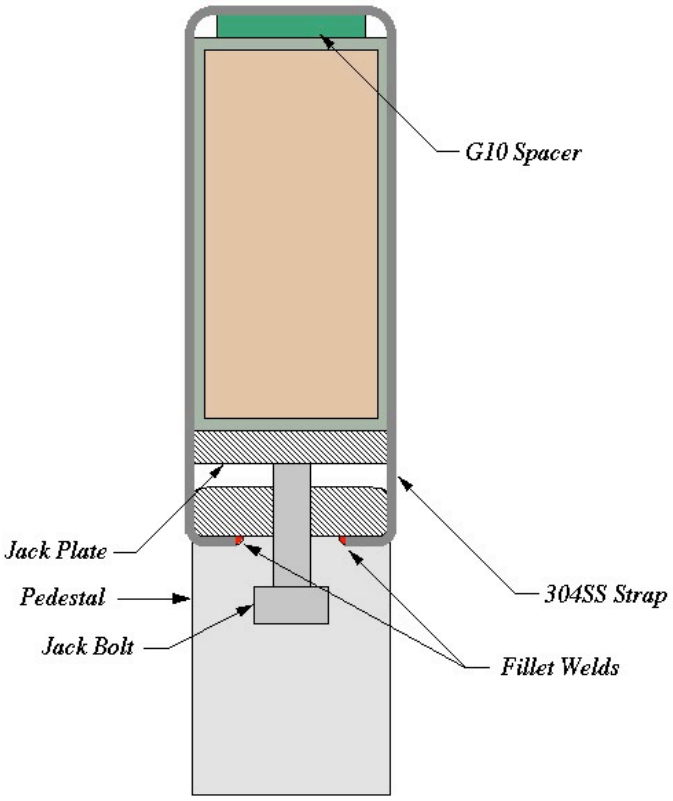
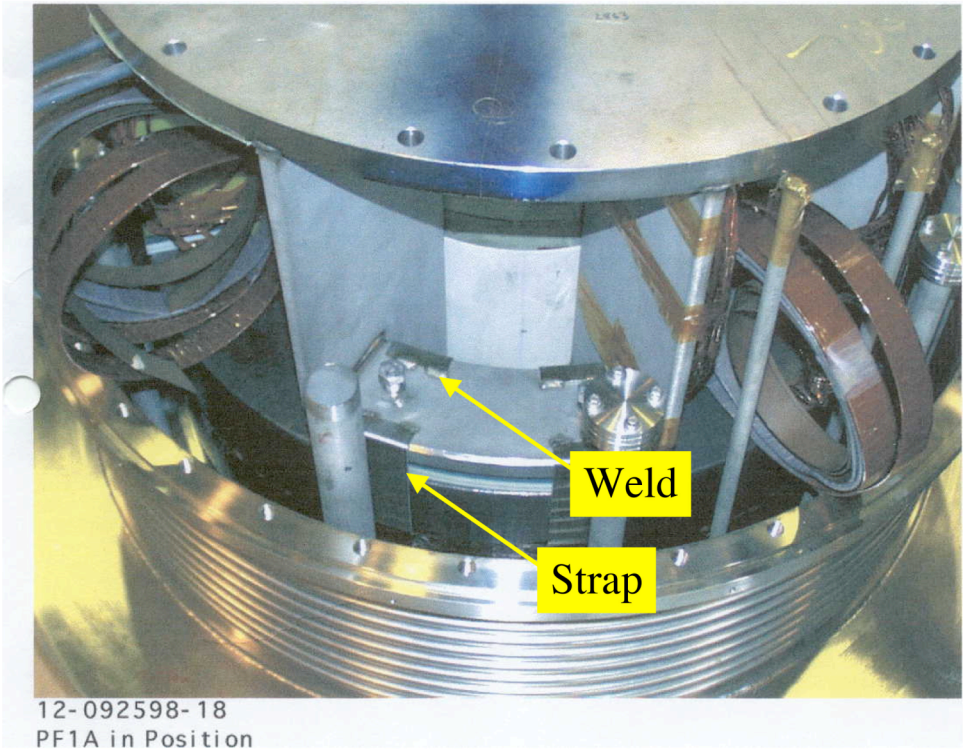
TO: DISTRIBUTION
FROM: C NEUMEYER
SUBJECT: PF1A AND PF1B FORCES AND OPERATING LIMITS

This memo addresses the forces imposed on the PF1AL and PF1B supports and presents a rationale for a revision to the operating limits. Further work will be required to better quantify the structural situation. Also, if the proposed limits are too restrictive, a more advanced protection feature, and/or a modification to the supports, will be required.

PF1A and PF1B coils are supported using the scheme depicted below.

