Lawrence Berkeley National Laboratory	Cat Code SU3322	TECHNICAL NOTE	LBNL Technical Note # SU-1007-3140	Rev B	Page
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Title LARP QXF LQXF - MAGNET **MQXFA1 Allowable Axial Preload at RT**					

I. Introduction

This note describes the calculations of axial loading configuration of the MQXFA1 axial rods and bullets under the nominal total longitudinal Lorentz force of 1.37 MN (308,000 lbs) at 140 T/m. The axial rods are made of 316L stainless steel, and the bullets are made of Nitronic 50, with thread sizes of 1-1/4”-12 and M16-2.0, respectively. Each axial rod is assembled through the endplate and bolted with two nuts; each fully threaded bullet is bolted into the endplate. See Figure 1.

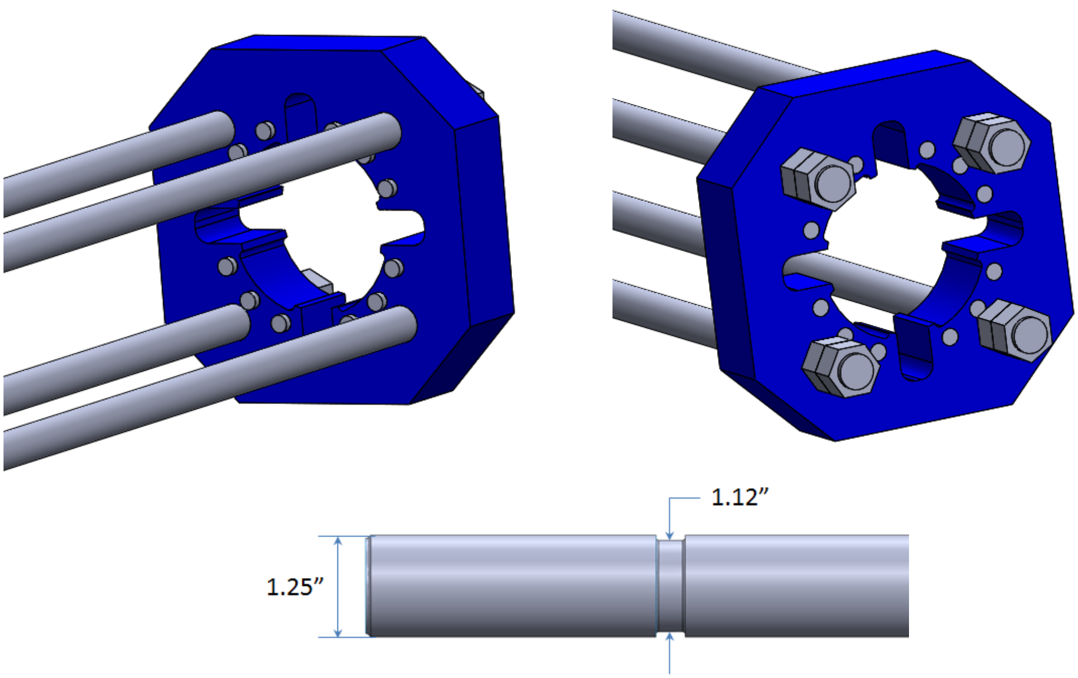

Fig. 1 Endplate assembly and the thread relief dimension on the rod (rod drawing see Appendix I)

The axial rods and two Nitronic 50 end plates provide a longitudinal force that counteracts the axial Lorentz forces from the coils. As a precedent, the axial preload of MQXFS3b (short model, tested at CERN) was set to 1.24 MN (278,000 lbs) at 4.2 K, and this note presents a calculation of the maximum force that can be applied in MQXFA1 structure configuration with these materials based on their properties. Though the axial rods are in tension and the bullets are in compression, there are no differences for thread strength verifications.

The yield stress of axial rod is 289 MPa (42,000 psi) at room temperature (material certification shown in Appendix II) and it increases to 930 MPa (135,000 psi, literature) at 4.2 K. The yield stress of Nitronic 50 is 555 MPa (80,500 psi) at room temperature (material certs shown in Appendix III), and 1240 MPa (180,000 psi, literature) at 4.2 K. The modulus of materials is shown in Table I.

Table I. Mechanical properties of 316L and Nitronic 50.

