Project

Solenoidal Tracker at RHIC (STAR)

Subproject

Time Projection Chamber - Wheel and Supports

Title

Selection of TPC Support Arm Bolts

Introduction

The TPC is supported by the magnet through a set of four support arms (TPC513-E). Each arm is attached to the Magnet Inner End Ring (MAG340E) by 8 bolts. The connection between the arm and the TPC is via a vertical post which rests on a pair of spherical washers. The pins transmit a vertical force but do not introduce a moment due to the sag of the arm as the TPC's weight is applied. The following note is a recalculation of the bolt stress and material selection with the known 25,000 lb. weight of the TPC. The basis of the original calculations, contained in STAR Note 0117, was an assumed TPC weight of 34,000 lb. For hole pattern and bolt size selection refer to STAR Note 0117.

Force per arm: $F := \frac{25000}{4}$

Bolt Pattern

The following matrix, L, is the x and y positions of the screws with respect a datum axis centered on the hole pattern. The xy plane represents an idealized, flat mounting surface with x horizontal, y vertical and z normal to the mounting surface. This coordinate system should not be confused with the global STAR coordinates system. It should also be noted that the arm mounts on the inner bore of the Inner Magnet End Ring, a curved surface.

$$L := \begin{bmatrix} -2.5 & 6.9 \\ -2.5 & 2.3 \\ -2.5 & -2.3 \\ -2.5 & -6.9 \\ 2.5 & 6.9 \\ 2.5 & 2.3 \\ 2.5 & -2.3 \\ 2.5 & -6.9 \end{bmatrix}$$

The centroid of the bolt pattern is, by symmetry the datum axis origin.

$cg_0 := 0$ $cg_1 := 0$

The distance from each screw to the centoid in the xy plane is determined from the following:

$i := 0, 1 .. 7$

$x_i := L_{(i,0)} - cg_0 \qquad y_i := L_{(i,1)} - cg_1$

$D_i := \sqrt{(x_i)^2 + (y_i)^2}$

$\alpha_i := \operatorname{atan}\left(\frac{x_i}{|y_i|}\right)$

$Dsqr := \overrightarrow{\Sigma D^2}$

i	D_i	x_i	y_i	α_i
0	7.339	-2.5	6.9	-0.348
1	3.397	-2.5	2.3	-0.827
2	3.397	-2.5	-2.3	-0.827
3	7.339	-2.5	-6.9	-0.348
4	7.339	2.5	6.9	0.348
5	3.397	2.5	2.3	0.827
6	3.397	2.5	-2.3	0.827
7	7.339	2.5	-6.9	0.348

Shear Force on Screws

The horizontal distance from the applied force to the datum axis is Df.

$Df := (134.72 - 6.85) - 98.646$

The horizontal offset between the applied force and the bolt pattern centroid results in an applied moment about the z-direction.

$M_z := F \cdot (cg_0 - Df)$

The applied torque can be related to the force on each screw (in the xy plane), by the following relation:

$j := 0, 1 .. 7 \qquad Ft_j := \frac{M_z \cdot D_j}{Dsqr}$

Ft_j
$-5.124 \cdot 10^3$
$-2.372 \cdot 10^3$
$-2.372 \cdot 10^3$
$-5.124 \cdot 10^3$
$-5.124 \cdot 10^3$
$-2.372 \cdot 10^3$
$-2.372 \cdot 10^3$
$-5.124 \cdot 10^3$

The bolts must also transmit the vertical reaction forces from the TPC weight. Assuming the force is evenly distributed among the 8 bolts gives.

The vertical force/bolt: $Fs := \frac{F}{8}$

The applied forces can be resolved into x and y components and algebraically summed to give a shear force on each screw, Frj.

$$Fr_j := \sqrt{\left(Ft_j \cdot \cos\left(\alpha_j\right)\right)^2 + \left(Ft_j \cdot \sin\left(\alpha_j\right) + Fs\right)^2}$$

Fr_j
$5.44 \cdot 10^3$
$2.994 \cdot 10^3$
$2.994 \cdot 10^3$
$5.44 \cdot 10^3$
$4.913 \cdot 10^3$
$1.873 \cdot 10^3$
$1.873 \cdot 10^3$
$4.913 \cdot 10^3$

Axial Force Due to Prying Action

Assuming that the arm region near the bolts acts as a rigid member and the pivot or fulcrum corresponds to a horizontal line through the lower edge of the arm mounting surface. The moment generated by the force being at a distance Dz from the surface of the wheel is resisted by the screws. The force on these screws is proportional to their distance from the fulcrum. If Yp is the vertical distance from the screw to the fulcrum Fai/Ypi is a constant and:

$$Yp := \begin{bmatrix} 3.0 \\ 3.0 \\ 7.6 \\ 7.6 \\ 12.2 \\ 12.2 \\ 16.8 \\ 16.8 \end{bmatrix}$$

The distance in the z-direction from the centroid to the applied force is:

$$D_z := 103.75 - 78.5$$

$$i := 0, 1 .. 7$$

$$Fa_i := \frac{F \cdot D_z \cdot Yp_i}{\overrightarrow{\Sigma Yp^2}}$$

$$Fa = \begin{bmatrix} 475.492 \\ 475.492 \\ 1.205 \cdot 10^3 \\ 1.205 \cdot 10^3 \\ 1.934 \cdot 10^3 \\ 1.934 \cdot 10^3 \\ 2.663 \cdot 10^3 \\ 2.663 \cdot 10^3 \end{bmatrix}$$

Bolt Stresses

The arm mounting screws are 1-1/4 - 7 UNC socket head cap screws made from a non-magnetic material.

Stress area for a 1-1/4 UNC screw, $A := .9684$

Shear stress on each bolt in the pattern. $Tau_i := \frac{Fr_i}{A}$

Axial stress on each bolt in the pattern. $Sigma_i := \frac{Fa_i}{A}$

Combined stress, von Mises yield criterion using stress component wrt. non-principal axes and eliminating all but non-zero terms:

$$Seq_i := \sqrt{(Sigma_i)^2 + 3 \cdot (Tau_i)^2}$$

$$Seq = \begin{bmatrix} 9.742 \cdot 10^3 \\ 5.377 \cdot 10^3 \\ 5.497 \cdot 10^3 \\ 9.809 \cdot 10^3 \\ 9.012 \cdot 10^3 \\ 3.9 \cdot 10^3 \\ 4.334 \cdot 10^3 \\ 9.208 \cdot 10^3 \end{bmatrix}$$

Yield and tensile stress of common non-magnetic fasteners.

Al 2024-T4 socket head cap screw - Y.S. 40,000, T.S. 67,000 psi
SS 316 socket head cap screw - Y.S. 40,000, T.S. 80,000 psi

Safety Factor (based on yield)

$$Sy := 40000$$

$$SF_i := \frac{Sy}{Seq_i}$$

$$SF = \begin{bmatrix} 4.106 \\ 7.439 \\ 7.276 \\ 4.078 \\ 4.439 \\ 10.256 \\ 9.229 \\ 4.344 \end{bmatrix}$$

Conclusion

The design of the TPC support arm incorporates a sufficient number and distribution of 1 -1/4" bolts. The use of 316 stainless steel for the bolt material assures that a safety factor of 4 is maintained under full loading conditions.