11-980223-CLN-01

TO: DISTRIBUTION
FROM: C NEUMEYER
SUBJECT: FORCES ON INTERNAL HARDWARE

Referenes:

[1] 11-971215-CLN-01, "Forces on Passive Plates"
[2] 13-970217-AWB-02, "Loads on CS Due to Plasma Disruption"
[3] 11-971117-CLN-01, "PFC Geometry"
[4] 11-980204-CLN-01, "PF Geometry Evolution"
[5] "Disruption Forces Due to Halo Currents", S Kaye 2/2/98

Force on the passive plates due to toroidal currents resulting from plasma disruptions were estimated in [1], based on the disruption simulation by A. Brooks [2], along with passive plate geometry given in [3]. This memo provides an update of the forces on all of the major internal hardware components (inner wall, outboard divertor, and passive plates) based on the latest geometry [4] and including forces due to poloidal halo currents [5].

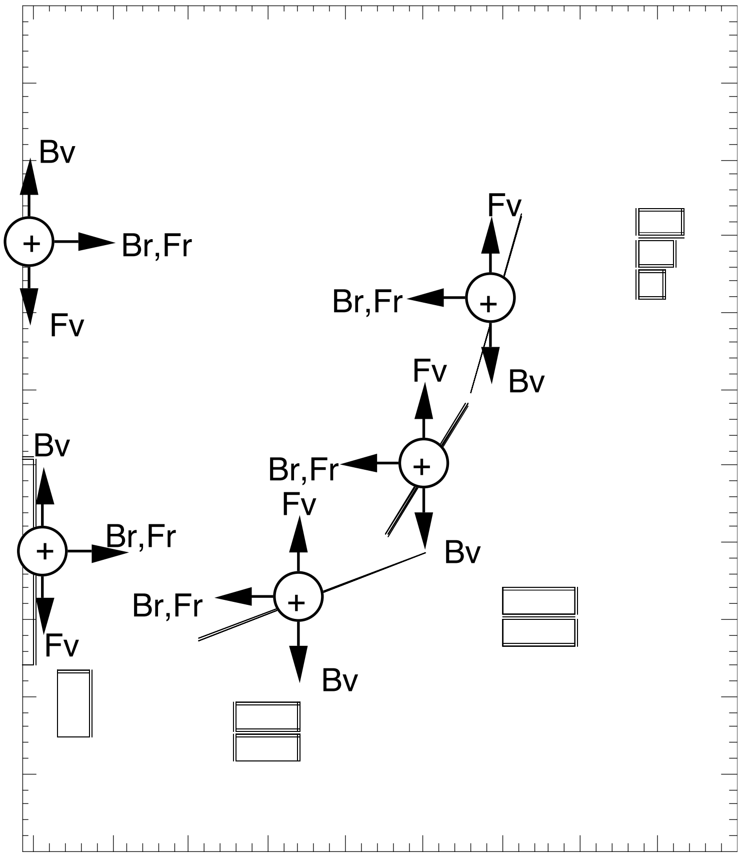
Forces Due To Poloidal Halo Currents

For the poloidal halo current calculations, 10% of I_p is assumed based on [5], with a toroidal peaking factor of 2.0. To calculate the force, the toroidal field at the average radius of the element in question is multiplied by the current and by the poloidal length of the segment. A poloidal force, normal to the element, results. According to [5] the polarity of the halo forces will always be outward from the plasma. The division of current between the tiles and the backplates of the various elements will likely be such that the great majority of current will flow in the backplates rather than the tiles due the resistivity effects, except where the halo current enters or exits. To be conservative, however, the full current flow should be assumed possible both in the tiles and the backplates.

