NSTX

13_041208_CLN_01.doc

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

This memo presents results from an analysis performed to estimate loads on the friction interface between the hub disks and flag boxes. The method is 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.

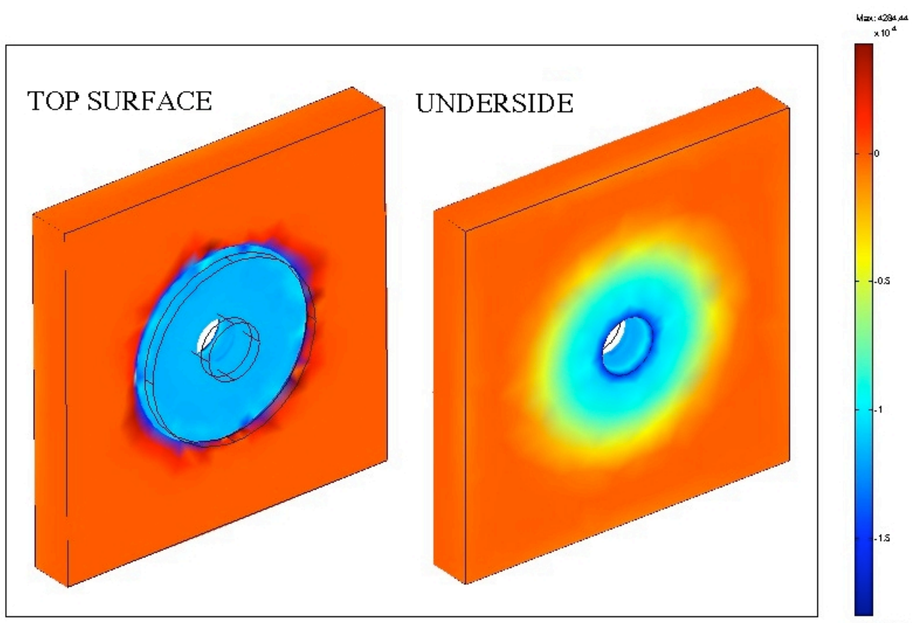

Figure 1 – FEMLAB Model of Box Bolts at 5500lbf applied on 1” OD Washer

Statics model is shown in figure 2. Moment on bundle is replaced by F_bundle acting at bundle radius. F1, F2, F3 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.

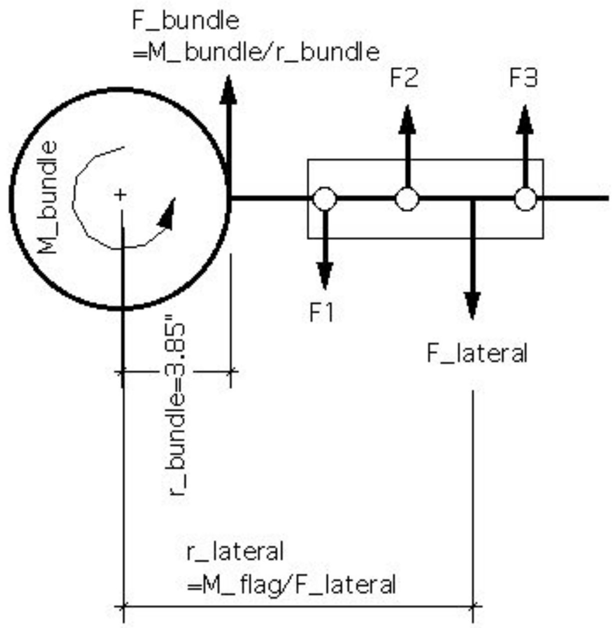

Figure 2 – Simplified Model of Load and Reactions on Flag Boxes

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 F1, F2, and F3 based on ∑F=0 and ∑M=0, assuming that F2 is linearly related to F1 and F3 based on the spacing of the bolts.

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

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

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

The above result applies to a single flag/box considered in 2d fashion. In reality each flag box has two surfaces. See figure 3.

