Check of disruption calculations for NSTX Upgrade passive plates

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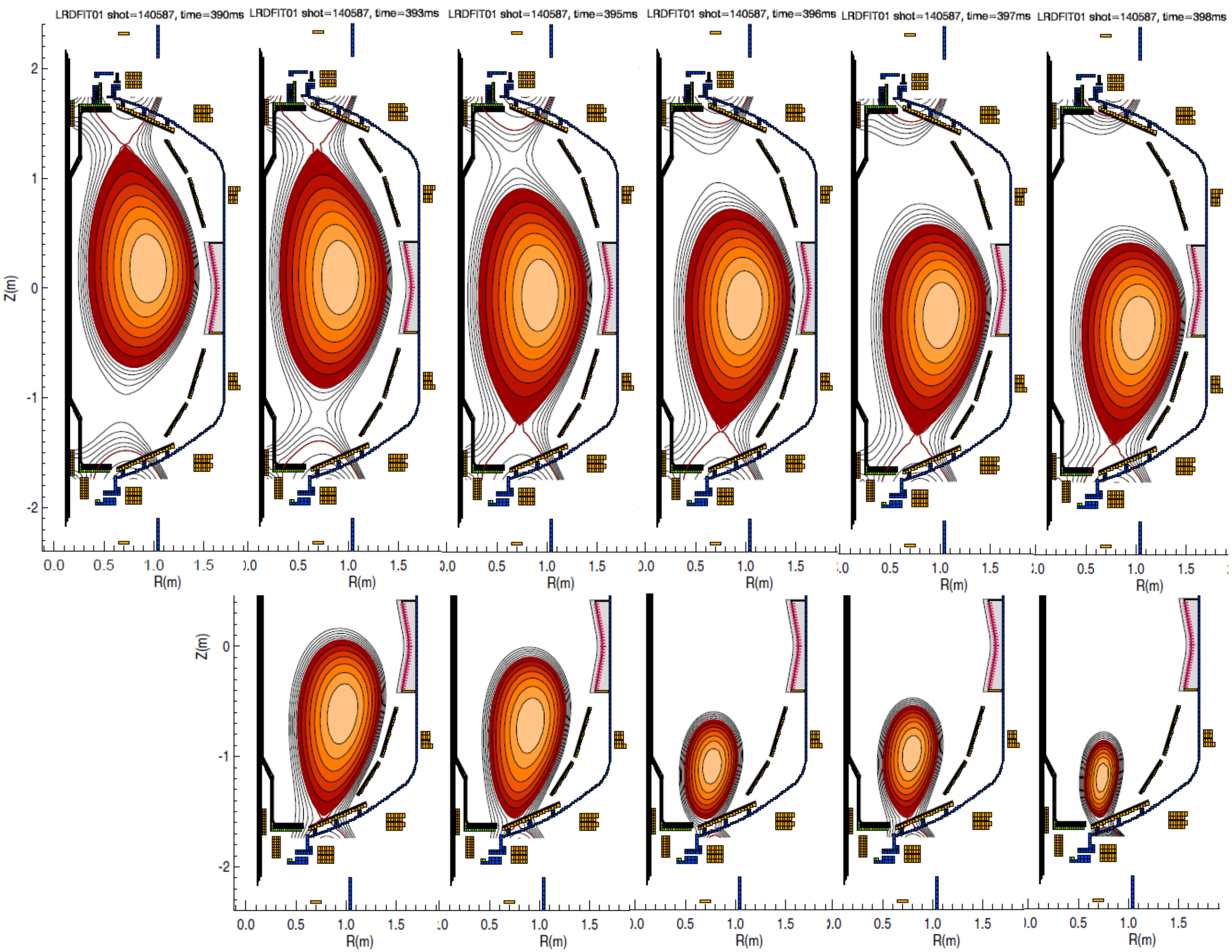
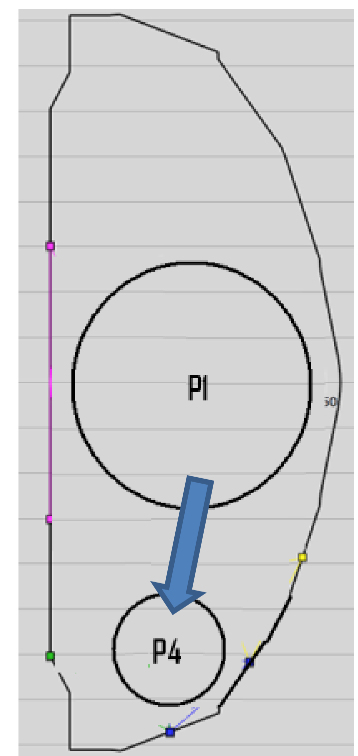
Shape evolution during VDE