Forces Due to Disruption (Toroidal Halo) Currents

For the disruption (toroidal halo) calculations, the currents calculated in [2] are assumed, with a factor of 1.5 to account for the possibility of a moving non-centered plasma instead of a stationary centered one. Since there were no explicit inboard or outboard divertor structures included in [2], for this exercise these currents are assumed to be equal to that in the secondary passive plate. This is very conservative because the divertor backplates will be constructed of stainless steel rather than copper as are the passive plate backplates. To calculate the force, the radial and poloidal fields at the approximate position of the element in question are multiplied by the current and by the toroidal length of the segment. Poloidal forces, vertical and radial, result.

Worst case background poloidal fields to create *inward radial and vertical forces, which are the design drivers for the internal hardware , supports, and the vacuum vessel,* were calculated as follows.



Assumptions:

1) Worst case forces occur in lower half plane due to presence of PF1b.

2) Initial Ip [+] (into page).

3) OH either [0] (corresponding to Ip ramped up from [0] to [+]) or [-] corresponding to sustainment of Ip [+].

4) PF1aU and PF1aL either both the same sign, [+] or [-], or one [0] and other of either sign. This corresponds to circuit with unipolar, same polarity power supplies but facility for difference current between upper and lower coils (three wire feed).

5) PF1b either [0] or [+], corresponding CHI X-point formation with Ip [+].

6) PF2U and PF2L either both the same sign, [+] or [-], or one [0] and other of either sign. This corresponds to circuit with unipolar, same polarity power supplies but facility for difference current between upper and lower coils (three wire feed).

7) PF3U and PF3L either both the same sign, [-], or one [0] and other [-]. This corresponds to circuit with unipolar, same polarity power supplies but facility for difference current between upper and lower coils (three wire feed), and with production of vertical field for radial position control with Ip [+]. Although PF3 is actually bipolar, this mode will be used only for initial compensation prior to breakdown.

8) PF4U & PF4L in series, either [0] or [-], corresponding to radial position control with Ip [+].

9) Passive plate currents either all [0] or all [+] corresponding to disruption from Ip [+].

10) Inner wall and outboard divertor currents neglected (high resistivity components).

Based on the above assumptions 9 cases were identified to give the worst case radial and vertical fields at each location as summarized in the following table.

Current Directions to Maximize Inward Forces on Internal Hardware Components in the Lower Half Plane

		IW +		IBD +		OBD +		SPP +		PPP +	
		Fv -	Fr +	Fv -	Fr +	Fv +	Fr -	Fv +	Fr -	Fv +	Fr -
		Br +	Bv +	Br +	Bv +	Br -	Bv -	Br -	Bv -	Br-	Bv-
OH	-/0	-	-	-	-	0	0	0	0	0	0
PF1au	+/-	0	+	-	-	+	+	0	+	0	+
PF1al		+	+	-	-	+	+	-	+	-	+
PF1b	+/0	+	+	+	+	0	+	0	+	0	+
PF2u	+/-	0	+	0	+	0	+	0	+	0	+
PF2l		+	+	+	+	-	+	-	+	-	+
PF3u	-/0	-	0	-	0	0	-	0	-	0	-
PF3l		0	0	-	0	-	-	-	-	-	-
PF4 u&l	-/0	-	0	-	0	0	-	0	-	0	-
SPP1u&l	+/0	0	+	0	+	+	0	+	+	0	+
SPP2 u&l											
PPP1 u&l											
PPP2 u&l											
Case		1	2	3	4	5	6	7	8	9	8
|B| max		0.27	0.37	0.68	0.52	0.31	0.60	0.44	0.56	0.22	0.56

Contour plots for each of the 9 cases are attached.

<u>Summary of Forces</u>

Summary of forces is given in the following table. Note that the poloidal and toroidal segment lengths were taken to be the lengths of the backplate structures in all cases except for the inner wall, in which case the segment lengths are taken as those of the individual tiles. So, the forces listed for the inner wall are per tile, whereas those listed for the other structures are per segment.

