Electron Positron Proton Spectrometer for use at Laboratory for Laser Energetics

S. L. Ayers

April 13, 2010
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Engineering Directorate Safety Note

Electron Positron Proton Spectrometer
for use at LLE
EDSN10-000004-AA

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Section A – Scope and Equipment (or System) Description

The Electron Positron Proton Spectrometer (EPPS) is mounted in a TIM (Ten-Inch Manipulator) system on the Omega-60 or Omega-EP laser facilities at the University of Rochester, Laboratory for Laser Energetics (LLE), when in use, see Fig. 1. The Spectrometer assembly, shown in Fig. 2, is constructed of a steel box containing magnets, surrounded by Lead 6% Antimony shielding with SS threaded insert, sitting on an Aluminum 6061-T6 plate.

Fig. 1. The EPPS with TIM interface  
Fig. 2. The EPPS assembly

To meet LLE TIM moment loading requirements, a counter-weight is added when the diagnostic is mounted in the TIM, see Fig. 3. For moving the diagnostic a two person lifting handle is used, see Fig. 4.

Fig. 3. The EPPS with counter weight and pointer, mount in TIM Boat  
Fig. 4. The EPPS with TIM interface and lifting handle
Section B – Operational Hazards

Failure of the EPPS device or device mechanical support components could cause injury to personnel, damage to equipment, and may have significant impact on programmatic schedule and cost.

There are no electrical hazards in the EPPS device.

Section C – Operational Procedure

Use of the EPPS at LLE is governed by LLE procedure D-TX-P-016.

Section D – Design Calculations

The analyses of the EPPS as compiled in this safety note can be split up into the following subsystems: The TIM Interface, the EPPS and TIM Mounting Interface, and the EPP Spectrometer Assembly.

Each of these subsystems contains numerous load path elements as enumerated in Fig. 5 and Table 1.

Fig. 5a. EPPS Load Path elements. Fig. 5b. EPPS Load Path elements, sectioned side view of spectrometer.
Table 1: Load path elements.

<table>
<thead>
<tr>
<th>Load Path</th>
<th>Description</th>
<th>Fasteners</th>
<th>App.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TIM Mounting Rail (Left mounting rail, TIM mounting) to TIM Boat</td>
<td>Fourteen 10-32 SS</td>
<td>App.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fasteners</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>TIM Mounting Rail to TIM Mounting Frame (Arm, TIM mounting)</td>
<td>Twelve 10-32 SS</td>
<td>App.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fasteners</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>TIM Mounting Frame (Arm, TIM mounting) to Support Plate (Support plate – TIM</td>
<td>Six 10-32 SS</td>
<td>App.</td>
</tr>
<tr>
<td></td>
<td>mounting)</td>
<td>fasteners</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Support Plate (Support plate – TIM mounting) to Side Plate</td>
<td>Four 10-32 SS</td>
<td>App.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fasteners</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hoist Ring to Lifting Bracket</td>
<td>One ½”-13 fastener</td>
<td>App.</td>
</tr>
<tr>
<td>6</td>
<td>Lifting Bracket to Side Plate</td>
<td>Four 10-32 SS</td>
<td>App.</td>
</tr>
<tr>
<td>7</td>
<td>Lifting Handle to Lifting Bracket</td>
<td>Two 3/8”-16 SS</td>
<td>App.</td>
</tr>
</tbody>
</table>

The TIM boat structure is outside of the scope of this safety note. This safety note includes everything from the mounting to the TIM boat to the spectrometer.

The following table lists the factors of safety for each load path item:

Table 2: Factors of safety for the EPPS.

<table>
<thead>
<tr>
<th>Configurations</th>
<th>Stress (ksi)</th>
<th>Yield Stress (ksi)</th>
<th>Ultimate Stress (ksi)</th>
<th>Safety Factor (yield)</th>
<th>Safety Factor (Ult)</th>
<th>Required Safety Factor*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 TIM Rail/ TIM Boat Bolt Stress, von Mises</td>
<td>1.16</td>
<td>30.0</td>
<td>25.9</td>
<td>3 SY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2 TIM Rail/ TIM Boat Tapped Holes, Shear</td>
<td>5.01</td>
<td>20.2</td>
<td>4.0</td>
<td>3 SY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1a TIM Rail/ TIM Boat Bolt Stress, von Mises</td>
<td>1.41</td>
<td>30.0</td>
<td>21.3</td>
<td>1 SSY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 TIM Frame/ TIM Rail Bolt Stress, von Mises</td>
<td>2.29</td>
<td>30.0</td>
<td>13.1</td>
<td>3 SY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2 TIM Frame/ TIM Rail Tapped Holes, Shear</td>
<td>3.56</td>
<td>20.2</td>
<td>5.7</td>
<td>3 SY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1a TIM Frame/ TIM Rail Bolt Stress, von Mises</td>
<td>3.07</td>
<td>30.0</td>
<td>9.8</td>
<td>1 SSY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1 TIM Frame/ Support Plate Bolt Stress, von Mises</td>
<td>0.72</td>
<td>30.0</td>
<td>41.9</td>
<td>3 SY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2 TIM Frame/ Support Plate Tapped Holes, Shear</td>
<td>2.86</td>
<td>20.2</td>
<td>7.1</td>
<td>3 SY</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Configurations</th>
<th>Stress (ksi)</th>
<th>Yield Stress (ksi)</th>
<th>Ultimate Stress (ksi)</th>
<th>Safety Factor (yield)</th>
<th>Safety Factor (Ult)</th>
<th>Required Safety Factor*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1a TIM Frame/ Support Plate Bolt Stress, von Mises</td>
<td>1.60</td>
<td>30.0</td>
<td>18.7</td>
<td>1</td>
<td>SSY</td>
<td>1</td>
</tr>
<tr>
<td>4.2 TIM Plate/ Side Plate Tapped Holes, Shear</td>
<td>5.71</td>
<td>20.8</td>
<td>3.6</td>
<td>3</td>
<td>SY</td>
<td></td>
</tr>
<tr>
<td>4.1a TIM Plate/ Side Plate Bolt Stress, von Mises</td>
<td>1.33</td>
<td>30.0</td>
<td>22.5</td>
<td>1</td>
<td>SSY</td>
<td></td>
</tr>
<tr>
<td>5.1 Hoist Ring/ Lifting Bracket Tapped Holes, Shear</td>
<td>4.21</td>
<td>20.2</td>
<td>4.1</td>
<td>6</td>
<td>SY</td>
<td></td>
</tr>
<tr>
<td>5.1 Hoist Ring/ Lifting Bracket Tapped Holes, Shear</td>
<td>4.21</td>
<td>43.3</td>
<td>10.3</td>
<td>8</td>
<td>SU</td>
<td></td>
</tr>
<tr>
<td>6.1 Lifting Bracket/ Side Plate Bolt Stress, von Mises</td>
<td>1.07</td>
<td>30.0</td>
<td>27.9</td>
<td>3</td>
<td>SY</td>
<td></td>
</tr>
<tr>
<td>6.2 Lifting Bracket/ Side Plate Tapped Holes, Shear</td>
<td>5.71</td>
<td>20.8</td>
<td>3.6</td>
<td>3</td>
<td>SY</td>
<td></td>
</tr>
<tr>
<td>7.1 Lifting Handle/ Lifting Plate Bolt Stress, von Mises</td>
<td>7.39</td>
<td>30.0</td>
<td>4.1</td>
<td>3</td>
<td>SY</td>
<td></td>
</tr>
<tr>
<td>7.2 Lifting Handle/ Lifting Plate Tapped Holes, Shear</td>
<td>4.50</td>
<td>17.3</td>
<td>3.8</td>
<td>3</td>
<td>SY</td>
<td></td>
</tr>
</tbody>
</table>