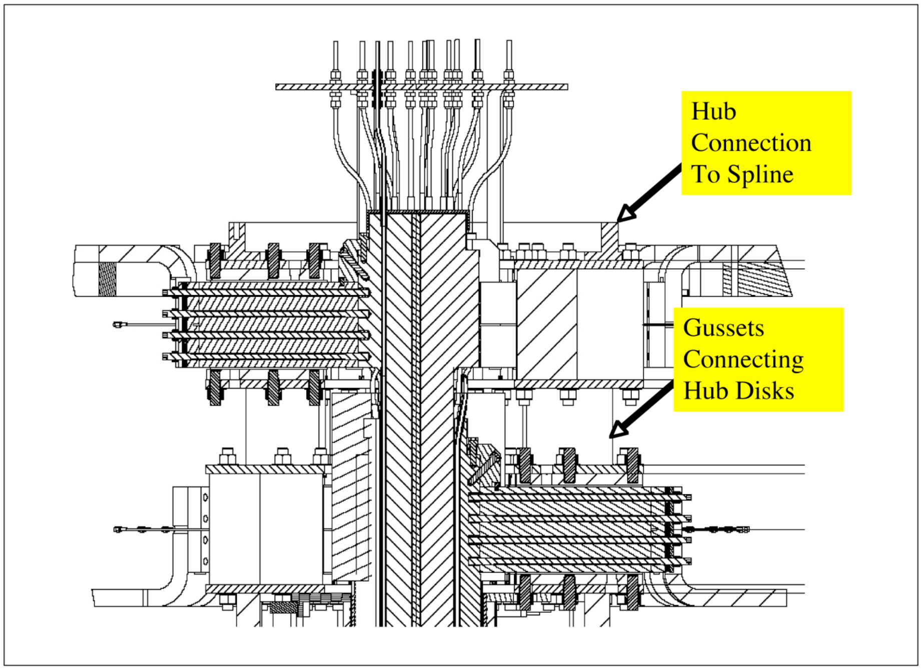

Figure 3 – Arrangment of Flags, Boxes, and Disks in Upper Half Plane

The outer layer flag boxes have two friction shear surfaces. Let us refer to the inner surface as the one closest to the midplane, and the outer surface as the one furthest from the midplane.

The inner surface interfaces with a hub disk element which has no connection to anything other than the boxes. In the original TF design it had a connection to the torque collar, but not in the latest design. Therefore, all it can do is react moments; it can't react any net out of plane force. The outer surface interfaces with a hub disk which has a connection, via a gusset to the inner layer flag boxes, and from there out to the spline to the VV. This surface, therefore, provides the reaction against the out of plane loads.

In the statics analysis the three forces F1, F2, and F3 represent the reaction of the box bolts which is necessary for static equilibrium, considering the load coming on to the flag from the bundle, along with the EM load on the flag itself. Adding F1+F2+F3 together has a net resultant value F which is the out of plane load which has to get out via the hub. Considering this in the allocation of the loads to the box bolts on the two surfaces, the forces on the inner surface bolts are assumed to be F1/2-F/3, F2/2-F/3, and F3/3-F/3, and on the outer surface, F1/2+F/3, F2/2+F/3, and F3/2+F/3. In this way the total force and moment (adding all six bolt loads together) is the same as calculated in the original 2d procedure, but the extra toroidal shear load is allocated to the three bolts on the outer surface, since this is where the load gets out.

On the inner layer flags, a similar situation exists with respect to the self-generated loads, but the total load includes that load flowing out of the outer layer flags. It is assumed here that this load flows equally through the three bolts on each surface, with due consideration of polarity.

With the above method used to estimate the out-of-plane friction shear loading, the in-plane component previously estimated can be factored in to calculate the total resultant shear load.

The following tables shows the result of this calculation with Bt=6kG for the following PF current combinations (see figure 4):

SOFT:	Start of flat top
OHZC:	OH zero crossing
EOFT:	End of flat top
MAXMAX:	Condition where all OH/PF coils are simultaneously at maximum value in the same polarity
OTHER:	Solved for current combination in which all OH/PF coils are within their allowed current range but with polarity consistent with plasma operations, which minimizes the friction safety factor