	Rod thread (316L)		Bullet (Nitronic 50)	
	RT	4.2 K	RT	4.2K
Modulus (GPa/ksi)	193/28,000	210/30,4000	210/30,400	225/32,600
Yield Stress (MPa/ksi)	289/42	930/135	555/80.5	1240/180
Thermal shrinkage rate (1/K)	9.83E-6		9.00E-6	

II. Tensile Areas of the Threads

The tensile rating for thread connection is the maximum value of axial tension that can be applied on the rods without the material yielding. It can be determined by the yield strength and the tensile area (the expressions in this note are using Imperial units) [1]:

The tensile-stress area of the thread (Rods)

$$A_t = \frac{\pi}{4} * (D - \frac{0.9743}{n})^2$$

The tensile-stress area is calculated by the expression above when the ultimate tensile strength is less than 689MPa (100,000 psi).

D = the basic major diameter of the thread in inch.
n = the number of thread per inch.

However, because of the smaller 1.12” thread relief diameter on each end of the rod, the tensile stress area of rod is actually limited by that dimension:

$$A_t = 0.985\ in^2$$

III. Shear Area of the Threads

An important fundamental of threaded structure design is that the bolt or screw will break before the threads strip. To quantify the failure mode, the following facts are needed:

(1) The length of engagement of mating threads:

$$L_e = \frac{2 \cdot A_t}{D_{3\_max} \cdot \pi \cdot [1/2 + 0.57735 \cdot n \cdot (D_{2_{min}} – D_{3\_max})]}$$

Where:

D_{3_max} = the maximum minor diameter of internal thread (hole) in inch.

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[1]Mechanical Fasteners – Tensile and Shear Stress Areas, Lecture 28. University of Tennessee, http://www.lhe.no/Files/Bolts%20theory.pdf

D_{2_min} = the minimum pitch diameter of external thread (rod) in inch.

The length of engagement of mating threads should be sufficient to carry the full load necessary to break the screw without the threads stripping. The factor of two (2) means that it is assumed that the area of the screw in shear must be twice the tensile-stress area to attain the full strength of the screw (this value is slightly larger than required and thus provides a small factor of safety against stripping).

(2) The shear area of external thread (bolt):

$$A_{s\_ex} = \pi \cdot n \cdot L_e \cdot D_{3\_max}[\frac{1}{2n} + 0.57735(D_{2\_min} - D_{3\_max})]$$

(3) The shear area of the internal thread (hole):

$$A_{s\_in} = \pi \cdot n \cdot L_e \cdot D_{s\_min}[\frac{1}{2n} + 0.57735(D_{s\_min} - D_{2\_max})]$$

Where:

D_{2_max} = maximum pitch diameter of internal thread.
D_{s_max} = maximum major diameter of external thread.
D_{s_min} = minimum major diameter of external thread.

IV. Results

The parameters of the thread calculations are shown inTable II, and the results are tabulated in Table III. Minimum thread engagement of the axial rods must be greater than 19.812 mm (0.78"), and the minimum thread engagement of the bullets must be greater than 10 mm.

Table II. Basic parameters of the rod thread and bullet thread

Parameters	Rod thread	Bullet thread
Type	1-1/4"-12	M16-2.0
D	1.25 in	16mm
D_{3_max}	1.1490 in	14.21 mm
D_{2_min}	1.1879 in	14.50 mm
D_{2_max}	1.1941 in	14.91 mm
D_{s_min}	1.2368 in	15.68 mm
D_{s_max}	1.2482 in	15.96 mm
n	12 / in	12/ in

Table III. The calculated results:

	Rod thread	Bullet
Required engagement length (Le)	0.78 inch	10 mm
Tensile area (A_t)	0.985 $inch^2$	156 mm^2
Shear area of external thread (A_{s_ex})	2.146 $inch^2$	312 mm^2
Shear area of internal thread (A_{s_in})	2.331 $inch^2$	400 mm^2

The shear and tensile stress under the given load is:

$$F = \sigma_t * A_t \quad \sigma_s = \frac{F}{A_{s\_ex}}$$

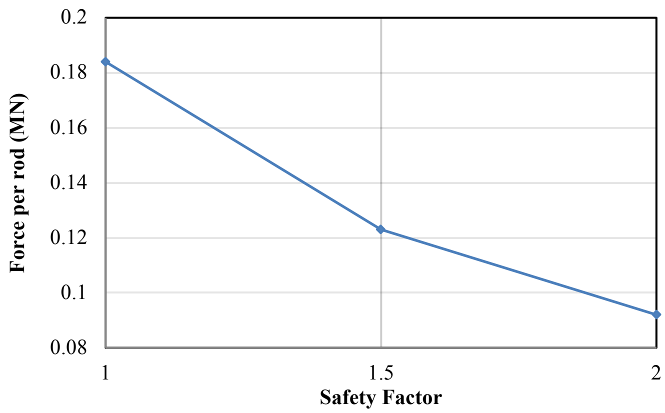


Fig. 2 Allowable force per rod at room temperature

The allowable force per rod is limited by the yield stress of 316 stainless steel at RT. From Fig. 2, the maximum force applied on each rod at RT is 0.184 MN (41,360 lbs.), where the tensile stress in each rod has a SF of 1. See Table IV and V.