Representative 700kA shot 140587 from NSTX



GRD approximation

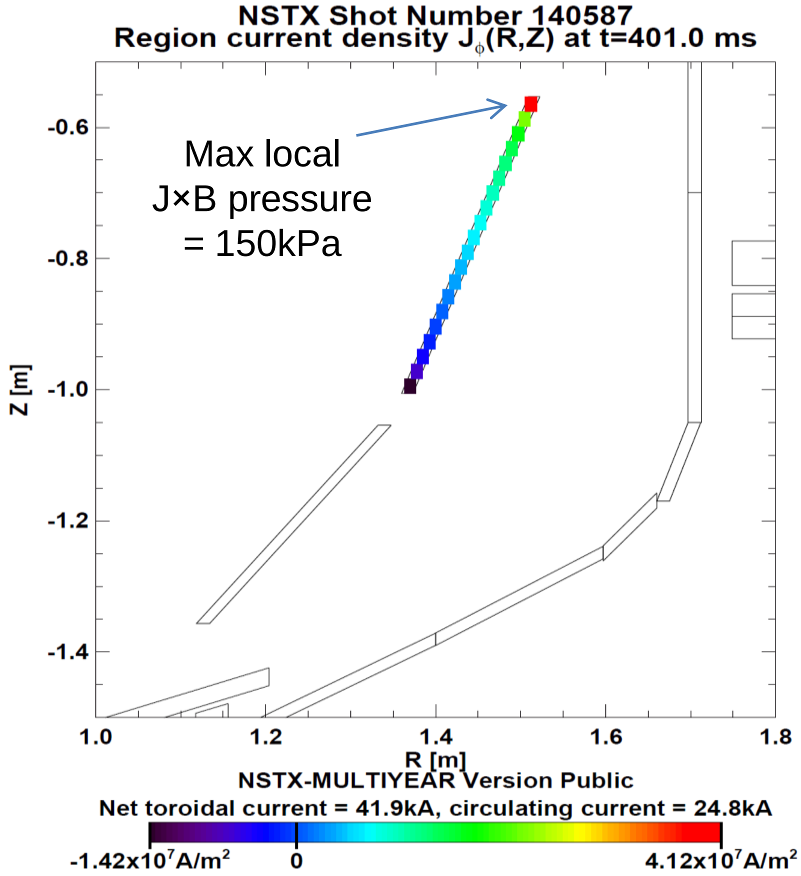


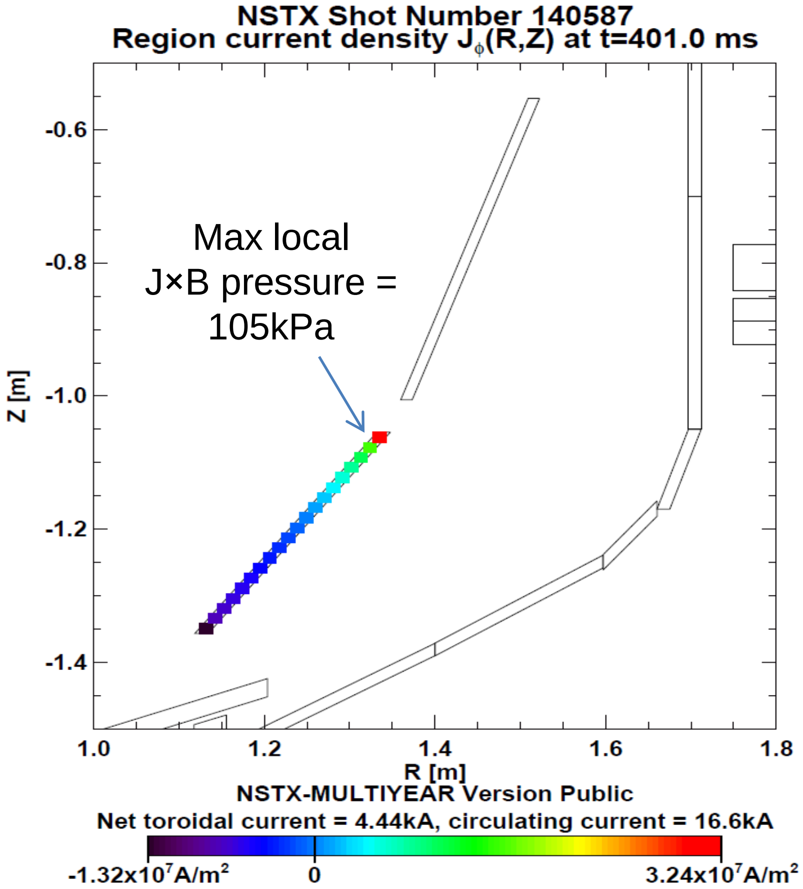
Reconstructing this evolution is quite challenging – requires circuit model of vessel (LRDFIT)

Peak plate current density calculation using LRDFIT axisymmetric equivalent

(same code used for reconstructions)

- 30-40MA/m^2 (0.7MA) → 100-120MA/m^2 in Upgrade (2MA)