* SY=Static Yield, SU=Static Ultimate, SSY=Static+Seismic Yield, SSU=Static+Seismic Ultimate
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1) The mounting rails are connected to the TIM boat (the TIM boat is LLE equipment) using 14 10-32 stainless steel fasteners and helicoil inserts. The fasteners will be analyzed under both static and seismic loading conditions. The two horizontal and one vertical seismic forces will be assumed to occur simultaneously, acting through the center of gravity of the equipment, and will be combined to calculate seismic response values. Conservatively, only two of the fasteners will be used in the calculations. No information is known about the inserts in the TIM Boat, therefore the thread shear will be calculated based on a 10-32 thread directly into aluminum (building additional conservatism into the calculations).

2) The mounting rails are connected to the TIM mounting frame using 12 10-32 stainless steel fasteners and helicoil inserts. The fasteners will be analyzed under both static and seismic loading conditions. The two horizontal and one vertical seismic forces will be assumed to occur simultaneously, acting through the center of gravity of the equipment, and will be combined to calculate seismic response values. Conservatively, only two of the fasteners will be used in the calculations.

3) The EPPS assembly is mounted to the Support plate, which is connected to the TIM mounting frame, using six 10-32 fasteners. The fasteners are assembled through the TIM mounting plate and threaded into the TIM mounting frame. The two horizontal and one vertical seismic forces will be assumed to occur simultaneously, acting through the center of gravity of the equipment, and will be combined to calculate seismic response values. Conservatively, only two fasteners are used for tension calculations.

4) The EPPS is secured to the aluminum Support plate, using four 10-32 fasteners. The fasteners are assembled through the support plate, through the lead shield and threaded into the steel side plate. The two horizontal and one vertical seismic forces will be assumed to occur simultaneously, acting through the center of gravity of the equipment, and will be combined to calculate seismic response values.

5) The EPP Spectrometer assembly is lifted by a single hoist ring threaded into a 304SS lifting bracket.

6) The lifting bracket is mounted to the EPPS, using four 10-32 fasteners. The fasteners are assembled through lifting bracket, through the lead shield and threaded into the steel side plate. The two horizontal and one vertical seismic forces will be assumed to occur simultaneously, acting through the center of gravity of the equipment, and will be combined to calculate seismic response values. Conservatively, only two fasteners are used for tension calculations.

7) The EPP Spectrometer assembly is lifted by two people, using an aluminum handle. The handle is mounted to the stainless steel lifting bracket using two 3/8”-16 fasteners.
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The following table lists the torque value for each fastener:

Table 3: Torque values for the EPPS.

<table>
<thead>
<tr>
<th>Item #</th>
<th>Screw Size</th>
<th>Minimum Length of Thread Engagement</th>
<th>Female Threads</th>
<th>Recommended Torque (in-lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10-32</td>
<td>0.29”</td>
<td>Al 6061-T6 w/ SS Helicoil Inserts</td>
<td>13.5</td>
</tr>
<tr>
<td>2</td>
<td>10-32</td>
<td>0.29”</td>
<td>Al 6061-T6 w/ SS Helicoil Inserts</td>
<td>13.5</td>
</tr>
<tr>
<td>3</td>
<td>10-32</td>
<td>0.29”</td>
<td>Al 6061-T6</td>
<td>13.5</td>
</tr>
<tr>
<td>4</td>
<td>10-32</td>
<td>0.29”</td>
<td>A36 Steel</td>
<td>13.5</td>
</tr>
<tr>
<td>6</td>
<td>10-32</td>
<td>0.29”</td>
<td>A36 Steel</td>
<td>13.5</td>
</tr>
<tr>
<td>7</td>
<td>3/8-16</td>
<td>0.625”</td>
<td>304 SS</td>
<td>103.5</td>
</tr>
</tbody>
</table>

Section E - Testing Requirements

No Testing Requirements.

Section F – Labeling Requirements

The equipment needs to be labeled per the requirement in LLE Seismic Criteria NIF-0116027-AC, with the EDSN number “EDSN10-000004”. If labeling is not possible, the equipment must be bagged and tagged with the EDSN number “EDSN10-000004”.

The equipment needs to be labeled per the requirement in LLE Seismic Criteria NIF-0116027-AC, “For Use at LLE Only”. If labeling is not possible, the equipment must be bagged and tagged with the message “For Use at LLE Only”.

Section G – Associated Procedures

None

Section H – References


Appendix A – Calculations

System Weight & CG:

\[ W_{\text{spect}} = 851.6 \text{ lb} \]

\[ CG_{\text{spect}} = 8.727 \text{ in} \]

Weight of Spectrometer Assembly ( Obtained from M. Saculla CAD Model 9/31/10)

from the Tooling Balls: CG = 38 125° from the last set of rollers on TIM (Obtained from M. Saculla CAD Model 9/31/10)

Material Properties:

\[ \sigma_{y, \text{Al6061T6}} = 35000 \text{ psi} \]

Yield strength of Aluminum 6060-T6

\[ \sigma_{y, \text{SS bolt}} = 30000 \text{ psi} \]

Yield strength of SS bolt

\[ \sigma_{u, \text{SS bolt}} = 80000 \text{ psi} \]

Ultimate strength of SS bolt

\[ \sigma_{y, \text{Lead Ant}} = 41100 \text{ psi} \]

Yield strength of Lead-9% Antimony

\[ \sigma_{y, \text{Hvsmet}} = 90000 \text{ psi} \]

Yield strength of Heavy Metal, 17.5 g/m² from Rambar

\[ \sigma_{y, \text{304SS}} = 300000 \text{ psi} \]

Yield strength of 304 Stainless Steel

\[ \sigma_{u, \text{304SS}} = 750000 \text{ psi} \]

Ultimate strength of 304 Stainless Steel

\[ \sigma_{y, \text{Al6}} = 36000 \text{ psi} \]

Ultimate strength of A36 Steel

Seismic:

\[ Z = 0.15 \]

\[ C_p = 2 \]

Elevated equipment

\[ S_{D_h} = Z \cdot C_p = 0.3 \]

Horizontal Seismic Demand

\[ S_{D_v} = ( \frac{2}{3} ) \cdot Z \cdot C_p = 0.2 \]

Vertical Seismic Demand

\[ S_{D_z} = S_{D_h} = 0.3 \]

\[ S_{D_v} = S_{D_v} = 0.2 \]

\[ S_{D_z} = S_{D_h} = 0.3 \]

