BNL-224792-2023-TECH

C-A/AP/701

Design of a removable vacuum bellow restraint for RHIC vacuum vessels

F. Micolon

August 2023

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC), Nuclear Physics (NP) (SC-26)

DISCLAIMER

Design of a removable vacuum bellow restraint for RHIC vacuum vessels

F. Micolon, S. Seberg – May 2023

Version	Date	Modification
0.3	8/10/2023	Corrections following review from Scott
1.0	9/6/2023	Initial release

1. Introduction

In preparation for the rework of a RHIC Siberian snake for EIC, a DU7 cold section is being refurbished to replace the snake magnet before the RHIC run 25. There is a need to check the vacuum vessel leak tightness before tunnel installation, however the vacuum vessel original restraints have been removed. So there is a need to design a new removable bellow restraint for this vacuum testing.

This report details the design and analysis done to ensure the safe operation of this bellow restraint.

2. System integration

The vacuum vessel bellow is a thin stainless-steel sheet hydroformed to make the convolutions that gives its flexibility. The design is described in drawing 12100014.

On the DU7, two stainless ¾" nuts have been welded on each side of the bellow at about 13" distance. Each bellow has three pair of nuts at about 120° distance.

Figure 1 Bellow nut restraint installation

When under vacuum, if unrestrained, the bellow would shrink and yield beyond repair. The restraint will keep the bellow in its original form and prevent any damage to it.

3. Vacuum force evaluation

The drawing 12100014 gives an outer diameter for the bellow of Φ26" +/- 1,3". Conservatively assuming the bellow is at its maximum allowed diameter (Φ27.3") :

$$F = P.S = 0{,}1\ [MPa] * \pi.\left(\frac{27{,}3}{2}.25{,}4\right)^2\ [mm^2] = 37{,}8\ kN$$

There is 3x rods around the profile. So the maximum force expected per rod is $12{,}6\ kN$

4. Restraint design

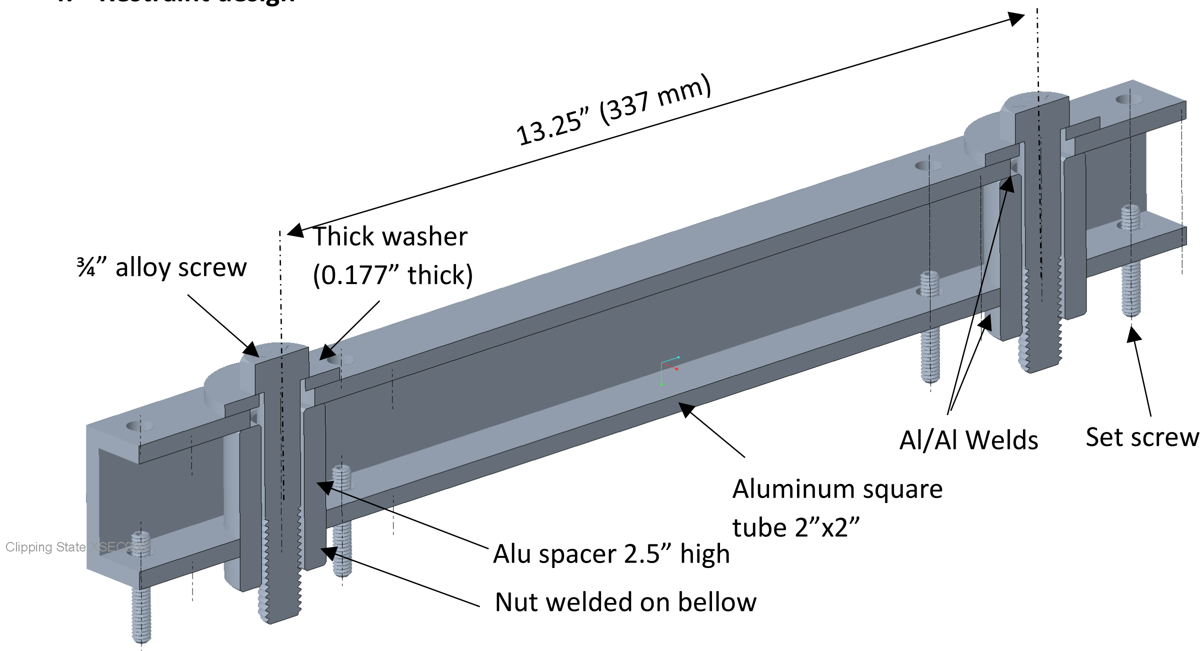

Figure 2 CAD model of the restraint design

The vacuum force will be shearing/bending the bolted assembly. If the friction is sufficient within the bolted stack, the shear will mostly be resisted by the aluminum spacer and welded nut.