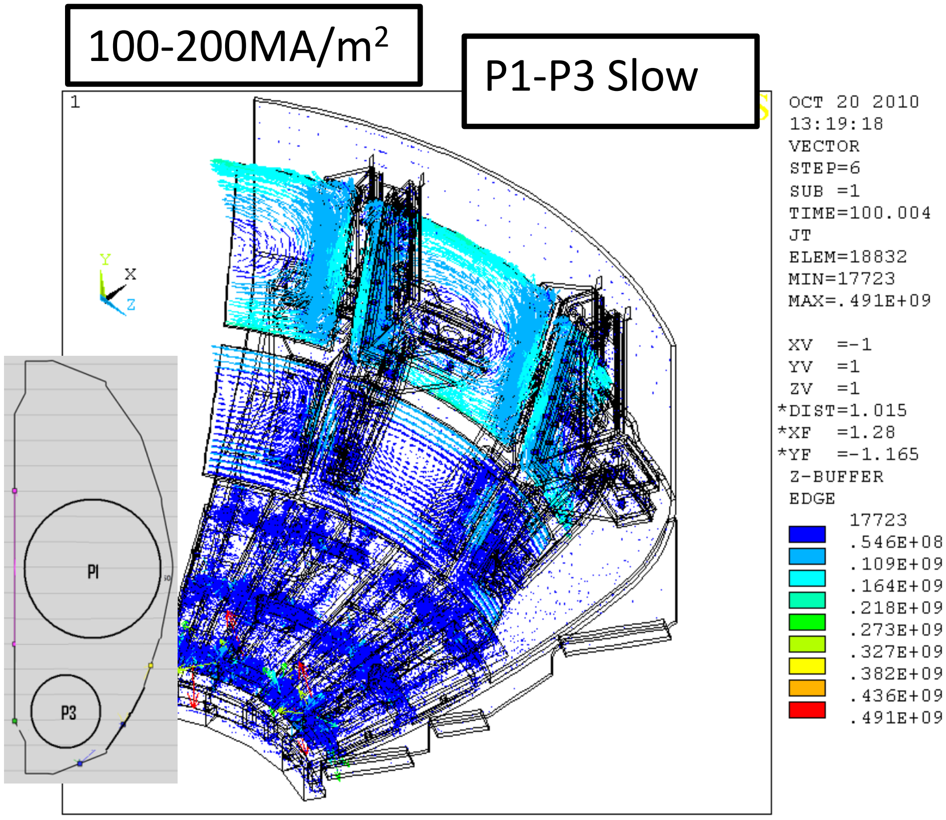


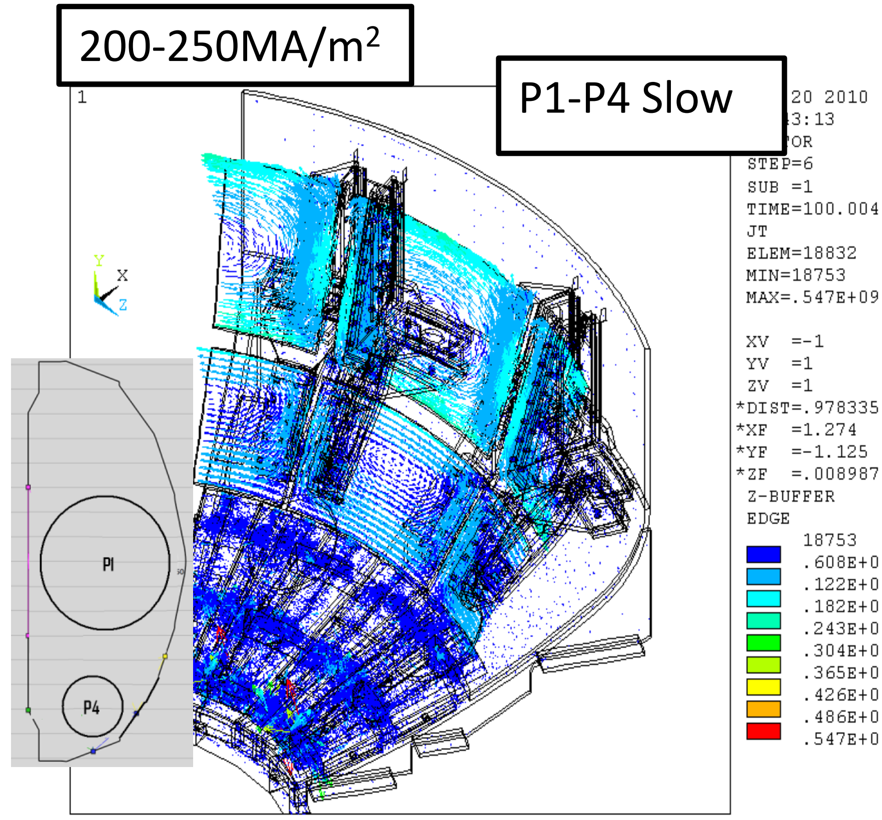


50-70kPa local pressure on significant fraction (~1/4) of plate → 400-600kPa at 2MA