Table IV. Safety factor of the tensile results for rods and bullets.

	Rod thread		Bullet	
	RT	4.2 K	RT	4.2K
Tensile stress (MPa/psi)	289/42,000	426/61,830	393/57,000	579/84,000
Safety factor (tensile/shear)	1	2.183	1.412	2.14

Table V. Safety factor of the shear results for rods and bullets.

	Rod thread		Bullet	
	RT	4.2 K	RT	4.2K
Shear stress (MPa/psi)	133/19,280	196/28,390	196/28,500	289/42,000
Safety factor (tensile/shear)	2.178	4.78	2.825	4.29

Elongation of the Rods

The overall length of each rod is initially 4828 mm (189.9 in) (see Appendix I). Under the maximum force applied, as calculated above, the elongation in each rod and bullet are shown in Table V.

Table V. Elongation of the rods and bullets at calculated load conditions.

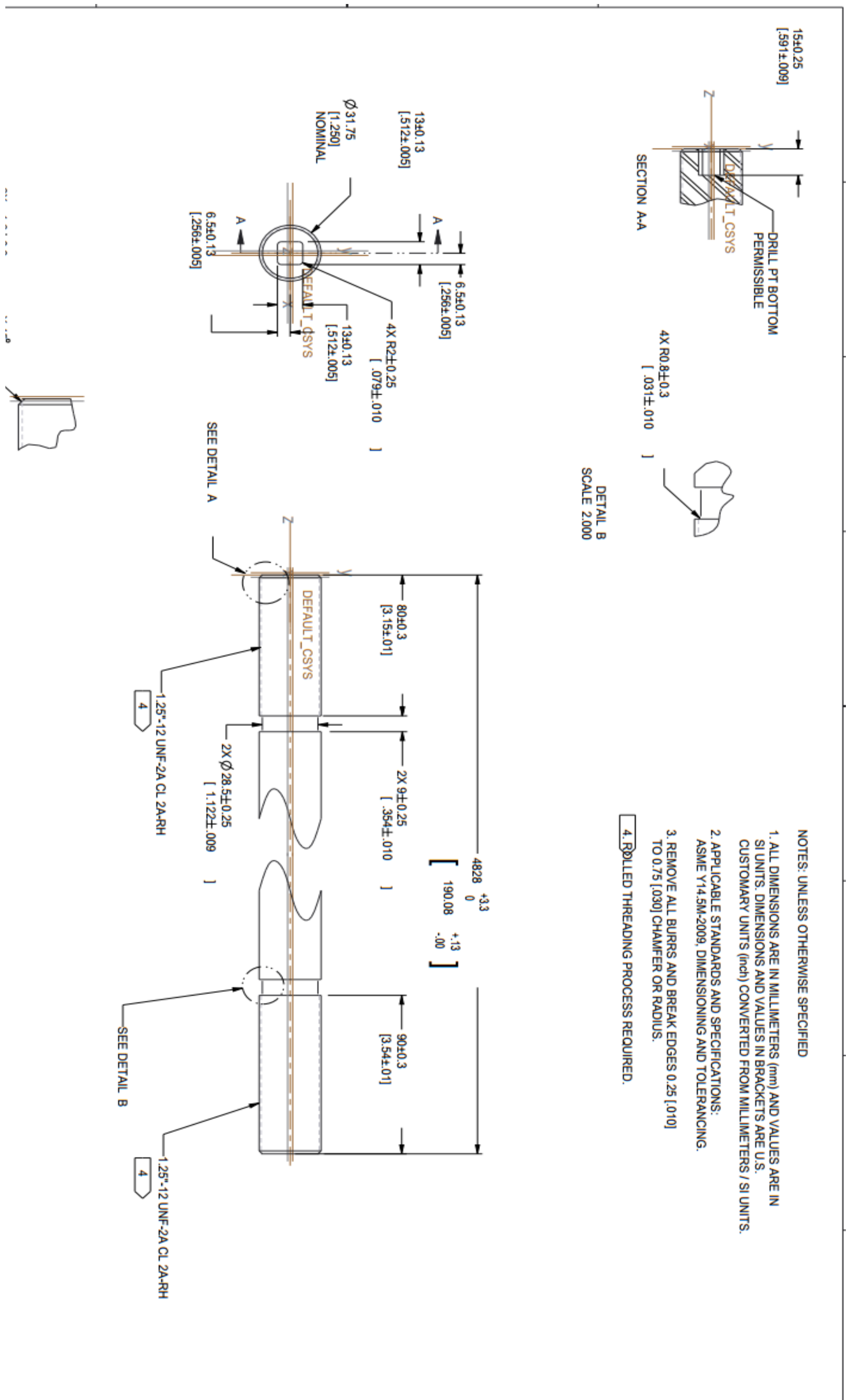
	Rod thread		Bullet	
	RT	4.2 K	RT	4.2K
Elongation (mm/in) (See below)	7.282 / 0.287	9.77*/0.385	-0.16/-0.006	-0.212*/-0.008