Axis used for seismic calculations
1. TIM Mounting Rail (Left mounting rail - TIM mounting) to TIM Beat

Given:

\[ W_{f} = W_{spect} = 85 \text{ lbf} \]

\[ CG_{t} = CG_{spect} = 0.625 \text{ in} = 8.102 \text{ in} \]

\[ d_{10} = 15 \text{ in} \]

\[ d_{19} = (3.770 + 0.75 + 0.54 + .54) \text{ in} = 7.75 \text{ in} \]

\[ n_{ul} = 2 \]

\[ n_{totl} = 14 \]

dead weight of Spectrometer Assembly

CG of Spectrometer Assembly

Distance between fasteners (x-direction)

Distance between fasteners (z-direction)

Number of fasteners used for tension only

Total number of fasteners
1.1 10-32 Fasteners:

\[ D_{m1} = 0.19 \text{ in} \]
\[ TPI_1 = \frac{32}{\text{ in}} \]
\[ D_{m1} = D_{n1} - \frac{1}{TPI_1} = 0.159 \text{ in} \]
\[ A_{m1} = \frac{\pi (D_{m1})^2}{4} = 0.02 \text{ in}^2 \]
\[ T_1 = \frac{W_1 \cdot CG_1}{d_1 c_1^n_1} = 22.956 \text{ lbf} \]
\[ \sigma_1 = \frac{T_1}{A_{m1}} = 1.16 \times 10^3 \text{ psi} \]
\[ \sigma_{\text{allow bolt}} = \sigma_{y, SS, bolt} = 3 \times 10^5 \text{ psi} \]
\[ SF_1 = \frac{\sigma_{\text{allow bolt}}}{\sigma_1} = 25.857 \]

1.1a Seismic Analysis:

\[ SD_{x1} = SD_{H} \cdot W_1 = 25.5 \text{ lbf} \]
\[ SD_{y1} = SD_{V} \cdot W_1 = 17 \text{ lbf} \]
\[ SD_{z1} = SD_{R} \cdot W_1 = 25.5 \text{ lbf} \]

X-Dir:
\[ \tau_{1SDx} = \frac{SD_{x1}}{n_{rot1} A_{m1}} = 92.023 \text{ psi} \]

Y-Dir:
\[ T_{1SDy} = \left( \frac{W_1 + SD_{y1}}{d_1 c_1^n_1} \cdot CG_1 \right) = 27.547 \text{ lbf} \]
\[ \sigma_{1SDy} = \frac{T_{1SDy}}{A_{m1}} = 1.392 \times 10^3 \text{ psi} \]

Z-Dir:
\[ \tau_{1SDz} = \frac{SD_{z1}}{n_{rot1} A_{m1}} = 92.023 \text{ psi} \]
\[ \sigma_{1SD} = \sigma_{1SDy} = 1.392 \times 10^3 \text{ psi} \]
\[ \tau_{1SD} = \sqrt{\tau_{1SDx}^2 + \tau_{1SDz}^2} = 130.14 \text{ psi} \]
### 1.2 Thread Shear in the Tapped Holes:

\[
\sigma_{\text{yield}} = \sigma_{\text{y, Al6061T6}} = 3.5 \times 10^4 \text{ psi}
\]

\[
D_{m1} = 0.159 \text{-in}
\]

\[
L_1 := 1.5D_{m1} = 0.285 \text{-in}
\]

\[
A_1 := \frac{\pi D_{m1}^2 L_1}{2} = 0.071 \text{-in}^2
\]

\[
\tau_{\text{thread}} := \frac{T_1}{A_1} = 323.007 \text{-psi}
\]

\[
F_{\text{preload}} := 0.6\sigma_{\text{allow,bolt}} \left( \frac{\pi D_{m1}^2}{4} \right) = 356.279 \text{-lbf}
\]

\[
\tau_{\text{preload}} := \frac{F_{\text{preload}}}{A_1} = 5013.16 \text{-psi}
\]

\[
\tau_{\text{max,thread}} := \begin{cases} 
\tau_{\text{preload}} \text{ if } \tau_{\text{preload}} > \tau_{\text{thread}} \\
\tau_{\text{thread}} \text{ otherwise}
\end{cases}
\]

\[
SF_{\text{thread}} := \frac{\sigma_{\text{yield}}}{\sqrt[3]{\tau_{\text{max,thread}}}} = 4.031
\]

#### 1.2.1 Seismic Analysis:

**Y-Cir:**

\[
\tau_{\text{thread ISDy}} := \frac{\sigma_{\text{ISDy}}}{A_1} = 387.608 \text{-psi}
\]

\[
\tau_{\text{thread ISD}} := \tau_{\text{thread ISDy}} = 387.608 \text{-psi}
\]

\[
SF_{\text{thread ISD}} := \frac{\sigma_{\text{yield}}}{\sqrt[3]{\tau_{\text{thread ISD}}}} = 52.133
\]
<table>
<thead>
<tr>
<th>1.3 Recommended Torque:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{\text{bolt _ yield}} := 0_{\text{allow _ bolt}} \cdot A_{n1} = 593.798\text{-lbf}$</td>
<td>Maximum force allowed on SS bolt</td>
</tr>
<tr>
<td>$F_{\text{thread _ yield}} := \frac{\gamma_{\text{yield}}}{\sqrt{3}} \cdot A_{n1} = 1.436 \times 10^3\text{-lbf}$</td>
<td>Maximum force allowed on female threads</td>
</tr>
<tr>
<td>$F_{\text{max _ torque}} := \begin{cases} F_{\text{bolt _ yield}} &amp; \text{if } F_{\text{thread _ yield}} &gt; F_{\text{bolt _ yield}} \ F_{\text{thread _ yield}} &amp; \text{otherwise} \end{cases}$</td>
<td>Maximum force allowed on Bolt / Female Threads</td>
</tr>
<tr>
<td>$K_1 := 0.20$</td>
<td>Friction factor for threads, per EDSN table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Stainless Steel, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)</td>
</tr>
<tr>
<td>$T_{1.3} := K_1 \cdot D_{n1} \cdot F_{\text{max _ torque}} \cdot (0.6) = 13.539\text{-in_lbf}$</td>
<td>Recommended torque for bolt (60% of material yield strength used, per EDSN section 1.2). The TIM Boat has SS threaded inserts, therefore the bolt will actually yield first.</td>
</tr>
</tbody>
</table>
Title  Electron Positron Proton Spectrometer

2. TIM Mounting Rail (Left mounting rail, TIM mounting) to TIM Mounting Frame (Arm, TIM mounting)

Given:
\[ W_2 = W_{spect} = 85 \text{ lbf} \]
\[ C_{G2} = C_{G_{spect}} = 0.625 \text{ in} = 8.102 \text{ in} \]
\[ d_{2x} = 13.125 \text{ in} \]
\[ d_{2z} = (5.170 + 75 + 75) = 6.67 \text{ in} \]
\[ n_{12} = 2 \]
\[ n_{tot2} = 12 \]