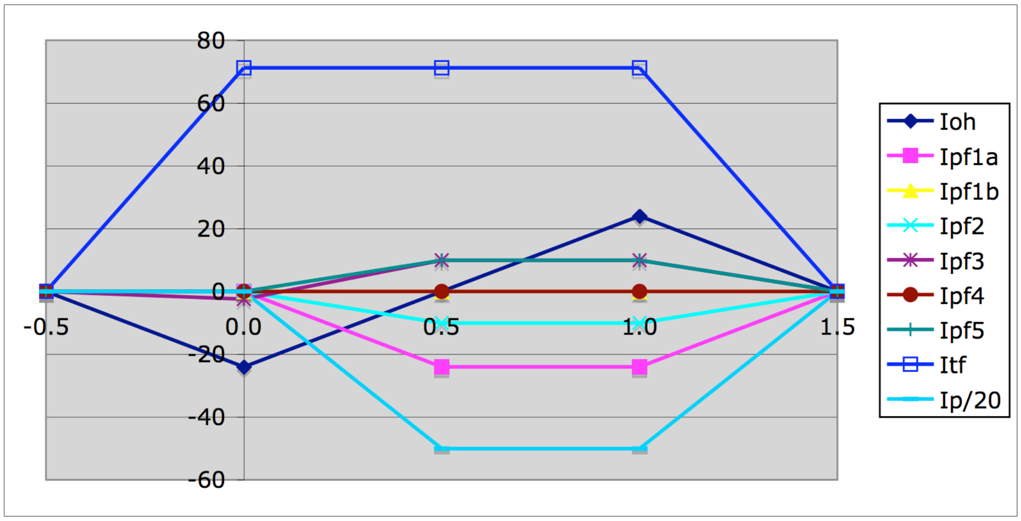

Figure 4 – Typical Pattern of Currents

Note that it is assumed that 80% of the moment generated on the TF bundle is reacted through the outer flag joints and 20% through the inner flag joints. Also, while the in-plane box bolt shear loads are reduced based on the NASTRAN FEA findings, the out-of-plane loads are taken as 100% of the values estimated using the technique outlined above. The box bolt torque variation is not considered. COF =0.6 is assumed based on the small sample tests of the high friction coating.

Table 1 – Outer Flag Box Calculations

	SOFT	OHZC	EOFT	MAXMAX	OTHER	
M_bundle	26851	753	-26063	-30025	-25518	ft-lbf
	322217	9036	-312751	-360299	-306217	in-lbf
R_bundle	3.85	3.85	3.85	3.85	3.85	in
F_bundle	83736	2348	-81276	-93633	-79578	lbf
#Inner Turns	12	12	12	12	12	
#Outer Turns	24	24	24	24	24	
f_Inner	0.20	0.20	0.20	0.20	0.20	
f_Outer	0.80	0.80	0.80	0.80	0.80	
Bt	6	kG				
In-Plane Moment at 6kG	70653	in-lbf				
In-Plane EM Moment @ Bt	70653	in-lbf				
% In Plane Load to Hub/Box Shear	42%					
Moment Arm to Interface	3.25	in				
In Plane Shear Load per Interface	4569	lbf				
In Plane Shear Load per Bolt	1523	lbf				
F_Bundle_Flag	2791	78	-2709	-3121	-2653	lbf
M_Lateral_Flag	-6309	3119	7758	40421	-24019	in-lbf
F_Lateral_Flag	-503	211	591	3077	-1790	lbf
F_net_Flag	2288	290	-2118	-44	-4443	lbf
R_Lateral	12.55	14.75	13.13	13.14	13.42	in
R_bolt1	6.51	6.51	6.51	6.51	6.51	in
R_bolt2	9.14	9.14	9.14	9.14	9.14	in
R_bolt3	12.89	12.89	12.89	12.89	12.89	in
F1	-3297	0	3261	4227	2656	
F2	-1080	-84	1026	541	1628	
F3	2088	-206	-2168	-4724	159	
∑F_bolt	-2288	-290	2118	44	4443	
F1_Inner_Surface	-886	97	925	2099	-153	
F2_Inner Surface	223	54	-193	256	-667	
F3_Inner_Surface	1807	-6	-1790	-2377	-1401	
F1_Outer_Surface	-2411	-96	2337	2128	2809	
F2_Outer Surface	-1303	-139	1219	285	2295	
F3_Outer_Surface	281	-199	-378	-2348	1560	
Max bolt	2411	199	2337	2377	2809	
f_FEA	100%	100%	100%	100%	100%	
OOP Shear Load	2411	199	2337	2377	2809	lbf
IP Shear Load	1523	1523	1523	1523	1523	
Resultant Shear Load	2852	1536	2789	2823	3195	lbf
COF	0.60	0.60	0.60	0.60	0.60	
Bolt Force	5500	5500	5500	5500	5500	lbf
Resisting Force/bolt	3300	3300	3300	3300	3300	lbf
SF_MIN	1.2	2.1	1.2	1.2	1.0	