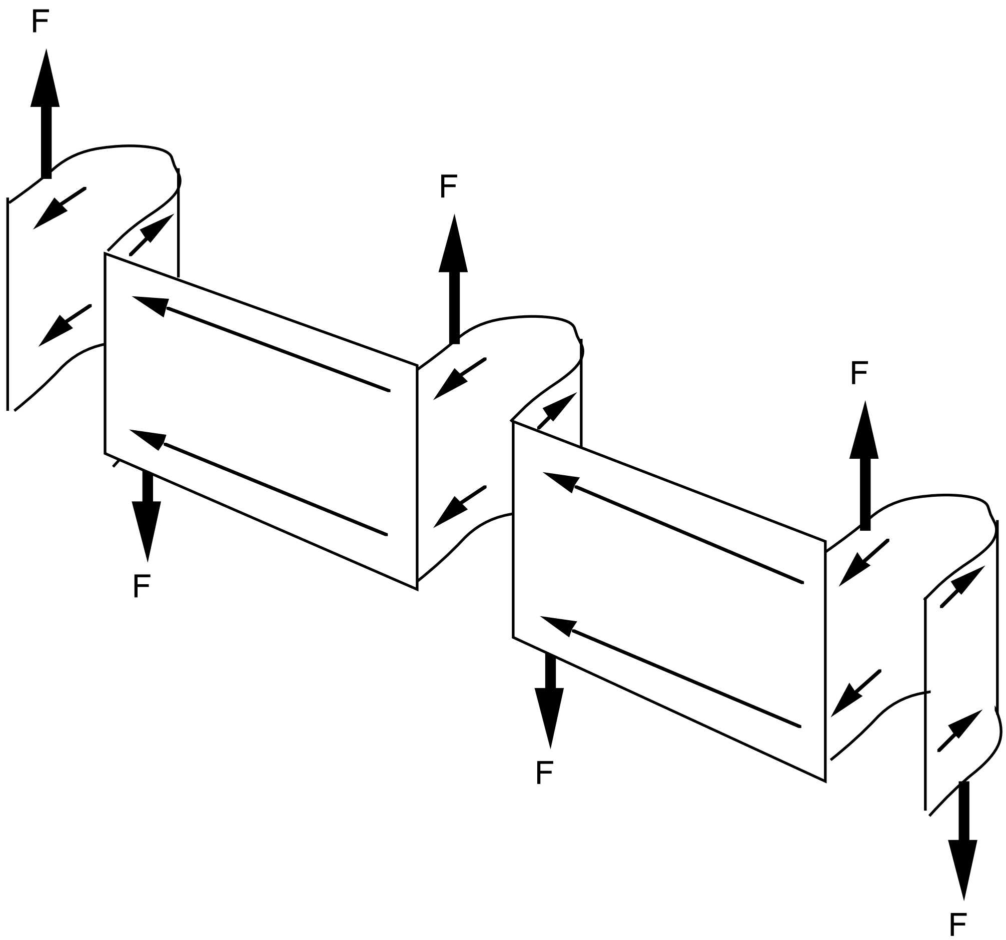
	Inner Wall	IBD	OBD	Sec Plate	Pri Plate	

Poloidal Halo...						
Ip	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	Amp
k	0.10	0.10	0.10	0.10	0.10	
peaking	2.00	2.00	2.00	2.00	2.00	
#segment	24.00	24.00	48.00	12.00	12.00	
Ipoloidal	8333.33	8333.33	4166.67	16666.67	16666.67	Amp
R1	0.190	0.279	0.624	1.100	1.260	m
Z1	0.152	1.116	1.652	1.370	1.090	m
R2	0.190	0.279	1.204	1.250	1.450	m
Z2	0.000	1.577	1.424	1.120	0.540	m
Theta	-90.000	-90.000	-21.447	-59.036	-70.942	degrees
Ravg	0.190	0.279	0.914	1.175	1.355	m
R0	0.854	0.854	0.854	0.854	0.854	m
Bt(R0)	0.600	0.600	0.600	0.600	0.600	T
Bt(Ravg)	2.694	1.834	0.561	0.436	0.378	T
L poloidal	0.152	0.461	0.624	0.292	0.582	m
Fnormal/segment	3421.39	7045.35	1456.92	2118.99	3667.43	N
	769.13	1583.79	327.52	476.35	824.44	lbs
Fradial/segment	769.13	1583.79	119.75	408.47	779.25	lbs
