

TO: DISTRIBUTION

FROM: C NEUMEYER

SUBJECT: LOADS ON FLAG BOX/HUB FRICTION INTERFACE

Reference:

[1] "Update of NSTX Influence Matricies and EM Loads", 13_041123_CLN_01

[2] NSTX-CALC-13-020, "PF Coil Axial and Radial Force Calculation", R2

[3] NSTX-CALC-13-025, "TF Flag Box/Hub Connection", R1

This memo presents results from analyses performed to estimate loads on the friction interface between the hub disks and flag boxes. In addition to the FEA another analysis method is presented based on a simplification which reduces the analysis to a statics problem. It is assumed that the flag/box assembly is a simple rigid body, and that the friction response of the interface can be modeled as point responses at the radii of the box bolts. The latter assumption is based on the idea that the pressure at the hub/box interface is concentrated in concentric regions around the box bolts. Figure 1 shows a FEMLAB simulation of the pressure distribution under a ½" stainless steel plate resulting from the application of 5500lbf over the annular region of a 1" OD washer on the other side of the plate. While this is a simplification of the actual condition, it supports the idea that the box bolt reaction can be modeled by a point response at the bolt radius.

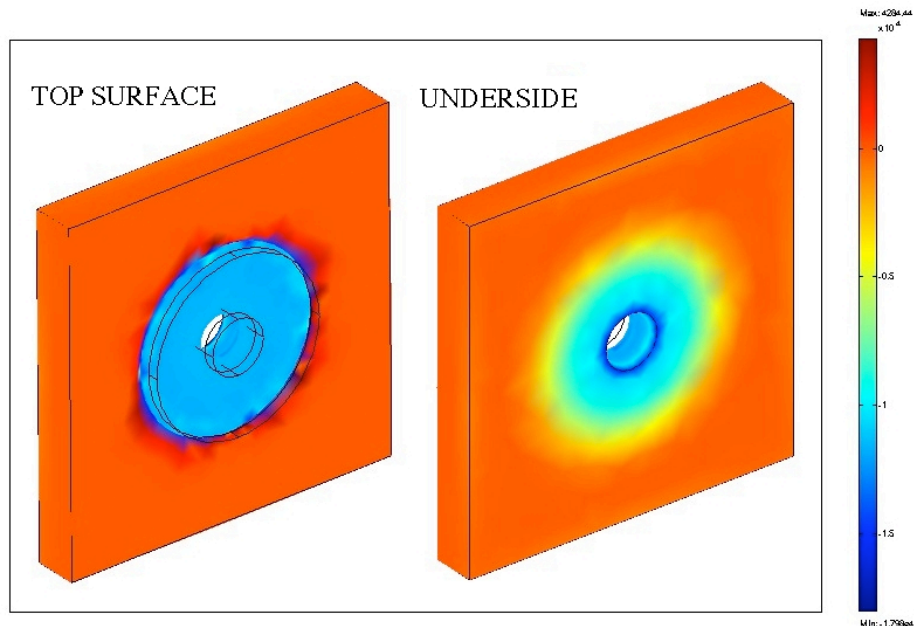


Figure 1 – FEMLAB Model of Box Bolts at 5500lbf applied on 1" OD Washer

The static model is shown in figure 2. Moment on bundle is replaced by F_{bundle} acting at bundle radius. F_1 , F_2 , F_3 represent the box bolt reactions, and F_{lateral} is the equivalent point force due to the out-of-plane EM load. Reactions out through the flex links are ignored, since that load path is relatively soft.