- Dead weight of Spectrometer Assembly
- CG of Spectrometer Assembly
- Distance between fasteners (x-direction)
- Distance between fasteners (z-direction)
- Number of fasteners used for shear, due to moment loading
- Total number of fasteners
Title  Electron Positron Proton Spectrometer

2.1.10-32 Fasteners:

\[ D_{m2} = 0.19\text{ in} \]

\[ T_{l2} = \frac{32}{\text{in}} \]

\[ D_{m2} = D_{m2} - \frac{1}{T_{l2}} = 0.159\text{ in} \]

\[ A_{m2} = \frac{\pi (D_{m2})^2}{4} = 0.022\text{ in}^2 \]

\[ V_2 = \frac{W_2 - C_{G2}}{d_2 c_{m2}} = 26.235\text{ lbf} \]

\[ \tau_2 = \frac{V_2}{A_{m2}} = 1325 \times 10^3\text{ psi} \]

\[ \sigma_{vm2} = \frac{3}{2} \left( \tau_2 \right)^2 = 2296 \times 10^3\text{ psi} \]

\[ \sigma_{y, SS, bolt} = 3 \times 10^4\text{ psi} \]

\[ SF_2 = \frac{\sigma_{allow, bolt}}{\sigma_{vm2}} = 13.668 \]

2.1a Seismic Analysis:

\[ SD_{x2} = SD_{x, W2} = 25.5\text{ lbf} \]

\[ SD_{y2} = SD_{y, W2} = 17\text{ lbf} \]

\[ SD_{z2} = SD_{z, W2} = 25.5\text{ lbf} \]

X-Dir:

\[ \tau_{2SDx} = \frac{SD_{x2}}{n_{102} A_{m2}} = 167.36\text{ psi} \]

\[ \sigma_{vm2SDx} = \frac{3}{2} \left( \tau_{2SDx} \right)^2 = 185.953\text{ psi} \]

Y-Dir:

\[ V_{2SDy} = \frac{(W_2 + SD_{y2}) C_{G2}}{d_2 c_{m2}} = 31.482\text{ lbf} \]

\[ \tau_{2SDy} = \frac{V_{2SDy}}{A_{m2}} = 1591 \times 10^3\text{ psi} \]

\[ \sigma_{vm2SDy} = \frac{3}{2} \left( \tau_{2SDy} \right)^2 = 2755 \times 10^3\text{ psi} \]
Z-Dir:

$$T_{2SDz} = \frac{SD_{2\text{-}CG2}}{d_{2c}\left(\frac{n_{SD2}}{2}\right)} = 2.624 \text{-lbf}$$

Tensile force acting on fastener, including seismic

$$\sigma_{2SDz} = \frac{T_{2SDz}}{A_{n2}} = 132.545 \text{-psi}$$

Tensile stress in fastener, including seismic

$$\sigma_{vm2SDz} = \sqrt{\sigma_{2SDz}^2} = 132.545 \text{-psi}$$

Von Mises stresses in fastener, including seismic in the Z-direction

$$\sigma_{vm2SD} = \sigma_{vm2SDx} + \sigma_{vm2SDy} + \sigma_{vm2SDz} = 3.073 \times 10^3 \text{-psi}$$

Von Mises stresses in fastener, including seismic

$$SF_{2SD} = \frac{\sigma_{allow2bolt}}{\sigma_{vm2SD}} = 9.761$$

Seismic Factor of Safety for Fastener

### 2.2 Thread Shear in the Tapped Holes:

$$\sigma_{yield2.2} = \sigma_{y, Al6061T6} = 3.5 \times 10^4 \text{-psi}$$

Yield strength of Aluminum

$$D_m = 0.159 \text{-in}$$

Information on threaded inserts is unknown, assume no inserts (this is a conservative assumption)

$$L_e = 0.401 \text{-in}$$

Length of engagement

$$A_{s2} = \frac{\pi D_m^2 L_e}{2} = 0.1 \text{-in}^2$$

Shear area of female threads

$$\tau_{thread2} = 0 \text{-psi}$$

Shear stress in female threads

$$F_{preload2} = 0.6 \sigma_{allow2bolt} \left(\frac{\pi D_m^2}{4}\right) = 356.279 \text{-lbf}$$

Force due to preload torque

$$\tau_{preload2} = \frac{F_{preload2}}{A_{s2}} = 356.279 \text{-psi}$$

Shear stress in female threads, due to preload torque

$$\tau_{maxthread2} = \begin{cases} 
\tau_{preload2} & \text{if } \tau_{preload2} > \tau_{thread2} \\
\tau_{thread2} & \text{otherwise} 
\end{cases} = 356.279 \text{-psi}$$

Maximum shear stress in female threads

$$SF_{thread2} = \frac{\sigma_{yield2.2}}{\sqrt[3]{\tau_{maxthread2}}} = 5.671$$

Factor of Safety for Female Threads

### 2.2a Seismic Analysis:

Since bolt pre-load is the greater force on the female threads, no seismic analysis is necessary
2.3 Recommended Torque:

\[
F_{\text{bolt\_yield}2} := \frac{d_{\text{allow\_bolt}} \cdot A_{m2}}{2} = 593.798\text{-lbf}
\]

Maximum force allowed on SS bolt

\[
F_{\text{thread\_yield}2} := \frac{d_{\text{yield}2} A_{t2}}{\sqrt{3}} = 2.021 \times 10^3\text{-lbf}
\]

Maximum force allowed on female threads

\[
F_{\text{max\_torque}2} := \begin{cases} F_{\text{bolt\_yield}2} & \text{if } F_{\text{thread\_yield}2} > F_{\text{bolt\_yield}2} \\ F_{\text{thread\_yield}2} & \text{otherwise} \end{cases}
\]

Maximum force allowed on Bolt / Female Threads

\[
K_2 := 0.20
\]

Friction factor for threads, per EDSS table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Stainless Steel, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)

\[
T_{2.3} := K_2 \cdot D_2 \cdot F_{\text{max\_torque}2} \cdot (0.6) = 13.339\text{-in-lbf}
\]

Recommended torque for bolt (90% of material yield strength used, per EDSS section 1.2). The TIM Mounting Frame has SS threaded inserts, therefore the bolt will actually yield first.
3. TIM Mounting Frame (Arm, TIM mounting) to Support Plate (Support plate - TIM mounting)

Given:

\[ W_3 = W_{spect} = 85.1 \text{bf} \]

Dead weight of Spectrometer Assembly

\[ CG_2 = (1.75 + 102) \text{in} = 1.852 \text{ in} \]

CG of Spectrometer Assembly

\[ a_{2x} = 4 \text{in} \]

Distance between fasteners (x-direction)

\[ a_{2z} = (6.233 - 0.313) \text{in} = 5.92 \text{ in} \]

Distance between fasteners (z-direction)

\[ a_{1z} = 6 \]

Number of fasteners used for tension only

\[ a_{1w3} = 6 \]