Fvertical/segment	0.00	0.00	304.84	245.08	269.20	lbs
Disruption (Toroidal Halo)...						
Itoroidal	35000.00	44100.00	44100.00	44100.00	105700.00	Amp
Br	0.27	0.68	0.31	0.44	0.22	T
Bv	0.37	0.52	0.60	0.56	0.56	T
L toroidal	0.05	0.07	0.12	0.62	0.71	m
k	1.50	1.50	1.50	1.50	1.50	
Fradial/segment	967.25	2516.10	4747.56	22790.53	62992.99	N
	217.44	565.62	1067.25	5123.31	14160.82	lbs
Fvertical/segment	705.83	3290.29	2452.91	17906.84	24747.24	N
	158.67	739.66	551.41	4025.46	5563.18	lbs

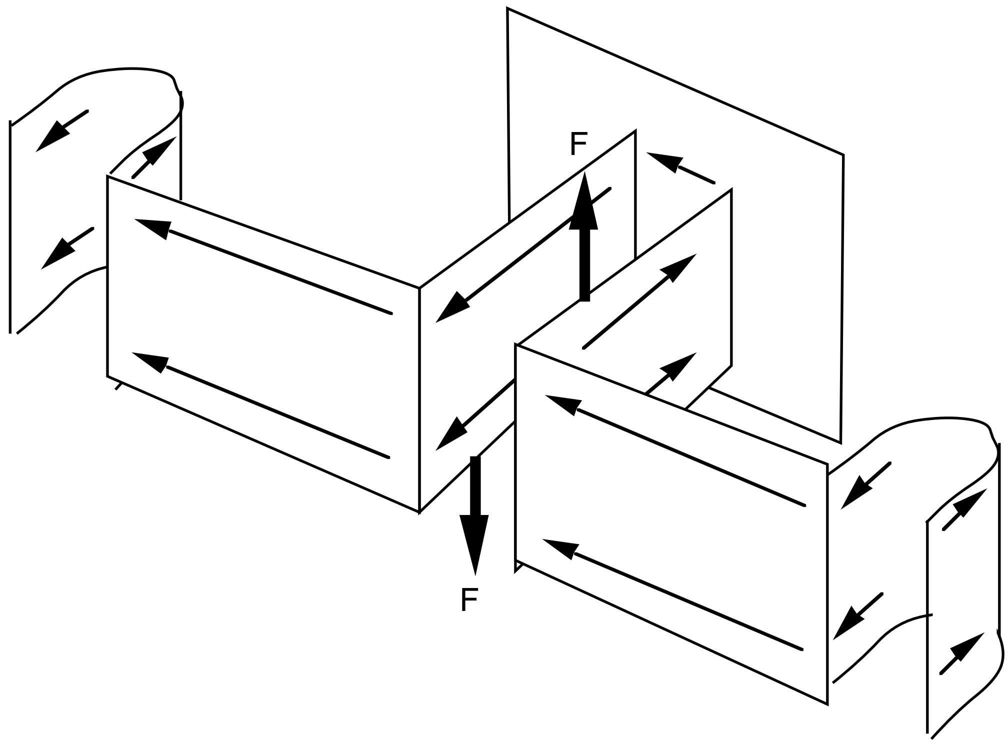
The above forces due to poloidal and toroidal halo are <u>not</u> additive. This is due to the facts that 1) the former occurs mainly while the plasma is in a drift phase prior to the latter which is due to current quench, and 2) the direction of the former is inward whereas the latter is outward.