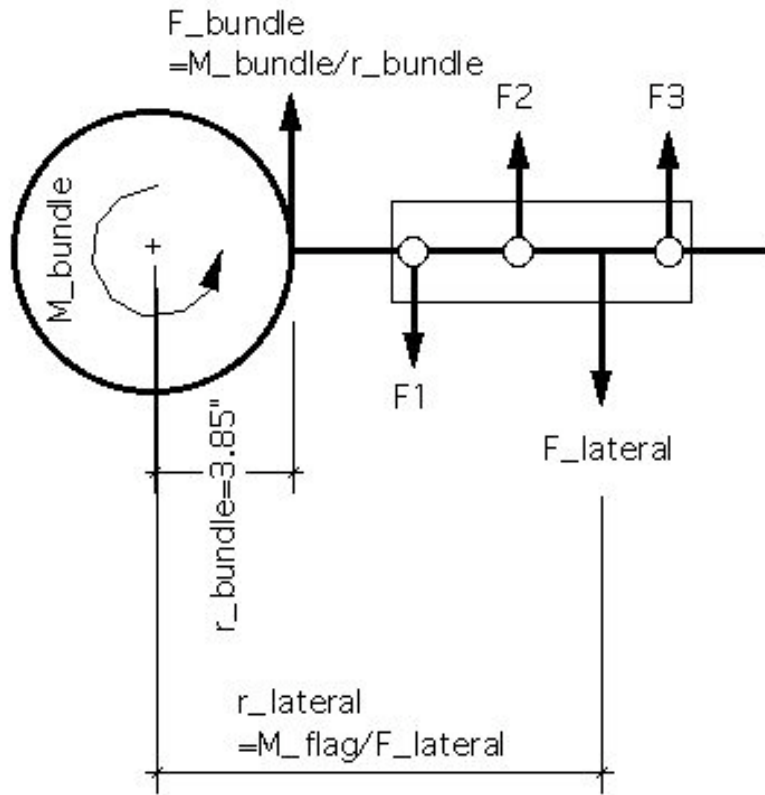


Figure 2 – Simplified Model of Load and Reactions on Flag Boxes

With the applied EM loads at bundle and on flag given, along with their radius, and the radii of the three box bolts know, one can solve for F_1 , F_2 , and F_3 based on $\sum F=0$ and $\sum M=0$, assuming that F_2 is linearly related to F_1 and F_3 based on the spacing of the bolts.

$$F_3 = \frac{\left[\frac{(F_b * r_b + F_l * r_l)(r_3 - r_1)}{(r_1(r_3 - r_1) + r_2(r_3 - r_2))} - \frac{(F_b + F_l)(r_3 - r_1)}{(2r_3 - r_1 - r_2)} \right]}{\left[\frac{(r_3 - 2 * r_1 + r_2)}{(2r_3 - r_1 - r_2)} - \frac{(r_3 * (r_3 - r_1) + r_2 * (r_2 - r_1))}{(r_1(r_3 - r_1) + r_2(r_3 - r_2))} \right]}$$

$$F_1 = \frac{[F_3(r_3 - 2r_1 + r_2) - (F_b + F_l)(r_3 - r_1)]}{(2r_3 - r_1 - r_2)}$$

$$F_2 = F_1 - \frac{(F_1 - F_3)(r_2 - r_1)}{(r_3 - r_1)}$$

Table 1 gives values of the forces calculated using the procedure given herein, and FEA results provided by I. Zatz, along with the friction safety factors (out-of-plane loads only), for various operating states: SOFT is the start of flat top, EOFT is the end of flat top, MAXMAX is the case where all currents are simultaneously at their maximum values in the same current direction, and OTHER is a solved for combination of currents found to give the minimum friction safety factor while respecting the constraint that the current ranges and polarities must be consistent with realistic plasma operation. EM loads are calculated using the influence matrices given in [1]. Bundle torque is assumed taken 80% by the outer layer flags and 20% by the inner. Loads are assumed to be equally shared between the friction interfaces at each surface of the box.