Total number of fasteners
3.1 10-32 Fasteners:

\[ D_m3 := 0.19\text{in} \]

\[ T_{m3} := \frac{32}{\text{in}} \]

\[ D_{m3} := D_m3 - \frac{1}{T_{m3}} = 0.159\text{-in} \]

\[ A_{m3} := \frac{\pi (D_{m3})^2}{4} = 0.02\text{-in}^2 \]

\[ T_3 := \frac{W_4}{n_3} = 14.167\text{-lbf} \]

\[ \sigma_3 := \frac{T_3}{A_{m3}} = 715.732\text{-psi} \]

\[ \sigma_{vm3} := \sqrt{\frac{\sigma_3^2}{3}} = 715.732\text{-psi} \]

\[ \sigma_{allow3bolt} := \sigma_{y, SS, bolt} = 3 \times 10^4\text{-psi} \]

\[ SF_3 := \frac{\sigma_{allow3bolt}}{\sigma_{vm3}} = 41.915 \]

3.1a Seismic Analysis:

\[ SD_{x3} := SD_{x,W3} = 25.5\text{-lbf} \]

\[ SD_{y3} := SD_{y,W3} = 17\text{-lbf} \]

\[ SD_{e3} := SD_{e,W3} = 25.5\text{-lbf} \]

X-Dir:

\[ \tau_{3SDx} := \frac{SD_{x3}}{n_{03}A_{m3}} = 214.72\text{-psi} \]

\[ \sigma_{vm3SDx} := \sqrt{3 \tau_{3SDx}} = 371.905\text{-psi} \]

Y-Dir:

\[ T_{3SDy} := \frac{W_4 + SD_{y3}}{n_3} = 17\text{-lbf} \]

\[ \sigma_{3SDy} := \frac{T_{3SDy}}{A_{m3}} = 858.878\text{-psi} \]

\[ \sigma_{vm3SDy} := \sigma_{3SDy} = 858.878\text{-psi} \]
Z-Dir:

\[ \tau_{3SDz} = \frac{SDz_3}{n_{tot3}A_{m3}} = 214.72 \text{ psi} \]

Shear stress in fastener, including seismic

\[ \sigma_{vm3SDz} = \sqrt{3} \tau_{3SDz} = 371.505 \text{ psi} \]

Von Mises stresses in fastener, including seismic in the
Z-direction

\[ \sigma_{vm3SD} := \sigma_{vm3SDx} + \sigma_{vm3SDy} + \sigma_{vm3SDz} = 1.603 \times 10^3 \text{ psi} \quad \text{Von Mises stresses in fastener, including seismic} \]

\[ SF_{3SD} := \frac{\sigma_{allow3bolt}}{\sigma_{vm3SD}} = 18.719 \]

Seismic Factor of Safety for Fastener

3.2 Thread Shear in the Tapped Holes:

\[ \sigma_{yield3.2} := \sigma_{y,Al6061T6} = 3.5 \times 10^4 \text{ psi} \]

Yield strength of Aluminum

\[ D_m3 = 0.159 \text{ in} \]

Mean Diameter

\[ L_{e3} := 0.50 \text{ in} \]

Minimum Length of engagement

\[ A_{e3} := \frac{\pi D_m3^2 L_{e3}}{2} = 0.125 \text{ in}^2 \]

Shear area of female threads

\[ \tau_{thread3} := \frac{T_3}{A_{e3}} = 113.622 \text{ psi} \]

Shear stress in female threads

\[ F_{preload3} := 0.6 \sigma_{allow3bolt} \left( \frac{\pi D_{m3}^2}{4} \right) = 356.279 \text{ lbf} \]

Force due to preload torque

\[ \tau_{preload3} := \frac{F_{preload3}}{A_{e3}} = 2857.5 \text{ psi} \]

Shear stress in female threads, due to preload torque

\[ \tau_{maxthread3} := \begin{cases} \tau_{preload3} & \text{if } \tau_{preload3} > \tau_{thread3} \\ \tau_{thread3} & \text{otherwise} \end{cases} = 2857.5 \text{ psi} \quad \text{Maximum shear stress in female threads} \]

\[ SF_{thread3} := \frac{\sigma_{yield3.2}}{\sqrt{3} \sigma_{maxthread3}} = 7.072 \]

Factor of Safety for Female Threads

3.2a Seismic Analysis:

Since bolt pre-load is the greater force on the female threads, no seismic analysis is necessary
3.3 Recommended Torque:

\[ F_{\text{bolt\_yield}} = \sigma_{\text{allow\_bolt}} A_m = 593.798 \text{ lb} \]

\[ F_{\text{thread\_yield}} = \frac{\sigma_{\text{yield}} A_3}{\sqrt{3}} = 2.519 \times 10^3 \text{ lb} \]

\[ F_{\text{max\_torque}} = \begin{cases} F_{\text{bolt\_yield}} & \text{if } F_{\text{thread\_yield}} > F_{\text{bolt\_yield}} \\ F_{\text{thread\_yield}} & \text{otherwise} \end{cases} = 593.798 \text{ Maximum force allowed on Bolt / Female Threads} \]

\[ K_3 = 0.20 \]

Friction factor for threads, per EDSS table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Aluminum, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)

\[ T_{3.3} = K_3 D_{13} F_{\text{max\_torque}}^{0.6} = 13.539 \text{ in-lbf} \]

Recommended torque for bolt (60% of material yield strength used, per EDSS section 1.2)
4. Support Plate (Support plate - TIM mounting) to Side Plate

Given:

\[ W_4 = W_{polet} = 85 \text{ lbf} \]

CG \( d_{ax} = (1.75 + 1.00) \text{ in} = 2.85 \text{ in} \)

Distance between fasteners (x-direction)

\[ d_{az} = 2.55 \text{ in} \]

Distance between fasteners (z-direction)

\[ n_{ax} = 4 \]

Number of fasteners used for tension only

\[ n_{az} = 4 \]

Total number of fasteners
4.1 10-32 Fasteners:

\[ D_{m4} = 0.19\text{ in} \]

\[ TP_{f4} = \frac{32}{\text{in}} \]

\[ D_{m4} = D_{n4} - \frac{1}{TP_{f4}} = 0.159\text{-in} \]

\[ A_{m4} = \frac{\pi (D_{m4})^2}{4} = 0.02\text{-in}^2 \]

\[ \sigma_{\text{allow, bolt}} = \sigma_{y, \text{SS bolt}} = 3 \times 10^4\text{ psi} \]

4.1a Seismic Analysis:

\[ SD_x = SD_x \cdot W_4 = 25.5\text{-lbf} \]

\[ SD_y = SD_y \cdot W_4 = 17\text{-lbf} \]

\[ SD_z = SD_z \cdot W_4 = 25.5\text{-lbf} \]

X-Dir:

\[ \tau_{4SD_x} = \frac{SD_x}{n_{tot} \cdot A_{m4}} = 322.079\text{-psi} \]

\[ \sigma_{vm4SD_x} = \sqrt{3} \tau_{4SD_x} = 557.858\text{-psi} \]

Shear stress in fastener, including seismic

Von Mises stresses in fastener, including seismic in the X-direction

Y-Dir:

\[ T_{4SD_y} = \frac{SD_y}{n_{tot}} = 4.25\text{-lbf} \]

\[ \sigma_{4SD_y} = \frac{T_{4SD_y}}{A_{m4}} = 214.72\text{-psi} \]

