides equal to thickness of plate.
4) JxB forces based on background fields projected in ref. 3 crossed with non-axisymmetric currents, in addition to the axisymmetric current given in ref. 4.

CALCULATION:

See attachments.

CONCLUSION:

Forces are significantly smaller than those on which the design was originally based when a large n=0 current flow was anticipated, due to the jumpers originally planned between plates.

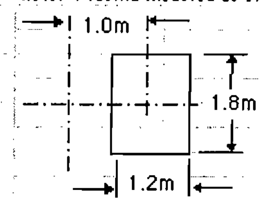
Non-Axisymmetic Currents In Passive Plates

With passive plate jumpers removed, net non-axisymmetric currents flow in plates. Taking a crude plasma model (rectangular cross section) used by ORNL during the project design, the field B due to the plasma, normal to the plates, can be estimated, along with the initial value of the flux $\phi = B*A$ linked by a path around the periphery of the plate.

Fields from 1 MA plasma at components (in gauss)

	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

note: Plasma modeled as shown, Ip = 1 MA



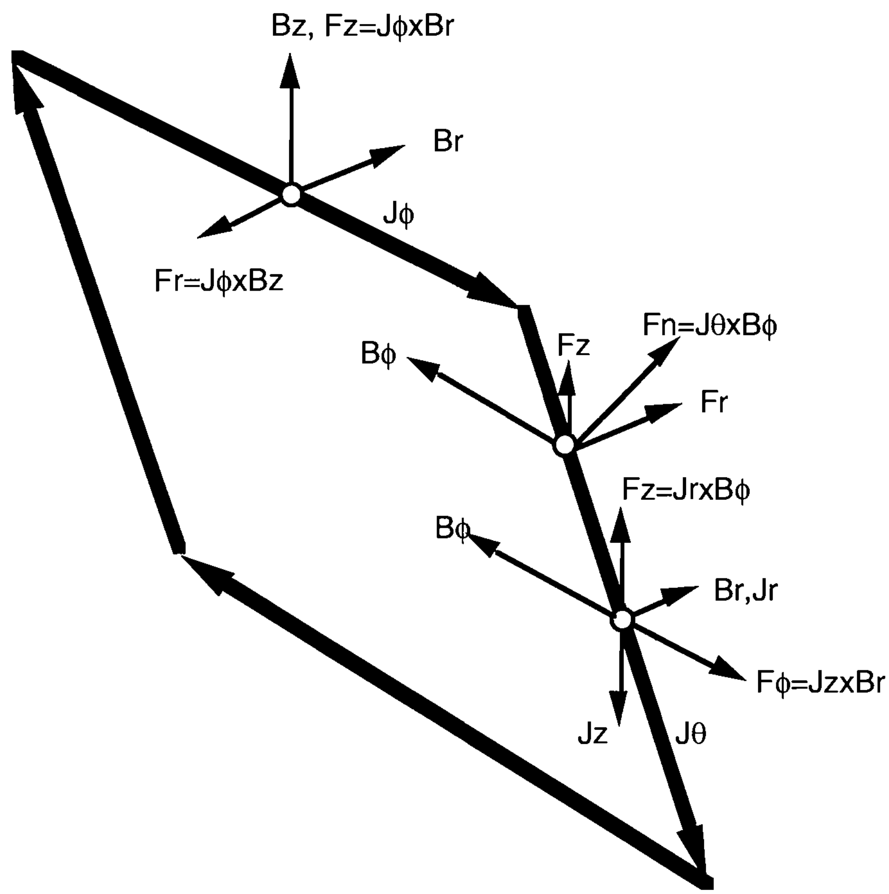
Then the current induced around the periphery of the plate can be estimated by $\Delta I = \Delta\phi / L$, where L is estimated via:

L = 0.004 * {a * ln(2a/ρ) + b * ln(2b/ρ) + 2 * sqrt(a^2+b^2) – a* arcsinh(a/b)-b*arcsinh(b/a)-2*(a+b)+μ/4*(a+b)}

Where:

a, b = sides of rectangular loop of conductor in cm
ρ = cross section of conductor = cm^2, assumed square conductor with width equal to thickness of plate
μ = 1
L = inductance in μH

(from Grover, p. 60, eq. 58)



Non-Axisymmetric Currents and Forces in Passive Plates

Forces of primary interest are those due to the poloidal current which form torsional couples and act in opposite directions on the supports at the ends of the plates.