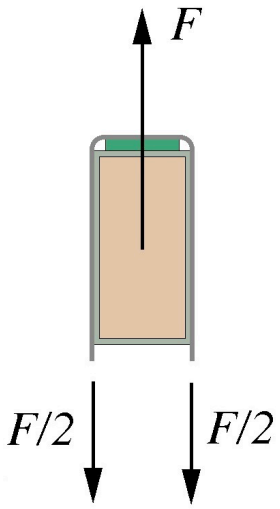


The coils are attached to a robust pedestal via 1/16" thick 304SS straps which are welded to the pedestals at eight toroidal locations. PF1A straps are 1.5" wide and PF1B straps are 2" wide. Coils are held in place using jack bolts. Refer to drawings NSTX EDC-1060, -1064, -1079, and –1096 for details.

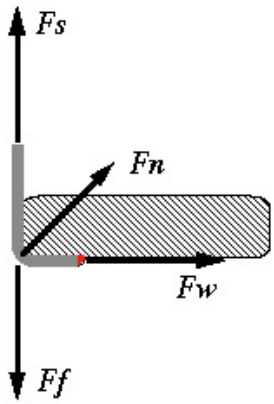


The extent of the weld is approximately 2/3 of the width of the strap.

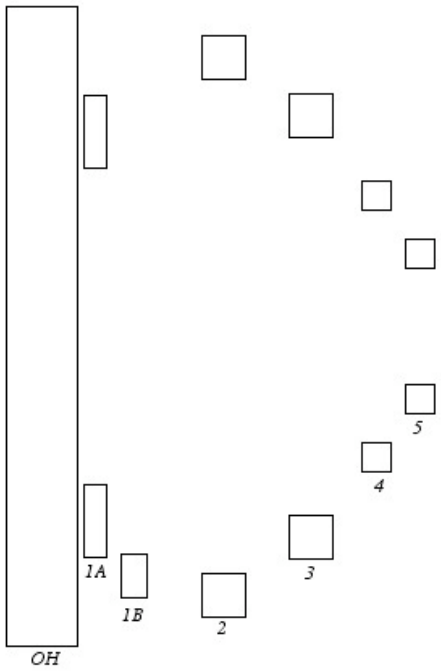
The support straps are challenged (on the bottom of the machine) by upward vertical forces which put the straps in tension and cause them to pull on the welds. Each strap is subject to 1/2 of the force on the coil.



As depicted below, the force on each weld F_w arises from the force on the strap F_s minus the load F_f taken by friction and bearing against the pedestal base plate as the strap turns the corner, which is determined by the normal force F_n and the coefficient of friction.



Per the simplified diagram below, PF1A sees upward vertical force when it has the same polarity as coils located above it and opposite polarity as coils located below it. The same is true for PF1B. Most of the force is generated by the coils in this local vicinity which include OH, PF1A, PF1B, and PF2. PF1A has the highest upward force when it PF1B has the opposite polarity and PF1B has the highest upward force when PF1A has the same polarity.



Forces are evaluated based on the influence matrix given below[1].

	Current (kA)	Axial EM Force (Fz) Influence Matrix for 1kA Current, unit in pound													
		OH	PF1AU	PF1AL	PF1BL	PF2U	PF2L	PF3U	PF3L	PF4U	PF4L	PF5U	PF5L	PLU	PLL
OH	24.0	0.0	-9.6	9.6	53.3	-54.1	54.1	-27.7	27.7	-4.6	4.6	-5.9	5.9	0.0	0.0
PF1AU	3.5	9.6	0.0	0.1	0.1	-24.2	0.3	-2.5	1.0	3.1	1.6	3.5	2.2	0.1	0.1
PF1AL	3.5	-9.6	-0.1	0.0	97.2	-0.3	24.2	-1.0	2.5	-1.6	-3.1	-2.2	-3.5	-0.1	-0.1
PF1BL	-5.0	-53.3	-0.1	-97.2	0.0	-0.3	17.9	-1.1	-7.2	-1.8	-4.9	-2.7	-5.8	-0.1	-0.1
PF2U	-20.0	54.1	24.2	0.3	0.3	0.0	1.7	99.0	6.6	33.0	11.1	40.3	16.7	0.5	0.4
PF2L	-20.0	-54.1	-0.3	-24.2	-17.9	-1.7	0.0	-6.6	-99.0	-11.1	-33.0	-16.7	-40.3	-0.5	-0.4
PF3U	20.0	27.7	2.5	1.0	1.1	-99.0	6.6	0.0	26.0	165.1	44.9	204.6	69.6	1.5	1.0
PF3L	20.0	-27.7	-1.0	-2.5	7.2	-6.6	99.0	-26.0	0.0	-44.9	-165.1	-69.6	-204.6	-1.5	-1.0
PF4U	0.0	4.6	-3.1	1.6	1.8	-33.0	11.1	-165.1	44.9	0.0	89.8	189.4	138.0	1.3	0.4
PF4L	0.0	-4.6	-1.6	3.1	4.9	-11.1	33.0	-44.9	165.1	-89.8	0.0	-138.0	-189.4	-1.3	-0.4
PF5U	20.0	5.9	-3.5	2.2	2.7	-40.3	16.7	-204.6	69.6	-189.4	138.0	0.0	225.9	1.3	0.4
PF5L	20.0	-5.9	-2.2	3.5	5.8	-16.7	40.3	-69.6	204.6	-138.0	189.4	-225.9	0.0	-1.3	-0.4
PLU	0.0	0.0	-0.1	0.1	0.1	-0.5	0.5	-1.5	1.5	-1.3	1.3	-1.3	1.3	0.0	0.0
PLL	0.0	0.0	-0.1	0.1	0.1	-0.4	0.4	-1.0	1.0	-0.4	0.4	-0.4	0.4	0.0	0.0