Tensile force acting on fastener, including seismic

Tensile stress in fastener, including seismic

\[ \sigma_{vm4SD_y} = 214.72\text{-psi} \]

Von Mises stresses in fastener, including seismic in the Y-direction

Z-Dir:

\[ \tau_{4SD_z} = \frac{SD_z}{n_{tot} \cdot A_{m4}} = 322.079\text{-psi} \]

Shear stress in fastener, including seismic

\[ \sigma_{vm4SD_z} = \sqrt{3} \tau_{4SD_z} = 557.858\text{-psi} \]

Von Mises stresses in fastener, including seismic in the Z-direction

\[ \sigma_{vm4SD} = \sigma_{vm4SD_x} + \sigma_{vm4SD_y} + \sigma_{vm4SD_z} = 1330.44\text{-psi} \]

Von Mises stresses in fastener, including seismic
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4.2 Thread Shear in the Tapped Holes:

\[ \sigma_{yield4.2} = \sigma_{y, A36} = 36000 \text{ psi} \]
\[ D_m4 = 0.159 \text{ in} \]
\[ L_{e4} = 0.25 \text{ in} \]
\[ A_{h4} = \frac{\pi D_m4 L_{e4}}{2} = 0.062 \text{ in}^2 \]
\[ \tau_{thread4} = 0 \text{ psi} \]

\[ F_{preload4} = 0.6 \sigma_{allow/bolt} \left( \frac{\pi D_m4^2}{4} \right) = 356.279 \text{ lbf} \]  
Force due to preload torque

\[ \tau_{preload4} = \frac{F_{preload4}}{A_{h4}} = 5715 \text{ psi} \]  
Shear stress in female threads, due to preload torque

\[ \tau_{maxthread4} = \begin{cases} \tau_{preload4} & \text{if } \tau_{preload4} > \tau_{thread4} \\ \tau_{thread4} & \text{otherwise} \end{cases} = 5715 \text{ psi} \]  
Maximum shear stress in female threads

\[ SF_{thread4} = \frac{\sigma_{yield4.2}}{\sqrt{3} \tau_{maxthread4}} = 3.637 \]  
Factor of Safety for Female Threads

4.2a Seismic Analysis:

Since bolt preload is the greater force on the female threads, no seismic analysis is necessary.

4.3 Recommended Torque:

\[ F_{bolt\_yield4} = \sigma_{allow/bolt} A_{h4} = 593.798 \text{ lbf} \]  
Maximum force allowed on SS bolt

\[ F_{thread\_yield4} = \frac{\sigma_{yield4.2} A_{h4}}{\sqrt{3}} = 1.296 \times 10^3 \text{ lbf} \]  
Maximum force allowed on female threads

\[ F_{max\_torque4} = \begin{cases} F_{bolt\_yield4} & \text{if } F_{thread\_yield4} > F_{bolt\_yield4} \\ F_{thread\_yield4} & \text{otherwise} \end{cases} = 593.8 \text{ lbf} \]  
Maximum force allowed on Bolt / Female Threads

\[ K_4 = 0.20 \]  
Friction factor for threads, per EDSS table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Aluminum, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)

\[ T_{4.3} = K_4 D_m4 F_{max\_torque4}(0.6) = 13.539 \text{ m-lbf} \]  
Recommended torque for bolt (60% of material yield strength used, per EDSS section 1.2)
5. Hoist Ring to Lifting Bracket

Given:

\[ W_{HR} = W_{spect} = 85 \text{ lbf} \]

\[ COG = CO_{spect} = 0.727 \text{ in} \]

\[ n_{L} = 1 \]

\[ n_{45} = 1 \]

Dead weight of Spectrometer Assembly

CG of Spectrometer Assembly

Number of fasteners used for tension only

Total number of fasteners

---

5.1 Thread Shear in the Tapped Holes:

\[ D_{HR} = \frac{1}{2} \text{ in} \]

\[ T_{PHR} = \frac{13}{\text{ in}} \]

\[ L_{eHR} = 1.2 \text{ in} \]

\[ T_{installHR} = 28 \text{ ft-lbf} \]

\[ f_{HR} = 0.20 \]

Nominal diameter of 1/2-13

Length of engagement

Installation torque, per manufacturer

Friction factor for threads, per EDSN table 1.2-1, section 1.24.2, rev 1 (Female threads = Stainless Steel, Male threads = Stainless Steel, Friction = Lubricated)

\[ \sigma_{y,HR} = \sigma_{y,304SS} = 3 \times 10^8 \text{ psi} \]

\[ \sigma_{u,HR} = \sigma_{u,304SS} = 7.5 \times 10^4 \text{ psi} \]

\[ D_{mHR} = D_{HR} - \frac{1}{T_{PHR}} = 0.423 \text{ in} \]

\[ D_{mHR} = \frac{\pi (D_{mHR})^2}{4} = 0.141 \text{ in}^2 \]

\[ \sigma_{HR} = \frac{T_{HR} L_{eHR}}{2 A_{HR}} = 0.797 \text{ in}^2 \]

\[ T_{HR} = W_{HR} = 85 \text{ lbf} \]

\[ T_{threadHR} = \frac{T_{HR}}{A_{HR}} = 106.586 \text{ psi} \]

Yield strength of 304 SS

Ultimate strength of 304 SS

Mean diameter of fastener

Area of fastener

Shear area of female threads

Tensile force acting on fastener

Shear stress in female threads

EPPS Analysis, S. Ayers
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\[
F_{\text{install HR}} := \frac{T_{\text{install HR}}}{K_{\text{HR}} \cdot A_{\text{HR}}} = 3.36 \times 10^3 \text{ lbf}
\]

Force due to installation torque

\[
\tau_{\text{install HR}} := \frac{F_{\text{install HR}}}{A_{\text{HR}}} = 4213.27 \text{ psi}
\]

Shear stress in female threads, due to installation torque

\[
\tau_{\text{max thread HR}} := \begin{cases} 
\tau_{\text{install HR}} & \text{if } \tau_{\text{install HR}} > \tau_{\text{thread HR}} \\
\tau_{\text{thread HR}} & \text{otherwise}
\end{cases} = 4213.27 \text{ psi} 
\]

Maximum shear stress in female threads

\[
S_{\text{F thread HRy}} := \frac{\sigma_{\text{yld HR}}}{\sqrt{3} \cdot \tau_{\text{max thread HR}}} = 4.111
\]

Yield Factor of Safety for Female Threads must be greater than 6 for single point failure

\[
S_{\text{F thread HRu}} := \frac{\sigma_{\text{ult HR}}}{\sqrt{3} \cdot \tau_{\text{max thread HR}}} = 10.277
\]

Ultimate Factor of Safety for Female Threads must be greater than 8 for single point failure

Look at manufacturers specifications: Manufacturer’s factor of safety on ultimate stress... The Crosby data sheet for an HR-125 UNC Swivel Hoist Ring specifies the ultimate load is 5 times the VLL.