Peak plate current density comparison

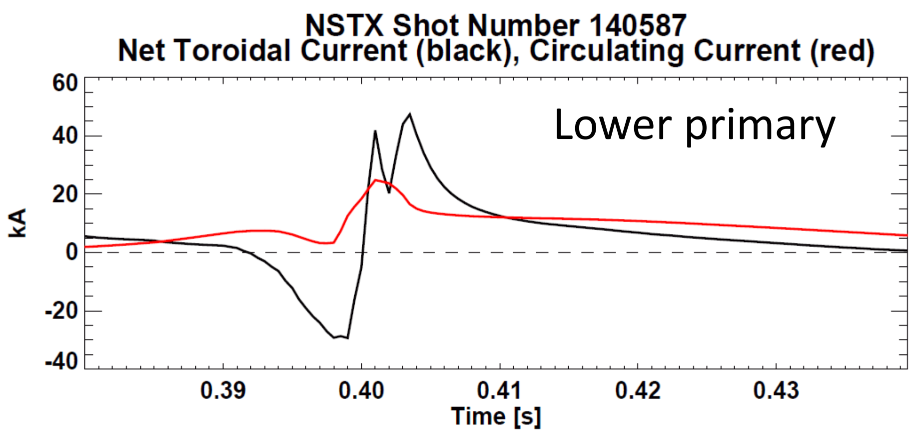
- 2D model circulating current density from representative plasma is within factor of 2 of GRD/XL specification