Basic pulse rating of PF1A is 15kA and PF1B 20kA. However, due to force considerations, and lack of a "smart" coil protection capability which can account for the real-time current values, the instantaneous peak of PF1A has been limited up to now to +3.5kA/-15kA and PF1B to –14kA. The analysis presented here shows that the present restrictions will protect the PF1A coils supports, but the combination of OH, PF1A, and PF1B all with the same polarity will cause excess force on the PF1B coil strap welds, so that further restrictions are necessary.

Considering that the yield strength of 304SS is 42ksi, the allowable stress in the strap is 2/3*42=28ksi. The other limiting factor is the weld, which should be limited to a load of 620lbf/inch of weld based on the following assumptions.

Weld dimension	0.0625	in
Throat	0.0442	in
Area	0.0442	in^2/in
Ultimate Tensile (assume same as parent material)	83.00	ksi
Tensile Yield (assume same as parent material)	42.00	ksi
UTS Safety Factor	2.00	
Yield Safety Factor	1.50	
Shear Factor	2.00	
Shear Allowable	14.00	ksi
Allowable Load per Unit Length	620	lbf/in

As a point of reference, a typically quoted rule of thumb is 700 lbf/in per 1/16 inch of diameter of weld material for SS welds, which is close to the above. Other references[2] would allow up to approximately 1klbf/in for a 1/16 inch weld with a UTS of 80ksi.

The following table shows the upward loads for various cases of OH, PF1A and PF1B current combinations, with the other PF coils set to worst-case conditions. The cells highlighted in yellow would violate the aforementioned allowables. If the allowable

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

[2] Kutz Mechanical Engineering Handbook based on AWS/AISC shear allowable of 0.3 UTS for 80ksi weld metal, Table 24.9, p. 609.

magnitude of IPF1A is reduced from 15kA to 10kA in the negative direction, and if the allowable magnitude of IPF1B is reduced from 14kA to 5kA, then safe conditions will be guaranteed. The limiting case is the cell highlighted in blue, which shows the loading of the weld in the PF1B coil support to be approximately equal to the 620 lbf/in limit, without taking any credit for the strap friction and bearing against the pedestal base plate.

Case	IOH (kA)	IPF1AL (kA)	IPF1B (kA)	FPF1AL (lbf)	FPF1B (lbf)	Strap PF1AL(ksi)	Strap PF1B (ksi)	Weld PF1A (klbf/in)	Weld PF1B (klbf/in)
Max Same Direction	-24.0	-15.0	-20.0	-17244	68503	0	34	0.0	3.21
Present Same Direction	-24.0	-15.0	-14.0	-8500	47952	0	24	0.0	2.25
New Limit Same Direction	-24.0	-10.0	-5.0	3075	14696	2	7	0.2	0.69
Max Opposite Direction	24.0	15.0	-20.0	41052	-68503	27	0	2.6	0.0
Present Opposite Direction	24.0	3.5	-14.0	7536	-32301	5	0	0.4	0.0
New Limit Opposite Direction	24.0	3.5	-5.0	4476	-11536	3	0	0.2	0.0

So, on this basis, the operating limits on PF1A and PF1B shall be set to the following:

PF1A: +3.5kA/-10kA
PF1B: -5kA

Further structural analysis is recommended to better quantify this situation. Pending this, the limits can be raised once again if a smart protection feature is added which accounts for the real-time currents using the influence matrix, or at least an algorithm relating IOH, IPF1A, and IPF1B. Or, for particular experiments, one or the other of PF1A or PF1B can be administratively locked out of service at FCPC. Or, if simultaneous operation of PF1A and PF1B with the same polarity is necessary above the limits imposed by the existing design, a modification of the supports will be necessary.

cc:

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