\[
F_{\text{total HR}} := F_{\text{install HR}} + \frac{T_{\text{HR}}}{7} = 3.372 \times 10^3 \text{ lbf}
\]

Total Load = Bolt Preload + (1/7) Applied Load

\[
\tau_{\text{total HR}} := \frac{F_{\text{total HR}}}{A_{\text{HR}}} = 4228 \times 10^3 \text{ psi}
\]

Shear stress in female threads, due to total load

\[
S_{\text{F thread HRm}} := \frac{\sigma_{\text{ult HR}}}{\tau_{\text{total HR}}} = 17.737
\]

Factor of Safety for Female Threads must be greater than 5, per manufacturers specifications
6. Lifting Bracket to Side Plate

Given:

\[ W_G = W_{spect} = 85 \text{ lb} \]

\[ C_{G_x} = (1.73 + 0.02) \text{ in} = 1.852 \text{ in} \]

\[ d_{Gx} = (3.023 - 3.98) \text{ in} = 2.023 \text{ in} \]

\[ n_{td} = 4 \]

\[ n_{td6} = 4 \]

Dead weight of Spectrometer Assembly

CG of Spectrometer Assembly

Distance between fasteners (x-direction)

Distance between fasteners (y-direction)

Number of fasteners used for tension only

Total number of fasteners
### 6.1 10-32 Fasteners:

\[ D_{m6} := 0.19 \text{ in} \]

\[ T_{Pl6} := \frac{32}{\text{in}} \]

\[ D_{m6} := D_m - \frac{1}{T_{Pl6}} = 0.159 \text{ in} \]

\[ A_{m6} := \frac{\pi (D_{m6})^2}{4} = 0.02 \text{ in}^2 \]

\[ T_6 := \frac{W_6}{t_{16}} = 21.25 \text{ lb} \]

\[ \sigma_6 := \frac{T_6}{A_{m6}} = 1.074 \times 10^3 \text{ psi} \]

\[ \sigma_{vm6} := \sqrt{\sigma_6^2 + (\frac{2T_6}{D_{m6}})^2} = 1.074 \times 10^3 \text{ psi} \]

\[ \sigma_{allow, bolt} := \sigma_{y, SS, bolt} = 3 \times 10^9 \text{ psi} \]

\[ \text{SF}_6 := \frac{\sigma_{allow, bolt}}{\sigma_{vm6}} = 27.943 \]

**Nominal diameter of 10-32**

**Mean diameter of fastener**

**Area of fastener**

**Tensile force acting on fastener**

**Tensile stress in fastener**

**Von Mises stresses in fastener**

**Yield strength of SS SHCS**

**Static Factor of Safety for Fastener**

### 6.2 Thread Shear in the Tapped Holes:

\[ \sigma_{yield, 2} := \sigma_{y, A36} = 36000 \text{ psi} \]

\[ D_{m6} = 0.159 \text{ in} \]

\[ L_{e6} := 0.25 \text{ in} \]

\[ A_{6} := \frac{\pi D_{m6} t_{e6}}{2} = 0.062 \text{ in}^2 \]

\[ \tau_{thread6} := \frac{T_6}{A_6} = 340.867 \text{ psi} \]

\[ F_{preload6} := 0.6 \sigma_{allow, bolt} \left( \frac{\pi D_{m6}}{4} \right) = 356.279 \text{ lb} \]

\[ \tau_{preload} := \frac{F_{preload6}}{A_6} = 5715 \text{ psi} \]

\[ \tau_{preload} := \begin{cases} \tau_{preload} & \text{if } \tau_{preload} > \tau_{thread6} \\ \tau_{thread6} & \text{otherwise} \end{cases} = 5715 \text{ psi} \]

\[ \tau_{max, thread6} := \frac{\sigma_{yield, 2}}{\sqrt{3} \tau_{max, thread6}} = 3.637 \]

**Yield strength of A36 Steel**

**Mean Diameter**

**Minimum Length of engagement**

**Shear area of female threads**

**Shear stress in female threads**

**Force due to preload torque**

**Shear stress in female threads, due to preload torque**

**Maximum shear stress in female threads**

**Factor of Safety for Female Threads**
6.3 Recommended Torque:

- $F_{\text{bolt\_yield6}} := \sigma_{\text{allow\_bolt}} A_{\text{m6}} = 593.798$-lbf
- $F_{\text{thread\_yield6}} := \frac{\sigma_{\text{yield6}}}{\sqrt{3}} A_{\text{n6}} = 1.296 \times 10^3$-lbf
- $F_{\text{max\_torque6}} := \begin{cases} F_{\text{bolt\_yield6}} & \text{if } F_{\text{thread\_yield6}} > F_{\text{bolt\_yield6}} \\ F_{\text{thread\_yield6}} & \text{otherwise} \end{cases} = 593.8$-lbf

- $K_6 := 0.20$

- $T_{6.3} := K_6 D_{16} F_{\text{max\_torque6}} (0.6) = 13.539$-in-lbf

Maximum force allowed on SS bolt

Maximum force allowed on female threads

Maximum force allowed on Bolt / Female Threads

Friction factor for threads, per EDSS table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Aluminum, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)

Recommended torque for bolt (90% of material yield strength used, per EDSS section 1.2)
7. Lifting Handle to Lifting Bracket

Given:

\[ W_H = W_{spect} = 85 \text{ lb} \]

\[ CG_Y = (1.75 + 0.02) \text{ in} = 1.832 \text{ in} \]

\[ d_{H1} = 1.5 \text{ in} \]

\[ d_{H2} = 8.5 \text{ in} \]

\[ d_{H3} = 2.25 \text{ in} \]

\[ n_T = 2 \]

\[ n_{tot} = 2 \]

Dead weight of Spectrometer Assembly

CG of Spectrometer Assembly

Distance H1

Distance H2

Distance H3

Number of fasteners used for tension only

Total number of fasteners

7.1 3/8-16 Fasteners:

\[ D_{ah} = 1.03 \text{ in} \]

\[ T_{PH} = \frac{16}{\text{ in}} \]

\[ D_{mH} = D_{ah} - \frac{1}{T_{PH}} = 0.312 \text{ in} \]

Nominal diameter of 3/8-16

Mean diameter of fastener

\[ A_{mH} = \frac{\pi (D_{mH})^2}{4} = 0.077 \text{ in}^2 \]

Area of fastener

EPPS Analysis, S. Ayers
Title Electron Positron Proton Spectrometer

7.1a. Pick up Handle by Furthest Edge (worst case):

\[ T_{H1a} := \frac{W_{H}(d_{H1} + d_{H2})}{d_{H1}} = 566.667 \text{lbf} \]

Tensile force acting on fastener

\[ \sigma_{H1a} := \frac{T_{H1a}}{A_{mh}} = 7.388 \times 10^3 \text{psi} \]

Tensile stress in fastener

\[ \sigma_{\text{allow bolt}} := \sigma_{Y, SS, bolt} = 3 \times 10^4 \text{psi} \]

Yield strength of SS SHCS

\[ SF_{H1a} := \frac{\sigma_{\text{allow bolt}}}{\sigma_{H1a}} = 4.061 \]

