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Vacuum Vessel Weld and Thread Calculations For the 3.9-GHz Cryomodule

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Introduction

This document presents the calculations for the Vacuum Vessel for the 3.9-GHz Cryomodule. Calculations include weld sizing and sizing of threaded parts for the pick points (lifting lugs) and the bottom supports. The calculated stresses for the welds and the threaded bosses fall within the allowable stress according to the AISC Manual of Steel Construction [1]. The stresses are calculated based on the weight of the cryomodule assembly.

Dimensions of Parts

Table 1 is a list of drawings showing the pick point and bottom support weldments. All dimensions for the weld sizing and sizing of threaded parts come from the drawings shown in Table 1.

Table 1 – Drawing List of Pick Point and Bottom Support Weldments

Drawing Title	Drawing Number
Vacuum Vessel Weldment Assy.	ME – 439317
Vessel Shell	ME – 439262
Pad Base Support	MC – 439241
Pad Weld Upper	MC – 439242
Vessel Support Weldment	MC – 439254
Pick Point Weldment	MC – 439257

Weld Sizing

Table 2 summarizes the sizes of fillet welds at the pick points and the bottom supports. The table shows that all of the fillet weld sizes are within the specifications of the AISC Manual of Steel Construction [1]. The average shear stress in the fillet weld is calculated as the applied load divided by the weld's throat size and its effective length, as shown in the following equation [2]:

$$\tau_{avg} = \frac{P}{0.707hl}$$

Where τ_{avg} = average shear stress in a fillet weld (psi)
P = applied load = ¼ of the cryomodule weight = ¼ * (8000-lb) = 2000-lb. [3]
h = fillet weld size (inch)
l = effective length (inch)

The weight of the cryomodule includes the vacuum vessel, the dressed cavity, and the end caps that are used for shipping the assembly to DESY. For a conservative calculation, it is assumed that each weld has an applied load of a quarter of the cryomodule weight as if there is only one weld at each pick point assembly. In reality, at each pick point assembly there are a total of six welds, so the applied load is less than 2000-lb. for each weld.

The allowable shear stress in a fillet weld is specified in Table 1.5.3 [1]. The shear stress in a fillet weld must be less than 0.3 times the tensile (ultimate) strength of the weld metal and less than 0.4 times the yield strength of the base metal. The weld metal is not known, so it is assumed to have the same material properties as the weaker of the two base metals at the weld. The shear stresses of all fillet welds are less than the allowable shear stress, so the welds are adequately sized.

Table 3 summarizes the sizes of the full penetration groove welds. The groove welds also are within the specifications of the AISC Manual of Steel Construction [1]. The tensile and compressive stresses and the shear stress are calculated using the following equation [2]. In the same manner as the fillet welds, for each groove weld, a conservative calculation is made where it is assumed that each weld takes a quarter of the total weight of the cryomodule assembly.

$$\sigma_{groove} = \tau_{groove} = \frac{P}{h_{groove} l_{groove}}$$

Where σ_{groove} = tensile and compressive stresses normal to the weld axis (psi)
τ_{groove} = shear stress (psi)
P = applied load = ¼ of the cryomodule weight = ¼ * (8000-lb) = 2000-lb. [3]
h_{groove} = weld throad (inch)
l_{groove} = effective weld length (inch)

As shown in Table 1.5.3, the allowable tensile and compressive stresses (normal to the effective area of the full penetration groove weld) are the same as the base metal's allowable stresses [1]. For both pick point weld and the bottom support weld, the base metal is ASTM A516 Gr 70, which has an allowable stress of 20,000-psi [4]. As shown in Table 1.5.3, the allowable shear stress on the effective area is the lesser of 0.3 times the tensile strength of the weld metal or 0.4 times the yield stress of the base metal [1]. The tensile, compressive, and shear stresses of all fillet welds are less than the allowable shear stress, so the welds are adequately sized.

Table 2 – Fillet Weld Sizes at the Pick Points and the Bottom Supports

Drawing	Weld Location	Size (inch)	Effective Length (inch)	Average shear stress (psi)	Weld metal tensile strength (psi)	Base metal yield strength (psi) [4]	Allowable shear stress (psi)	Weld strength OK?
MC-439257	Around threaded boss	0.38	9.90	752.3	58000	36000	14400	YES
ME-439317	Pick point to weld pad	0.75	6.00	628.6	70000	40000	16000	YES
ME-439317	Inner edge of weld pad	0.31	4.86	1877.6	70000	40000	16000	YES
MC-439254	Around threaded boss	0.38	10.21	729.1	58000	36000	14400	YES
ME-439317	Vessel support to Pad base support	0.38	8.00	930.5	70000	40000	16000	YES
ME-439317	Inner edge of pad base	0.31	8.00	1140.7	70000	40000	16000	YES

Table 3 – Full-Penetration Groove Weld Sizes at the Pick Points and the Bottom Supports

Drawing	Weld Location	Size (inch)	Effective Length (inch)	Average tensile/compressive stress (psi)	Base metal tensile strength (psi)	Base metal yield strength (psi)	Allowable tension and compression stress (psi)	(Table 1.5.3) Allowable shear stress (psi)	Weld strength OK?
ME-439317	Outer edge of weld pad	0.75	8.00	333.3	70000	38000	20000	15200	YES
ME-439317	Outer edge of pad base	0.75	8.00	333.3	70000	38000	20000	15200	YES

The material properties for the metals in both tables are found in the ASME BPVC Section II tables [4].

Sizing of Threaded Parts

At all four of the pick points and all four of the bottom supports are threaded bosses. The sizes of the tapped holes are the same: M36 x 4. The threaded bosses experience two types of stresses that are calculated: the bearing stress σ_b and the shear stress τ.

The nominal bearing stress σ_b on the threaded boss is calculated using the following equation [5]:

$$\sigma_b = \frac{4F}{\pi\left(d^2 - d_r^2\right)}\left(\frac{p}{h}\right) = 12{,}086 \text{ psi}$$

Where σ_b = nominal bearing stress = 12,086-psi
F = applied load = ¼ of the cryomodule weight = 2000-lb.
d = major diameter = 36-mm
d_r = minor diameter = 32-mm
p = thread pitch = 4-mm
h = height of engaged threads = 2-mm

For inner threads, the maximum shear stress τ that can result in shear or stripping the thread due to the load force is calculated [5]:

$$\tau = \frac{3F}{\pi dh} = 17{,}122 \text{ psi}$$

Where τ = maximum shear stress at the root of the thread = 17,122-psi
F = applied load = ¼ of the cryomodule weight = 2000-lb.
d = major diameter = 36-mm
h = height of engaged threads = 2-mm

The bosses are all made of the ASTM A36 steel. The ultimate stress for this steel is 58,000-psi. The specification for threaded parts, following the AISC Manual [1], Table 1.5.2.1, gives an allowable stress in tension as

$$F_t = 0.33F_u = 19{,}100 \text{ psi}$$

Where F_t = allowable stress in tension = 19,100-psi
F_u = ultimate stress for ASTM A36 = 58,000-psi

For the M36x4 inner thread, the bearing stress σ_b and the shear stress τ are less than the allowable stress Ft, so the threaded boss is adequately designed for the applied load.

References

1. AISC, Manual of Steel Construction, 8th edition, 1980.
2. Shigley and Mischke, Mechanical Engineering Design, 5th edition, 1989.
3. (reference for weight of cryomodule)
4. ASME, Boiler and Pressure Vessel Code, Section II, Part D, 2007.
5. Shigley and Mischke, Standard Handbook of Machine Design, 2nd edition, 1996.