National Spherical Torus eXperiment Upgrade

NSTX-U Magnetic Permeability Requirements

NSTX-U-RQMT-RD-010-00

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References

[1] ES-MECH-17, Guidance for Using Stainless Steel in Low Permeability Applications

Change Record

Revision	Date	Description of Change
0	12/1/17	Initial Release

For purposes of material selections and acceptance[1], magnetic materials shall be divided into four categories: welds, fasteners, bulk material, and magnetic shields.

Table 1 presents permeability guidelines based on the location of objects which may reside either inside the outer TF (OTF) legs (R<OTF) or outside (R>OTF). Any non-conformances must be approved by the NSTX Upgrade Project so that an inventory of such materials can be maintained.

Table 1 - Magnetic Permeability Guidelines

	Large Toroidally Localized[4]		Toroidally Symmetrical		Toroidally Symmetrical Arrays[3]	
	R<OTF	R>OTF	R<OTF	R>OTF	R<OTF	R>OTF
Welds	2.0	3.0	2.3	3.0	2.3	3.0
Base Material	1.04[4]	1.2	1.1	1.2	1.1	1.2
Machined Components	1.2[1]	1.4	1.2	1.4	1.2	1.4
Fasteners ≤5/8”	316SS or 304SS[2]	316SS or 304SS	316SS or 304SS[2]	316SS or 304SS	316SS or 304SS[2]	316SS or 304SS
Fasteners >5/8”	Inconel	316SS	316SS or 304SS[2]	316SS or 304SS	316SS or 304SS[2]	316SS or 304SS
Magnetic Shields	Each evaluated individually					
	[1] Large machined/formed components mounted on the vessel should be annealed before installation to reduce their bulk permeability to the minimum possible. [2] 304SS fasteners should generally be avoided on NSTX for installations inside the TF boundary, and their use should be approved. [3] Here, array refers to an installation with more than 8 objects equally spaced in toroidal angle. [4] If a toroidally localized object weighs less than 1.5 kg, see Figure 1 for allowable bulk permeability.					

Welds: Welds are generally regions of higher permeability, but also have small volume. For toroidally localized installations inside the TF boundary, welds on NSTX-U may have a bulk permeability up to μ_R=2.0; small isolated locations up to 3 may be tolerated. Proper choice of weld wire can aid in meeting this requirement. Toroidally symmetric welds or arrays of welds inside the TF boundary may have permeabilities up to 2.3. Welds outside the TF boundary may have permeabilities up to 3.0.

Fasteners: Small fasteners on NSTX-U should, in general, be made from 316 (or other low permeability material); here, small is defined as 5/8” thread diameter or below. Other more magnetic alloys of stainless steel (304, 18-8) shall not be used without approval. If quantities of specialized hardened bolts (or others with elevated permeability) are used whose weight exceeds ~1 kg in a localized installation, then approval shall be required. Inconel fasteners should be considered for these installations where possible.

[1] “General Magnetic Permeability Guidelines for NSTX-U”, Rev. 3, S. Gerhardt, May 10th, 2012

Magnetic Shields and other High μ_R Materials: Magnetic shields are devices designed to exclude the magnetic field from a volume containing some sensitive instrument; they typically have relative permeability levels exceeding 1000, and often exceeding 10,000. All magnetic shields must be reviewed by the magnetic material committee for both i) forces on the shields, and ii) perturbations to the plasma. Based on past NSTX and present DIII-D practice, the field perturbation at the nearest point on the plasma surface from these shields shall be less than 1 G.

Bulk Permeability: It has recently become more difficult to procure 316 stainless steel base material with low permeability (μ_R<1.02). In light of this trend, general guidance for base material is as follows.

For material outside the TF boundary, the relative permeability for base material shall be beneath μ_R=1.2. The permeability of machined components may be up to 1.4.

For material inside the TF boundary, the following guidance is given:

- For discrete, large toroidally localized installations on or inside the vessel, every reasonable effort shall be made to keep the final bulk permeability beneath μ_R=1.04. Here, “large” is defined as exceeding ~1.5 kg. Annealing and shot peening are techniques that can be used to reduce the permeability, provided that base material of sufficiently high quality has been procured. Smaller toroidally localized installations can have somewhat higher permeabilities, as indicated by the curves in Fig. 1.

- For toroidally symmetric objects inside the TF, bulk permeability up to μ_R=1.1 is acceptable. If discrete objects are installed in toroidally symmetric arrays, the target μ_R values can also be raised to 1.1.

- It is anticipated that there shall be some permeability increases in the vicinity of machining or other metal working. These shall not exceed μ_R=1.2. Annealing or other techniques should be considered to eliminate this permeability increase once the machining is finished.

Additional information on the use of low permeability steel can be found in Ref. [1].

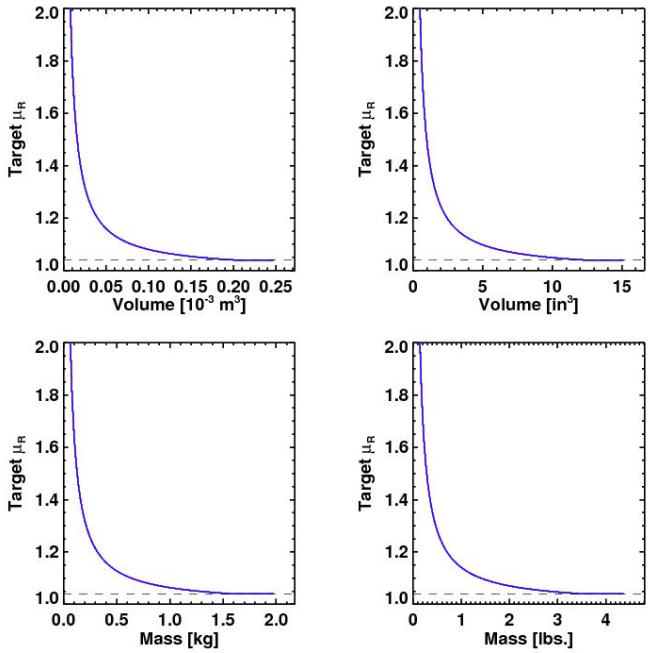

Figure 1: Target μ_R and object sizes that result in a 1 G midplane separatrix magnetic perturbation, for a typical NSTX-Upgrade equilibrium and object position of Z=0, R=1.65. Masses greater than 1.5 kg have a target base material permeability of 1.04.