Set screws have been placed on each side of the bolt to limit the tube bending. They will run through the aluminum wall thickness and have a counter nut to secure them. Limiting the tube ability to bend is important to avoid any sideways buckling of the entire vacuum vessel bellow and end cap.

5. Restraint analysis

Areas of concern for this design are the buckling of the aluminum tube itself and stresses in the bolted assembly.

a. Buckling of the restraint

We have used a simple Euler force analysis, with a minimum safety factor of 10x to account for any manufacturing tolerance and initial beam bending under load.

$$F_{crit} = \frac{\pi^2 . E . I}{(K . L)^2}\ (Euler\ force)$$

We have conservatively assumed the beam to be free to yaw at its extremities (sideways rotations will only be limited by the bolt friction) so K=1. The moment of inertia of a 2" square pipe with 0.25" wall thickness is 0.91 in^4 (~379 000 mm^4).

$$F_{crit} = \frac{\pi^2.70\,000.379\,000}{(1.337)^2} = 2\,305\;kN$$

The safety factor wrt to buckling if >180. This is sufficient.

b. Stress analysis

A FEM analysis has been made using ANSYS.

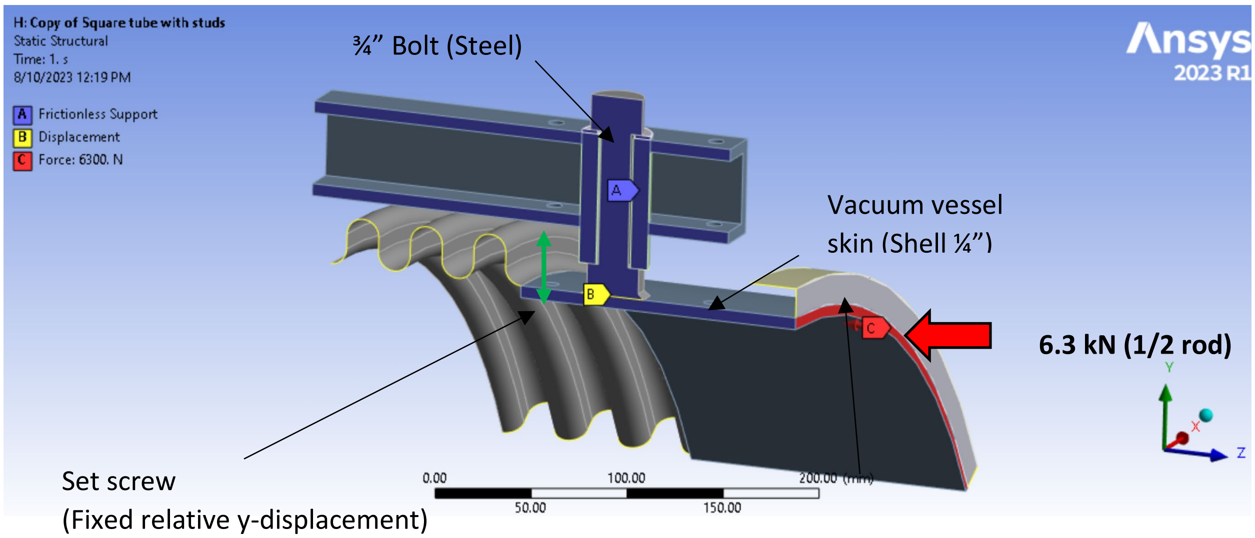

Figure 3 Overview of the ANSYS FEM model

All contacts are bonded. The nut weld is represented by 5 mm chamfer in contact bonded contact with the vacuum vessel skin. *Note: the current welding pattern includes only welding on the side of the nut (4 sides). It is recommended to weld all six sides of the nut to avoid prying it out.*