*Note that the elongation at 4.2 K is with respect to the "cold length", which is the length of the rod when cooled from room temperature to 4.2K without constraints. For instance, the "cold length" of the rod is 4814 mm (189.528 in); with the elongation of 9.77 mm (0.385 in) at cold and under load, the length at 4.2 K is 4824 mm (189.921 in).

V. Conclusion

Because stainless steel rods increase their load less than Aluminum rods upon cool-down, a higher RT preload is required by stainless rods to achieve the same axial load at 4.2 K as Al rods. However, the 316L SST rod material properties at R.T. limit the preload target and the final load after cooldown, accordingly. As a result, the maximum axial load of the four rods can achieve about 0.7 MN (157400 lbs) at R.T., and the corresponding axial load at cold is 1.1 MN (247300 lbs).

Appendix I Axial Rod drawing



NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS ARE IN MILLIMETERS (mm) AND VALUES ARE IN SI UNITS. DIMENSIONS AND VALUES IN BRACKETS ARE U.S. CUSTOMARY UNITS (inch) CONVERTED FROM MILLIMETERS / SI UNITS.
2. APPLICABLE STANDARDS AND SPECIFICATIONS: ASME Y14.5M-2009, DIMENSIONING AND TOLERANCING.
3. REMOVE ALL BURRS AND BREAK EDGES 0.25 [.010] TO 0.75 [.030] CHAMFER OR RADIUS.
4. ROLLED THREADING PROCESS REQUIRED.
SECTION A-A
DRILL PT BOTTOM PERMISSIBLE
15±0.25 [.591±.009]
DETAIL B SCALE 2.000
4X R0.8±0.3 [.031±.010]
13±0.13 [.512±.005]
Ø31.75 [1.250] NOMINAL
6.5±0.13 [.256±.005]
4X R2±0.25 [.079±.010]
SEE DETAIL A
SEE DETAIL B
80±0.3 [3.15±.01]
2X 9±0.25 [.354±.010]
2X Ø 28.5±0.25 [1.122±.009]
4828 +3.3 0 [190.08 +.13 .00]
90±0.3 [3.54±.01]
1.25"-12 UNF-2A CL 2A-RH
DEFAULT_CSYS

Appendix II Axial Rod Material Cert (Photocopy)

Customer: UC Berkeley Lab P.O.# 7285127-1
H&R Job# 14316 Part# 27K610A B
Prepared by: K. Berdiago Date: 6/29/16
Horspool & Romine Mfg. Co., Inc., Oakland ,CA 94608

EMJ

CERTIFICATE OF TEST

Page 01 of 02

Certification Date
8-JUN-2016

CUSTOMER ORDER NUMBER
74169-J

EARLE M. JORGENSEN COMPANY
31100 WIEGMAN ROAD
HAYWARD CA 94544

Invoice Number
T452245

CUSTOMER PART NUMBER

SOLD TO: HORSPOOL & ROMINE MFG CO INC
5850 MARSHALL STREET
OAKLAND CA 94608

SHIP TO: HORSPOOL & ROMINE MFG CO INC
5850 MARSHALL STREET
OAKLAND CA 94608

Description: 316/316L ANN PSQ BAR
1-1/4 RD X 20'2"/24'2"
HEAT: W2H1

ASTM A479
Line Total: 334 LB

ITEM: 509393

Specifications:
ASTM A276 13
QQ S 763 F
AMS 5648 K
ASTM A479 13A
AMS QQ S 763 A
ASME SA479 13
AMS 5653 G