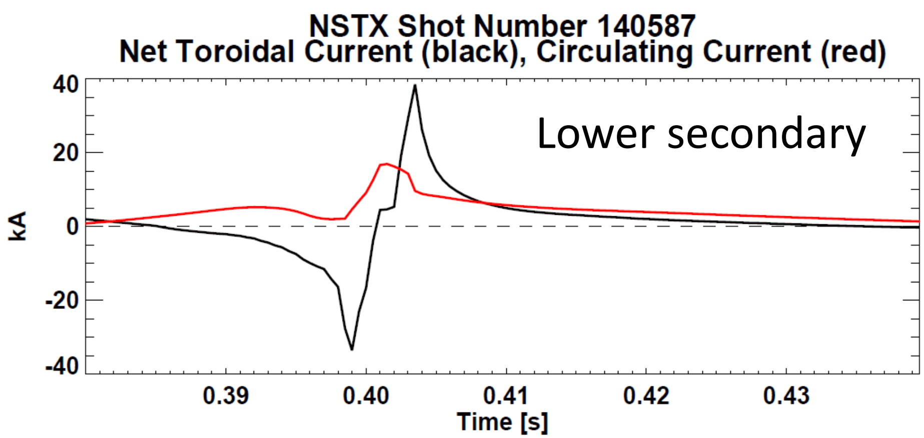


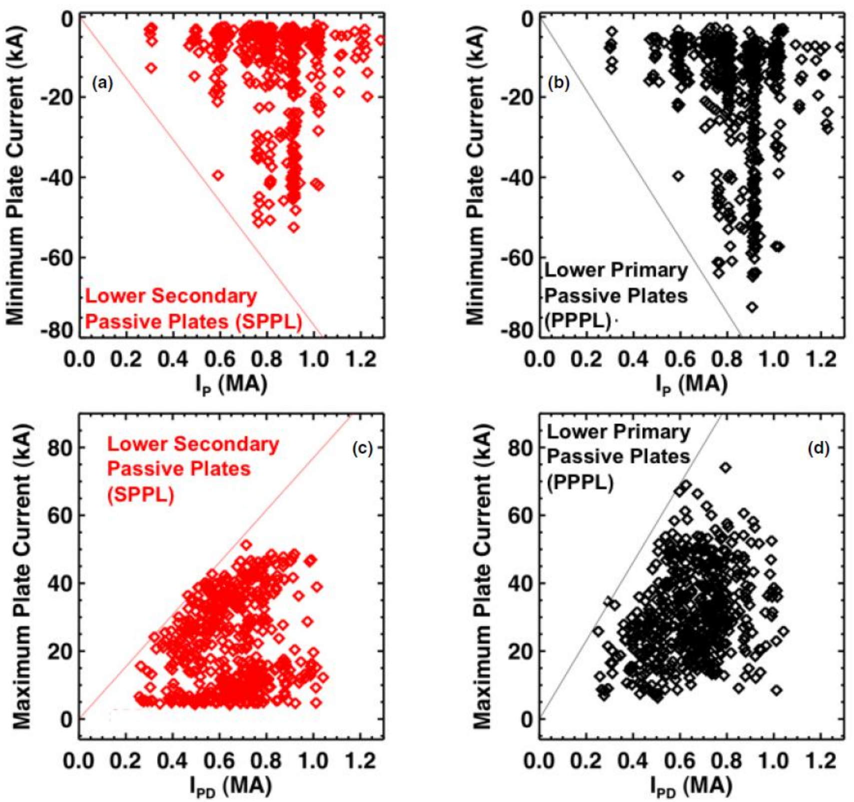


Peak plate current comparison

- LRDFIT for 140587 = 50kA net toroidal current → 150kA at 2MA
- Full database → higher values → 160-200kA plate current at 2MA