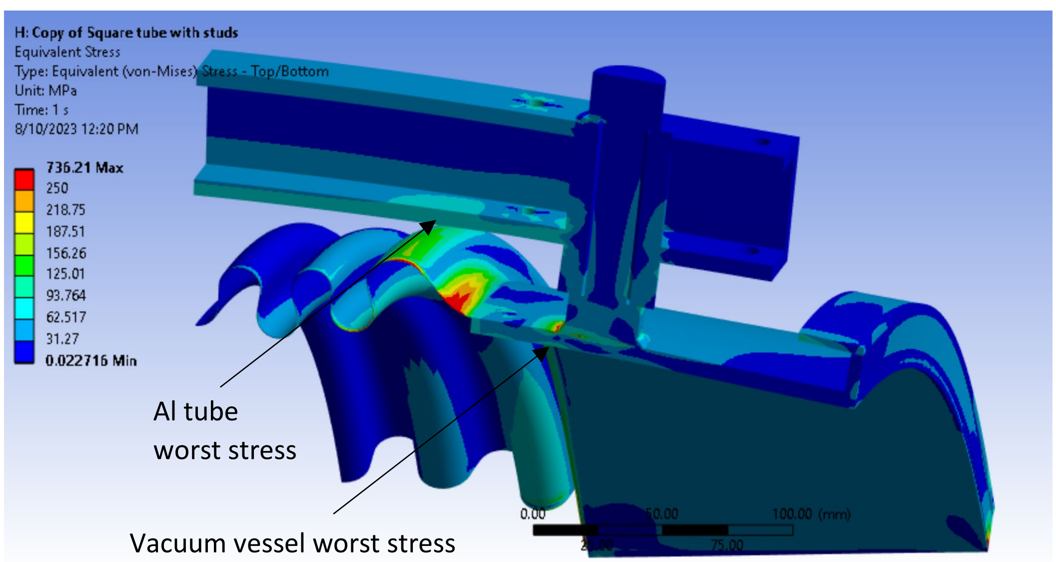

Figure 4 Resulting Von Mises stress in the assembly with sliding contact

Table 1 represents the maximum stress found in the part mentioned and the reference yields strength.

Table 1 - Stress status away from the stress discontinuity

Part	Vacuum vessel skin	Bolt	Aluminum tube
Von Mises stress (MPa)	129	76	74
Yield strength (MPa)	300	1034	241
Safety factor	**2.3**	**13**	**3.26**

Note: assuming a friction coefficient of 0.2, the bolt needs to be tightened of to $\frac{12\,600}{0.2} = 63\ kN$ *to avoid sliding in the bolted assembly. With a ¾ " bolt this corresponds to a tightening torque around 200 N.m (1770 lbf/in – 148 lbf/ft) with a greased bolt. The tensile stress in the bolt will then be ~291 MPa tensile.*

The thread insertion length with the stack-up described in Fig. 2 is 0.51". Even assuming a low strength stainless steel nut (Tensile strength = 700 MPa), no thread shear is expected at this level of force (safety factor 4x).

With a good ¾"bolt tightening and with the benefit of the set screws that will prevent bending, this assembly is expected to behave safely during vacuum testing of the vacuum vessel.

6. Summary

The design of a vacuum restraint for the RHIC vacuum vessel bellows has been described. With the following measures it is considered that the vacuum test of the RHIC vacuum vessels can be conducted safely with three of these rods around the perimeter:

- Use of a grade 8 (or above) ¾" screws. Good tightening torque of the screw to limit bolt shearing (Torque ~200 N.m-148 lbf/ft with greased bolt).
- Continuous welding of the nut all around its perimeter on the vacuum vessel skin
- Use of set screws to prevent excessive tube bending (to be tightened after the main bolt is tightened to torque)

Reference for procurement

Aluminum tube – *Multipurpose 6061 Aluminum Rectangular Tube 1/4" Wall Thickness, 2" High x 2" Wide - McMaster 6546K27*
Bolts – Zinc Yellow-Chromate Plated Hex Head Screw, Grade 8 Steel, 3/4"-10 Thread, 3-1/2" Long, Partially Threaded - McMaster 91257A849