<u>Other Forces</u>

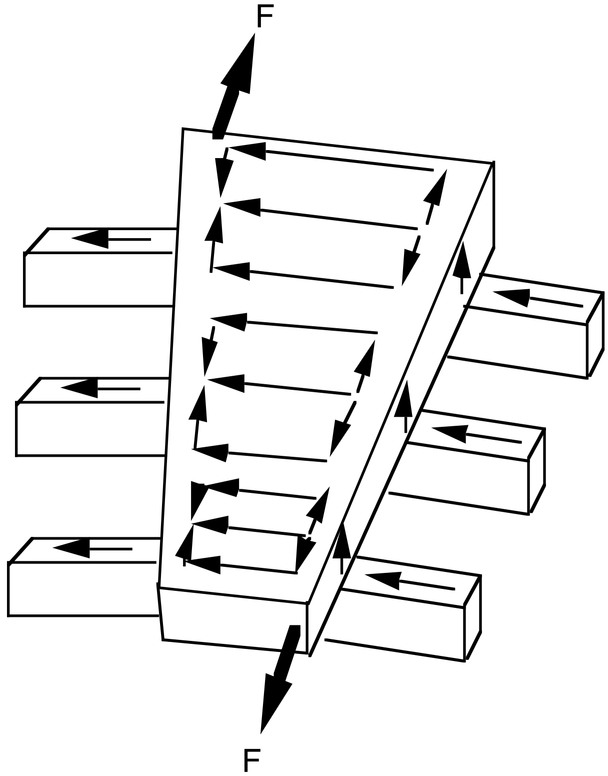
For the segmented structures, the induced toroidal currents (e.g. in case of stationary disruption) do not have available simple current flow paths at constant r,z locations from toroidal angle ø = 0 to 360 degrees. Instead, e.g. in the case of the passive plates, the current flow must jump from plate to plate throught the flexible connectors between plates. There is a force on each flexible connector due to the cross product of the poloidal current with the toroidal field.



At the toroidal gap location, this current must flow all the way through the plate supports to the vessel wall and back. There is a force on each support due to the cross product o the poloidal current with the toroidal field.



In the case of the outboard divertors, this current must flow from the backplates into the support rings and back. As the current enters and exits the backplate there is a force due to the cross product of the poloidal component of current with the toroidal field.



Assuming that the poloidal component of current associated with the passive plates is purely radial, and that with the outboard divertor purely vertical, the resultant forces are indicated in the following table.

Moments...						
	OBD	Sec Plate Flex	Pri Plate Flex	Sec Plate Toroidal Gap	Pri Plate Toroidal Gap	
Itoroidal	44100.0	44100.0	105700.0	44100.0	105700.0	Amp
Ir	0.0	44100.0	105700.0	44100.0	105700.0	Amp
Iv	44100.0	0.0	0.0	0.0	0.0	Amp
R	1.204	1.250	1.450	1.43256	1.69672	m
R0	0.854	0.854	0.854	0.854	0.854	m
Bt(R0)	0.600	0.600	0.600	0.600	0.600	T
Bt(R)	0.426	0.410	0.353	0.358	0.302	T
L poloidal	0.0254	0.1524	0.1524	0.44831	0.303784	m
Fradial/segment	476.71	0.00	0.00	0.00	0.00	N
	107.16	0.00	0.00	0.00	0.00	lbs
Fvertical/segment	0.0	2755.0	5692.5	7071.5	9697.0	N
	0.0	619.3	1279.7	1589.7	2179.9	lbs

In the above the assumed radial extent ($L_{poloidal}$) of the passive plate flex connectors is 6". That of the passive plate supports at the toroidal gap is, for each plate, the average distance from the plate to the vacuum vessel wall.

<u>Future Work</u>

The stationary disruption currents need to be recalculated given the latest NSTX configuration, and the force estimates need to be updated accordingly. Also, in case any of forces calculated on the basis given herein prove to be cause for concern, they can be recalculated with less conservatism.

cc:

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* = w/o attachment

NSTX File (w/attachment)