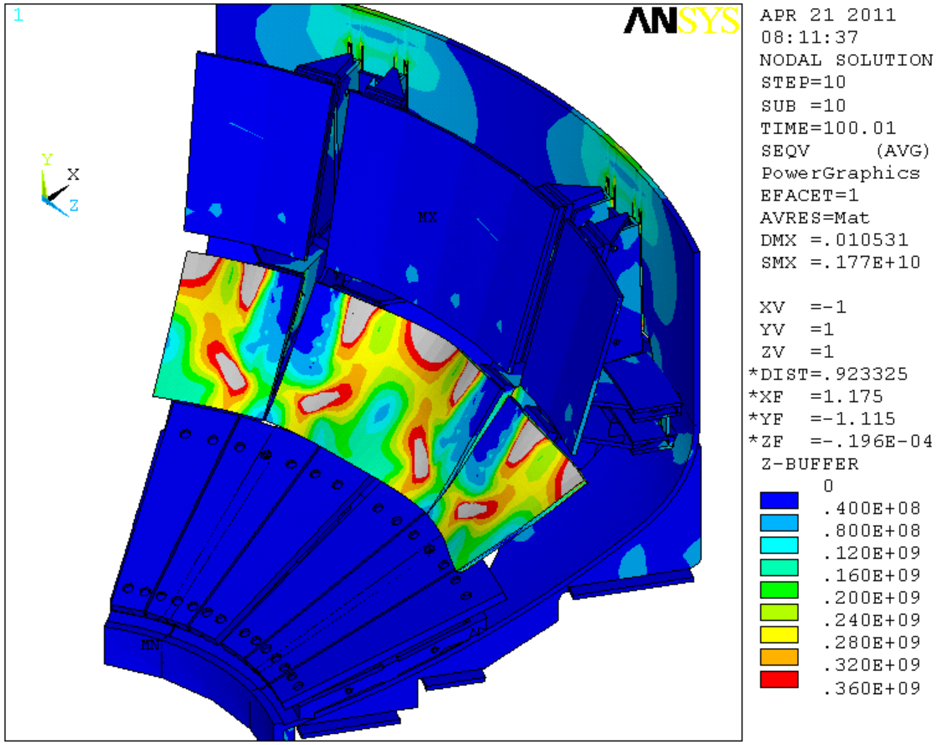
Assessment of maximum local field

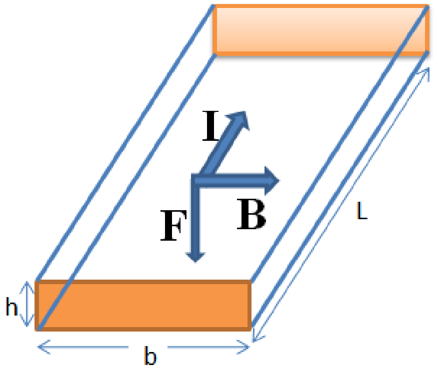
- In GRD, the VDE plasma equilibria are not self-consistent
  - Actual plasma must be in radial force balance
  - Assuming poloidal fields are worst case might therefore be overly conservative
- However, largest pressures on plates can occur near end of current quench, i.e. at time when field $\approx$ vacuum field
  - 140587 at 401ms is time of peak instantaneous JxB pressure → local B_P at plate is 0.22T → 0.5-0.6T for 2MA
  - 0.5-0.6T is comparable to that assumed in GRD for 2MA plasma