TABLE 1 – Loads and Friction Safety Factors

	SOFT	FEA SOFT	EOFT	FEA EOFT	MAXMAX	OTHER	
M_bundle	26317		-26330		-30025	-27873	ft-lbf
	315809		-315955		-360299	-334481	in-lbf
R_bundle	3.85		3.85		3.85	3.85	in
F_bundle	82071		-82109		-93633	-86923	lbf
#Inner Turns	12		12		12	12	
#Outer Turns	24		24		24	24	
f_Inner	0.20		0.20		0.20	0.20	
f_Outer	0.80		0.80		0.80	0.80	
F_Bundle_Outer_Flag	2736		-2737		-3121	-2897	lbf
M_Lateral_Outer_Flag	-2621		13775		65160	35549	in-lbf
F_Lateral_Outer_Flag	-367		1141		5077	2765	lbf
F_net_Outer_Flag	2368		-1596		1956	-132	lbf
R_Lateral	7.14		12.07		12.83	12.86	in
R_bolt1	6.51		6.51		6.51	6.51	in
R_bolt2	9.14		9.14		9.14	9.14	in
R_bolt3	12.89		12.89		12.89	12.89	in
F1	-2927	-1424	3225	1318	4395	3793	
F2	-1057	-154	869	218	-21	513	
F3	1615	552	-2497	-428	-6330	-4174	
COF	0.60	0.60	0.60	0.60	0.60	0.60	
Bolt Force	5500	5500	5500	5500	5500	5500	lbf
Number of Surfaces	2	2	2	2	2	2	
Resisting Force/bolt	6600	6600	6600	6600	6600	6600	lbf
SF1	2.3	4.6	2.0	5.0	1.5	1.7	
SF2	6.2	42.9	7.6	30.3	311.3	12.9	
SF3	4.1	12.0	2.6	15.4	1.0	1.6	
SF_MIN	2.3	4.6	2.0	5.0	1.0	1.6	

Load currents corresponding to the OTHER (practical worst case) condition are given in Table 2.

TABLE 2 – Current Combination for Worst Case Box/Hub Friction Loading

Ioh	24.0
Ipf1a	5.0
Ipf1b	0.0
Ipf2	0.0
Ipf3	20.0
Ipf4	0.0
Ipf5	20.0
Itf	71.2

Comparison between the FEA for the SOFT and EOFT cases is given in Table 3.

TABLE 3 – Comparison Between Bolt Load Calculations

	SOFT	EOFT
F_1	-1463	1612
F_1_FEA	-712	659
Ratio_1	49%	41%
F_2	-528	434
F_2_FEA	-77	109
Ratio_2	15%	25%
F_3	807	-1248
F3_3_FEA	276	-214
Ratio_3	34%	17%

The above suggests that the actual load may be as much as 49% of that calculated using the simplified analysis. Taking credit for the FEA result, and applying the realistic maximum condition, the friction safety factors including the vector sum of in-plane and out-of-plane loads are given in Table 4 (following the calculation technique used in [2]).

TABLE 4 – Box Bolt Safety Factor Calculations

COF for Coated Plates	0.600	0.600	0.600	
At 6 kG	6	6	6	kG
In Plane EM Moment	70653	70653	70653	in-lbf
% In Plane Load to Hub/Box Shear	42%	42%	42%	
Moment Arm to Interface	3.25	3.25	3.25	in
In Plane Shear Load per Interface	4569	4569	4569	lbf
In Plane Shear Load per Bolt	1523	1523	1523	
Max Out of Plane EM Load per Bolt	2087	2087	2087	
% Out Of Plane Shear Load per Bolt	49%	49%	49%	
Out of Plane Shear Load per Bolt	1023	1023	1023	
Field Strength kG	6.00	5.00	4.00	kG
In Plane Load	1523	1058	677	lbf
Out Of Plane Load	1023	852	682	lbf
Resultant Load	1834	1358	961	lbf
Min Bolt Tension	3900	3900	3900	lbf
Avg. Bolt Tension	5500	5500	5500	lbf
Max. Bolt Tension	6500	6500	6500	lbf
Min Resistance to Load	2340	2340	2340	lbf
Avg Resistance to Load	3300	3300	3300	lbf
Max Resistance to Load	3900	3900	3900	lbf
Min. FS Friction Resultant	1.3	1.7	2.4	
Avg. FS Friction Resultant	1.8	2.4	3.4	
Max. FS Friction Resultant	2.1	2.9	4.1	

Summary

The analysis predicts a safety factor of at least 1.3 at 6kG. However, the considering the complexity of the structural system, and the simplifications inherent not only in the statics analysis but also in the FEA, we need to proceed cautiously. A technique to inspect for relative displacement between box and hub needs to be developed.

L Dudek M Kalish M Ono J Schmidt A Von Halle M Williams
R Woolley IZatz