	1.0 MA		1.5 MA		
	PPP	SPP	PPP	SPP	
R1	53.540	43.823	53.540	43.823	in
Z1	39.594	54.143	39.594	54.143	in
R2	59.416	52.752	59.416	52.752	in
Z2	21.775	41.509	21.775	41.509	in
Lpoloidal	18.763	15.471	18.763	15.471	in
Theta	71.749	54.749	71.749	54.749	degrees
T	0.500	0.500	0.500	0.500	in
a	75.112	64.220	75.112	64.220	cm
b	47.658	39.296	47.658	39.296	cm
csa	1.613	1.613	1.613	1.613	cm^2
L	1.50668E-06	1.19654E-06	1.50668E-06	1.19654E-06	H
Bnormal	0.125	0.11	0.1875	0.165	T
A	0.358	0.252	0.358	0.252	m^2
Phi	0.045	0.028	0.067	0.042	weber
I	29698.4	23199.5	44547.6	34799.3	amp
Ravg	1.435	1.227	1.435	1.227	m
R0	0.854	0.854	0.854	0.854	m
$B\phi(R0)$	0.600	0.600	0.600	0.600	T
$B\phi(ravg)$	0.357	0.418	0.357	0.418	T
Fn $(I\theta)$	1137	857	1706	1285	lbs
Fz $(I\theta)$	356	494	534	742	lbs
Fr $(I\theta)$	1080	700	1620	1049	lbs
Ir	9301	13390	13951	20085	amp
Fz (Ir)	356	494	534	742	lbs
$I\phi$ (n=0)	16100	6400	17700	7300	amp
Br	0.22	0.44	0.22	0.44	T
Bz	0.56	0.56	0.56	0.56	T
Fr $(I\phi(n=0))$	1522	517	1674	590	lbs
Fz $(I\phi(n=0))$	598	407	658	464	lbs
ΣFr	2602	1217	3293	1639	lbs
Fr (design)	14160	5123	14160	5123	lbs
Fr (% of design)	18	24	23	32	%
ΣFz	1310	1395	1726	1947	lbs
Fz (design)	5563	4025	5563	4025	lbs
Fz (% of design)	24	35	31	48	%