- **GRD usage of max B_P at plate is reasonable assumption**

Crude estimate of plate deflection and peak stress similar to ANSYS results

	Input	Calculation	
Major radius [m]	1.3		
# of plates	12		
length fraction	0.6		
Plate length (no rescale)		0.408	
Plate length rescale factor	1		
Plate length (rescaled)		0.41	
Plate thickness [in]	0.5		
Plate thickness [m]		0.0127	
Plate width (b)	0.4		
Ixx		6.82794E-08	
Plasma current	2.00E+06		
Plate current fraction	0.1		
Plate current		2.00E+05	
Magnetic field [T]	0.5		
Normal force		4.08E+04	
Normal area		0.16336	
Normal pressure		2.50E+05	
Force / length		1.00E+05	
Cu-Cr-Zr Young's Modulus [psi]	1.70E+07		
Cu-Cr-Zr Young's Modulus [Pa]		1.17E+11	
Max deflection (uniform load) [m]		4.53E-03	4.5 mm
Max deflection (point load) [m]		7.24E-03	7.2 mm
Section modulus		1.08E-05	
Stress at center of const. CS		1.94E+08	193.9 MPa





Additional braces from plates to vessel to effectively reduce the plate length by a factor of 2 would be effective at reducing deflection and stress

	Input	Calculation		
Major radius [m]	1.3			
# of plates	12			
length fraction	0.6			
Plate length (no rescale)		0.408		
Plate length rescale factor	1			
Plate length (rescaled)		0.41		
Plate thickness [in]	0.5			
Plate thickness [m]		0.0127		
Plate width (b)	0.4			
Ixx		6.82794E-08		
Plasma current	2.00E+06			
Plate current fraction	0.1			
Plate current		2.00E+05		
Magnetic field [T]	0.5			
Normal force		4.08E+04		
Normal area		0.16336		
Normal pressure		2.50E+05		
Force / length		1.00E+05		
Cu-Cr-Zr Young's Modulus [psi]	1.70E+07			
Cu-Cr-Zr Young's Modulus [Pa]		1.17E+11		
Max deflection (uniform load) [m]		4.53E-03	4.5 mm	
Max deflection (point load) [m]		7.24E-03	7.2 mm	
Section modulus		1.08E-05		
Stress at center of const. CS		1.94E+08	193.9 MPa	

	Input	Calculation		
Major radius [m]	1.3			
# of plates	12			
length fraction	0.6			
Plate length (no rescale)		0.408		
Plate length rescale factor	0.5			
Plate length (rescaled)		0.20		
Plate thickness [in]	0.5			
Plate thickness [m]		0.0127		
Plate width (b)	0.4			
Ixx		6.82794E-08		
Plasma current	2.00E+06			
Plate current fraction	0.1			
Plate current		2.00E+05		
Magnetic field [T]	0.5			
Normal force		2.04E+04		
Normal area		0.08168		
Normal pressure		2.50E+05		
Force / length		1.00E+05		
Cu-Cr-Zr Young's Modulus [psi]	1.70E+07			
Cu-Cr-Zr Young's Modulus [Pa]		1.17E+11		
Max deflection (uniform load) [m]		2.83E-04	0.3 mm	
Max deflection (point load) [m]		4.53E-04	0.5 mm	
Section modulus		1.08E-05		
Stress at center of const. CS		4.85E+07	48.5 MPa	

- **Unclear if additional braces to vessel are compatible with bake-out, etc**
- **Additional strengthening elements on each plate is another possibility**

Comments on changing passive plate material, and comment on skin depth effects

- Have had initial discussions of changing plate material to SS with Columbia University group
  - Calculations for last NSTX 5 year plan + KSTAR
  - Simulations indicate RWM growth rate increases by ~ 1 order of magnitude (or more) → not acceptable
- Roughly speaking, do not want to reduce plate field penetration time more than factor of 2-4

- Skin depth for Cu at 70C: δ [mils] = 2837/sqrt(f [Hz])

  →90 mils at 1kHz (1ms) → 1/e decay of E-field

  →δ ~ 5x the thickness of the plate → induced current in plate on these time-scales could be significantly smaller than assumed