Table 2 – Inner Flag Box Calculations

	SOFT	OHZC	EOFT	MAXMAX	OTHER	
M_bundle	26851	753	-26063	-30025	-25518	ft-lbf
	322217	9036	-312751	-360299	-306217	in-lbf
R_bundle	3.85	3.85	3.85	3.85	3.85	in
F_bundle	83736	2348	-81276	-93633	-79578	lbf
#Inner Turns	12	12	12	12	12	
#Outer Turns	24	24	24	24	24	
f_Inner	0.20	0.20	0.20	0.20	0.20	
f_Outer	0.80	0.80	0.80	0.80	0.80	
Bt	6	kG				
In-Plane Moment at 6kG	17663	in-lbf				
In-Plane EM Moment @ Bt	17663	in-lbf				
% In Plane Load to Hub/Box Shear	42%					
Moment Arm to Interface	3.25	in				
In Plane Shear Load per Interface	1142	lbf				
In Plane Shear Load per Bolt	381	lbf				
F_Bundle_Flag	1396	39	-1355	-1561	-1326	lbf
M_Lateral_Flag	-10935	980	9618	65160	-38267	in-lbf
F_Lateral_Flag	-973	33	838	5077	-2754	lbf
F_net_Flag	423	72	-516	3517	-4080	lbf
F_Lateral_Outers	4577	579	-4237	-88	-8885	
R_Lateral	11.24	29.99	11.47	12.83	13.90	in
R_bolt1	6.51	6.51	6.51	6.51	6.51	in
R_bolt2	9.14	9.14	9.14	9.14	9.14	in
R_bolt3	12.89	12.89	12.89	12.89	12.89	in
F1	-1542	41	1534	2583	695	
F2	-316	-16	342	-703	1277	
F3	1435	-97	-1360	-5396	2108	
∑F_bolt	-423	-72	516	-3517	4080	
F1_Inner_Surface	-2156	-148	2007	2493	1949	
F2_Inner Surface	-1543	-177	1411	850	2240	
F3_Inner_Surface	-667	-218	560	-1497	2656	
F1_Outer_Surface	614	190	-473	90	-1254	
F2_Outer Surface	1227	161	-1069	-1553	-963	
F3_Outer_Surface	2102	120	-1920	-3900	-548	
Max bolt	2156	218	2007	3900	2656	
f_FEA	100%	100%	100%	100%	100%	
OOP Shear Load	2156	218	2007	3900	2656	lbf
IP Shear Load	381	381	381	381	381	
Resultant Shear Load	2189	439	2043	3918	2683	lbf
COF	0.60	0.60	0.60	0.60	0.60	
Bolt Force	5500	5500	5500	5500	5500	lbf
Resisting Force/bolt	3300	3300	3300	3300	3300	lbf
SF_MIN	1.5	7.5	1.6	0.8	1.2	

Table 3 – Summary of Currents and Safety Factors

Bt	6.0							
CASE	SOFT	SOFT	OHZC	EOFT	MAXMAX	OTHER	Min	Max
Ioh	-24.0	-24.0	0.0	24.0	24.0	24.0	-24.0	24.0
Ipf1a	0.0	0.0	-24.0	-24.0	24.0	5.0	-24.0	5.0
Ipf1b	0.0	0.0	0.0	0.0	20.0	-20.0	-20.0	0.0
Ipf2	0.0	0.0	-10.0	-10.0	20.0	-20.0	-20.0	0.0
Ipf3	-2.5	-2.5	10.0	10.0	20.0	-20.0	-20.0	20.0
Ipf4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ipf5	0.0	0.0	10.0	10.0	20.0	0.0	0.0	20.0
Itf	71.2	71.2	71.2	71.2	71.2	71.2	0.0	71.2
Min Box Bolt Friction SF Outer	1.2	1.2	2.1	1.2	1.2	1.0	1.0	
Min Box Bolt Friction SF Inner	1.5	1.5	7.5	1.6	0.8	1.2	1.0	

These results indicate that margins are small but finite at 6kG based on the assumptions made. As more data is extracted from the FEA it can be used to refine the assumptions. Confirmatory tests on the friction coefficient on the large hub disk samples will refine the COF assumption. Due to the transfer of loads from the outer layer flag/boxes through the inner layer flag/boxes, the inners are at least as critical as the outers, and the high friction coating is essential. A scheme needs to be developed to provide for inspection of the flag/hub interfaces to determine if any slippage has occurred.

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