Lawrence Berkeley National Laboratory	Cat Code LH1003	ENGINEERING NOTE	Serial # 10207	Rev A	Page 1 of 2
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Title US-LHC Collaboration Luminosity Detector Bolt calculations for case lid					

1. Introduction

The LHC beam luminosity monitor is a gas ionization chamber that observes minimum ionization particles near the shower maximum in the zero degree neutral particle absorbers (TAN) of IP's 1 and 5. The ionization chamber resides in a stainless steel case with a mixture of 94% argon and 6% nitrogen gas continuously flowing through at a pressure of up to 1 MPa absolute. This engineering note documents bolt calculations on the bolts sealing the case lid to the case. CERN refers to the luminosity monitors as Beam Rate of Neutrals (BRAN), and LBNL uses the term "LUMI" for these LHC luminosity monitors during its development stage.

2. Bolted joint design

The design of the bolted joint is documented in LBNL drawing 27E005. The case lid (LBNL drawing 27D908) compresses a tin gasket to seal against the case flange (see LBNL drawing 27D912). Socket head cap screws provide the joint compression. These cap screws have the following specifications:

- Material is stainless steel 316
- Size is M4-0.7
- Length is 20 mm

The thickness of the case lid is 12.2 mm. The case and case lid material is stainless steel 316.

3. Calculation of safety factors

Annealed 316 stainless steel has a yield strength of 240 MPa. For M4-07 cap screws, the tensile area is 8.78E-6 m^2. Using a proof strength of 85% yield strength and the bolt tensile area, the proof load for each bolt is 1791 N. Since the joint is permanent, we use 90% of the proof load for the bolt preload to yield a preload F_i of 1612 N.

The bolts are fully threaded. Assuming the pressure frustrum extends ½ of the bolt diameter into the case flange, the grip length is 14.2 mm. Given a modulus of 193 GPa for 316 stainless steel, the bolt spring constant is

$$k_b = \frac{A_t E}{l} = \frac{(8.78E-6)(193E9)}{0.0142} = 1.19E8 \text{ N/m}$$

For a washer face 50% greater than the bolt diameter and using a pressure frustrum angle of 30 degrees, the member spring constant is

$$k_m = \frac{0.577\pi Ed}{2\ln\left(5\frac{0.577l + 0.5d}{0.577l + 2.5d}\right)} = 6.79E8 \text{ N/m}$$

The joint constant, C, is therefore

$$C = \frac{k_b}{k_b + k_m} = 0.149$$

The maximum operating pressure is 1 MPa and the pressure area is 61 mm x 89 mm (0.00543 m^2). The total load is thus 1 MPa x 0.00543 m^2 = 5430 N. Since the load is distributed across 24 bolts, each bolt joint carries and external load *P* of 226 N.

The factor of safety guarding against joint separation is

$$n_{separation} = \frac{F_i}{P(1-C)} = 8.38$$

If the joint were to separate, the bolts would carry the full load. For this situation, the external load *P* of 226 N is the load on each bolt. For a tensile area of 8.78E-6 m^2, the bolt tensile stress is 2.58E7 Pa, resulting in a factor of safety of 9.32 guarding against bolt yield.

4. Experimental set up

A bench-top experiment was set up to evaluate the efficacy of the tin seal design in providing a long term positive pressure seal. The experiment replicates the bolted joint using the same cap screws as for the final design. The component representing the case was designed with a very small gas volume. The internal volume was pressurized to 1.0 MPa of nitrogen gas and has been holding pressure without any loss for 17 weeks. The experiment will continue for a minimum of 6 months.

5. References

1. Mechanical Engineering Design, Fifth Edition, J. E. Shigley and C. R. Mischke, McGraw-Hill, 1989.
2. LBNL drawing 27E005.
3. LBNL drawing 27D908.
4. LBNL drawing 27D912.