CHEMICAL ANALYSIS

C	CO	CR	CU	MN	MO	N	NI
0.017	0.27	16.60	0.25	1.36	2.00	0.033	10.51

P	S	SI
0.025	0.0245	0.27

RCPT: R792706
VENDOR: ROUND GROUND METALS INC
COUNTRY OF ORIGIN : USA

MECHANICAL PROPERTIES

DESCRIPTION	YLD STR KSI	ULT TEN KSI	%ELONG IN 02 IN	%RED IN AREA	HARDNESS BHN
	42.0	84.0	42.0	54.0	144

GRAIN SIZE :6 - 8

Appendix III Nitronic Material Cert (Photocopy)

outokumpu
high performance stainless steel

Certificate of Test

540356

Page: 1

HEAT 540356 ORDER 653766/ 01 BOL 0231045 * CERTIFICATION * 02/17/15

SHIP TO:
FRY STEEL C/O CMI
4201 WEST 36TH STREET

CHICAGO 606320000

------------------------------ YOUR ORDER & DATE ------------------------------
48161-16 8/21/14 CUST# 0438001 CUST TAG#S# 45410

------------------------------ ITEM DESCRIPTION ------------------------------
GRADE XM-19 Ship Condition CONDA
Size XM-19 RND CFA CONDA .7500 x 144.000 RL
Country of Melt: UNITED STATES Country of Mfg.: UNITED STATES
NAFTA Country of Origin is Country of Melt

No weld repair
Free of mercury contamination, Free of radiation contamination
No WEEE relevant substances; Meets EU electrical ROHS

Total Bundles 1 Total Weight 2694 Approx. Hot Red. Ratio 584:1

WO 2056814 Bundles: 1A

------------------------------ SPECIFICATIONS ------------------------------
THE PRODUCTS LISTED ON THIS MILL TEST REPORT SATISFY PREFERENCE CRITERION B
AS DEFINED IN ARTICLE 401 OF THE NORTH AMERICAN FREE TRADE AGREEMENT.

ASME SA479 2007-2013 Ed.
ASTM A370 14
NACE MR0175-09, ISO 15156:09
DFARS 225.7002-3(B)(1)
AMS 5764 Rev E
EN 10204 Type 3.1 Document
ASTM A276-15
ASTM A479/A479M 14
DFARS 252.225.7009 10/4/11
UNS S20910
ASTM A193 14 B8R Class 1

------------------------------ MECHANICAL & OTHER TESTS ------------------------------

Hardness as shipped	(222 HB)	Tensile strength,KSI (MPa)	115.0 (793)
Hardness as shipped	97 HRB	0.2% Yield Strngth,KSI(MPa)	80.5 (555)
Grain size	7.0	Elongation % in 4D	41.0
Micro	OK	Reduction of area %	70.0
Intergranular corrosion	OK		

------------------------------ CHEMICAL COMPOSITION ------------------------------

Carbon	(C)	.024	Manganese	(Mn)	4.980
Phosphorus	(P)	.030	Sulphur	(S)	.001
Silicon	(Si)	.290	Chromium	(Cr)	21.080
Nickel	(Ni)	12.030	Cobalt	(Co)	.078
Copper	(Cu)	.240	Moly	(Mo)	2.070
Nitrogen	(N)	.267	Columbium	(Cb)	.140
Titanium	(Ti)	.003	Aluminum	(Al)	.003
Tin	(Sn)	.005	Cerium	(Ce)	.010
Boron	(B)	.001	Tantalum	(Ta)	.005
Vanadium	(V)	.140	Tungsten	(W)	.020
Columbium/ Tantalum	(Cb+Ta)	.145			
Iron	(Fe)	Balance			
Melt Practice		EAF			
Refining Practice		AOD			
De-long Ferrite					

FRY STEEL CO. CERTIFIES THAT THIS IS A TRUE COPY OF THE ORIGINAL MILL TEST REPORT NOW ON FILE RECEIVED AND INSPECTED

FEB 2 5 2015

BY CHIP SANDOVAL - Q.C. MANAGER

3/4/15

Knowingly & willfully falsifying or concealing a material act on this form, or making false, fictitious or fraudulent statements or representations herein could constitute a felony punishable under federal statutes. We hereby certify that the test results shown in this report are correct and accurate as contained in the records of the company and are in compliance with the specifications, codes, and standards listed above.

M.F. Marcanio, Quality Manager

Outokumpu Stainless Bar, LLC
3043 Crenshaw Pkwy
Richburg, SC 29729

M.F. Marcanio