Forces are all less than the original design condition

	A	B	C	D	E	F	G	H	I	J	K
1		1.0 MA		1.5 MA			1.0 MA		1.5 MA		
2		PPP	SPP	PPP	SPP		PPP	SPP	PPP	SPP	
3	R1	53.540	43.823	53.540	43.823	in	53.540	43.823	53.540	43.823	in
4	Z1	39.594	54.143	39.594	54.143	in	39.594	54.143	39.594	54.143	in
5	R2	59.416	52.752	59.416	52.752	in	59.416	52.752	59.416	52.752	in
6	Z2	21.775	41.509	21.775	41.509	in	21.775	41.509	21.775	41.509	in
7	Lpoloidal	18.763	15.471	18.763	15.471	in	SQRT((G5-G3)^2+(G6-G4)^2)	SQRT((H5-H3)^2+(H6-H4)^2)	SQRT((I5-I3)^2+(I6-I4)^2)	SQRT((J5-J3)^2+(J6-J4)^2)	in
8	Theta	71.749	54.749	71.749	54.749	degrees	ASIN((G4-G6)/G7)*180/PI()	ASIN((H4-H6)/H7)*180/PI()	ASIN((I4-I6)/I7)*180/PI()	ASIN((J4-J6)/J7)*180/PI()	degrees
9	T	0.500	0.500	0.500	0.500	in	0.500	0.500	0.500	0.500	in
10	a	75.112	64.220	75.112	64.220	cm	2*PI()*(G3+G5)/2/12*2.54	2*PI()*(H3+H5)/2/12*2.54	2*PI()*(I3+I5)/2/12*2.54	2*PI()*(J3+J5)/2/12*2.54	cm
11	b	47.658	39.296	47.658	39.296	cm	G7*2.54	H7*2.54	I7*2.54	J7*2.54	cm
12	ρ	0.717	0.717	0.717	0.717	cm	SQRT(G9^2*2.54^2/PI())	SQRT(H9^2*2.54^2/PI())	SQRT(I9^2*2.54^2/PI())	SQRT(J9^2*2.54^2/PI())	cm^2
13	L	1.90513E-06	1.5325E-06	1.90513E-06	1.5325E-06	H	0.000001*0.004*(G10*LN(2*G10/G12)+G11*LN(2*G11/G12)+2*SQRT(G10^2+G11^2)-G10*ASINH(G10/G11)-G11*ASINH(G11/G10)-2*(G10+G11)+1/4*(G10+G11))	0.000001*0.004*(H10*LN(2*H10/H12)+H11*LN(2*H11/H12)+2*SQRT(H10^2+H11^2)-H10*ASINH(H10/H11)-H11*ASINH(H11/H10)-2*(H10+H11)+1/4*(H10+H11))	0.000001*0.004*(I10*LN(2*I10/I12)+I11*LN(2*I11/I12)+2*SQRT(I10^2+I11^2)-I10*ASINH(I10/I11)-I11*ASINH(I11/I10)-2*(I10+I11)+1/4*(I10+I11))	0.000001*0.004*(J10*LN(2*J10/J12)+J11*LN(2*J11/J12)+2*SQRT(J10^2+J11^2)-J10*ASINH(J10/J11)-J11*ASINH(J11/J10)-2*(J10+J11)+1/4*(J10+J11))	H
14	Bnormal	0.125	0.11	0.1875	0.165	T	1250/10000	1100/10000	1.5*G14	1.5*H14	T
15	A	0.358	0.252	0.358	0.252	m^2	G10*G11/100^2	H10*H11/100^2	I10*I11/100^2	J10*J11/100^2	m^2
16	Phi	0.045	0.028	0.067	0.042	weber	G14*G15	H14*H15	I14*I15	J14*J15	weber
17	I	23487.1	18113.6	35230.6	27170.4	amp	G16/G13	H16/H13	I16/I13	J16/J13	amp
18	Ravg	1.435	1.227	1.435	1.227	m	(G3+G5)/2*2.54/100	(H3+H5)/2*2.54/100	(I3+I5)/2*2.54/100	(J3+J5)/2*2.54/100	m
19	R0	0.854	0.854	0.854	0.854	m	0.854	0.854	0.854	0.854	m
20	Bϕ(R0)	0.600	0.600	0.600	0.600	T	4*PI()*0.0000001*36*71.2*1000/2/PI()/G19	4*PI()*0.0000001*36*71.2*1000/2/PI()/H19	4*PI()*0.0000001*36*71.2*1000/2/PI()/I19	4*PI()*0.0000001*36*71.2*1000/2/PI()/J19	T
21	Bϕ(ravg)	0.357	0.418	0.357	0.418	T	G20*G19/G18	H20*H19/H18	I20*I19/I18	J20*J19/J18	T
22	Fn (Iθ)	899	669	1349	1003	lbs	G17*G7*2.54/100*G21*0.2248	H17*H7*2.54/100*H21*0.2248	I17*I7*2.54/100*I21*0.2248	J17*J7*2.54/100*J21*0.2248	lbs
23	Fz (Iθ)	282	386	422	579	lbs	G22*SIN((90-G8)/180*PI())	H22*SIN((90-H8)/180*PI())	I22*SIN((90-I8)/180*PI())	J22*SIN((90-J8)/180*PI())	lbs
24	Fr (Iθ)	854	546	1281	819	lbs	G22*COS((90-G8)/180*PI())	H22*COS((90-H8)/180*PI())	I22*COS((90-I8)/180*PI())	J22*COS((90-J8)/180*PI())	lbs
25	Ir	7355	10454	11033	15681	amp	G17*SIN((90-G8)*PI()/180)	H17*SIN((90-H8)*PI()/180)	I17*SIN((90-I8)*PI()/180)	J17*SIN((90-J8)*PI()/180)	amp
26	Fz (Ir)	282	386	422	579	lbs	G25*G7*2.54/100*G21*0.2248	H25*H7*2.54/100*H21*0.2248	I25*I7*2.54/100*I21*0.2248	J25*J7*2.54/100*J21*0.2248	lbs
27	Iϕ (n=0)	16100	6400	17700	7300	amp	16100	6400	17700	7300	amp
28	Br	0.22	0.44	0.22	0.44	T	0.22	0.44	0.22	0.44	T
29	Bz	0.56	0.56	0.56	0.56	T	0.56	0.56	0.56	0.56	T
30	Fr (Iϕ(n=0))	1522	517	1674	590	lbs	G27*2*PI()*G18/12*G29*0.2248	H27*2*PI()*H18/12*H29*0.2248	I27*2*PI()*I18/12*I29*0.2248	J27*2*PI()*J18/12*J29*0.2248	lbs
31	Fz (Iϕ(n=0))	598	407	658	464	lbs	G27*2*PI()*G18/12*G28*0.2248	H27*2*PI()*H18/12*H28*0.2248	I27*2*PI()*I18/12*I28*0.2248	J27*2*PI()*J18/12*J28*0.2248	lbs
32	ΣFr	2376	1064	2955	1409	lbs	G24+G30	H24+H30	I24+I30	J24+J30	lbs
33	Fr (design)	14160	5123	14160	5123	lbs	14160	5123	14160	5123	lbs
34	Fr (% of design)	17	21	21	28	%	G32/G33*100	H32/H33*100	I32/I33*100	J32/J33*100	%
35	ΣFz	1161	1179	1502	1622	lbs	G23+G26+G31	H23+H26+H31	I23+I26+I31	J23+J26+J31	lbs
36	Fz (design)	5563	4025	5563	4025	lbs	5563	4025	5563	4025	lbs
37	Fz (% of design)	21	29	27	40	%	G35/G36*100	H35/H36*100	I35/I36*100	J35/J36*100	%