Yield Static Factor of Safety for Fastener

7.1b. Pick up Handle by One End:

\[ T_{H1b} := \frac{W_{H} \cdot d_{H3}}{d_{H1}} = 127.5 \text{lbf} \]

Tensile force acting on fastener

\[ \sigma_{H1b} := \frac{T_{H1b}}{A_{mh}} = 1.652 \times 10^3 \text{psi} \]

Tensile stress in fastener

\[ \tau_{H1b} := \frac{W_{H}}{A_{mh}} = 1.108 \times 10^3 \text{psi} \]

Shear stress in fastener

\[ \sigma_{\text{vmH1b}} = \sqrt{\sigma_{H1b}^2 + 3\left(\tau_{H1b}\right)^2} = 2.539 \times 10^3 \text{psi} \]

Von Mises stresses in fastener

\[ SF_{H1b} := \frac{\sigma_{\text{allow bolt}}}{\sigma_{\text{vmH1b}}} = 11.814 \]

Static Factor of Safety for Fastener

7.2 Thread Shear in the Tapped Holes:

\[ \sigma_{\text{yield H2}} := \sigma_{Y, 304 SS} = 3 \times 10^4 \text{psi} \]

Yield strength of 304 SS

\[ D_{mh} = 0.312 \text{ in} \]

Mean diameter of fastener

\[ L_{H} := 0.625 \text{ in} \]

Minimum length of engagement

\[ A_{sh} := \frac{\pi \cdot D_{mh} \cdot L_{H}}{2} = 0.307 \text{ in}^2 \]

Shear area of female threads

\[ \tau_{\text{thread H1}} := \frac{T_{H1a}}{A_{sh}} = 1.847 \times 10^3 \text{psi} \]

Shear stress in female threads
Title Electron Positron Proton Spectrometer

\[
F_{\text{preload}H} := 0.6 \sigma_{\text{allow}H} \left( \frac{\pi D_m h_H^2}{4} \right) = 1.381 \times 10^3 \text{ lbf}
\]

Force due to preload torque

\[
\tau_{\text{preload}H} = \frac{F_{\text{preload}H}}{A_{\text{H}}H} = 4500 \text{ psi}
\]

Shear stress in female threads, due to preload torque

\[
\tau_{\text{max thread}H} := \begin{cases} 
\tau_{\text{preload}H} & \text{if } \tau_{\text{preload}H} > \tau_{\text{thread}H} \\
\tau_{\text{thread}H} & \text{otherwise}
\end{cases}
\]

Maximum shear stress in female threads

\[
SF_{\text{thread}H} := \frac{\sigma_{\text{yield}H}^2}{\sqrt{3} \tau_{\text{max thread}H}} = 3.849
\]

Yield Factor of Safety for Female Threads

7.3 Recommended Torque:

\[
F_{\text{bolt yield}H} := \sigma_{\text{allow}H} \pi D_m h_H = 2.301 \times 10^3 \text{ lbf}
\]

Maximum force allowed on SS bolt

\[
F_{\text{thread yield}H} := \sqrt{3} \sigma_{\text{allow}H} = 5.314 \times 10^3 \text{ lbf}
\]

Maximum force allowed on female threads

\[
F_{\text{max torque}H} := \begin{cases} 
F_{\text{bolt yield}H} & \text{if } F_{\text{thread yield}H} > F_{\text{bolt yield}H} \\
F_{\text{thread yield}H} & \text{otherwise}
\end{cases} = 2300.97 \text{ lbf}
\]

Maximum force allowed on Bolt / Female Threads

\[
K_H := 0.20
\]

Friction factor for threads, per EDSS table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Aluminum, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)

\[
T_{H,3} := K_H D_m H F_{\text{max torque}H}^{(0.6)} = 103.544 \text{ in-lbf}
\]

Recommended torque for bolt (60% of material yield strength used, per EDSS section 1.2)
Appendix B – Counter Weight

The EPPS Counter weight is shown in figure B-1.

Fig. B-1. EPPS installed in TIM Boat, with Counter Weight.
System Weight & CG:

\[ W_{cw} = 191bf \]

Material Properties:

\[ \sigma_{y_{Al6061-T6}} = 35000psl \]
Yield strength of Aluminum 6061-T6

\[ \sigma_{y_{SS\,bolt}} = 30000psl \]
Yield strength of SS bolt

\[ \sigma_{y_{304SS}} = 30000psl \]
Yield strength of 304 Stainless Steel

1. Counterweight Part A to Counterweight Part B

Given:
\[ W_A = W_{cw} = 191bf \]
Dead weight of Counterweight Assembly

\[ d_{1a} = 1.125\text{in} \]
Distance a

\[ d_{1b} = (4.5 - 1.125)\text{in} = 3.375\text{in} \]
Distance b

\[ n_{tot} = 2 \]
Total number of fasteners

![Diagram](image)

1.1 1/4-20 Fasteners:

\[ D_{ml} = 0.25\text{in} \]
Nominal diameter of 1/4-20

\[ T_{ml} = \frac{20}{\text{in}} \]

\[ D_{ml} = D_{al} = \frac{1}{T_{ml}} = 0.2\text{in} \]
Mean diameter of fastener

\[ A_{ml} = \frac{\pi (D_{ml})^2}{4} = 0.033\text{in}^2 \]
Area of fastener
\[ T_1 = \frac{W_1}{d_{1a} + d_{1b}} = 38 \text{-lbf} \]

\[ \sigma_1 = \frac{T_1}{A_{m1}} = 1.21 \times 10^3 \text{ psi} \]

Tensile stress in fastener

\[ \sigma_{\text{allow1bolt}} = \sigma_{yy, SS \_bolt} = 3 \times 10^4 \text{ psi} \]

Yield strength of SS SHCS

\[ SF_1 = \frac{\sigma_{\text{allow1bolt}}}{\sigma_1} = 24.802 \]

Static Factor of Safety for Fastener

1.2 Thread Shear in the Tapped Holes:

\[ \sigma_{\text{yield,2}} = \sigma_{yy, 304SS} = 3 \times 10^4 \text{ psi} \]

Yield strength of 304 SS

\[ L_{e1} = 0.05 \text{ in} \]

Length of engagement

\[ A_{n1} = \frac{\pi D_{m1}^2 L_{e1}}{2} = 0.157 \text{ in}^2 \]

Shear area of female threads

\[ \tau_{\text{thread1}} = \frac{T_1}{A_{n1}} = 241.916 \text{ psi} \]

Shear stress in female threads

\[ F_{\text{preload1}} = 0.6 \sigma_{\text{allow1bolt}} \left( \frac{\pi D_{m1}^2}{4} \right) = 565.487 \text{ lbf} \]

Force due to preload torque

\[ \tau_{\text{preload1}} = \frac{F_{\text{preload1}}}{A_{n1}} = 3600 \text{ psi} \]

Shear stress in female threads, due to preload torque

\[ \tau_{\text{maxthread1}} = \begin{cases} \tau_{\text{preload1}} & \text{if } \tau_{\text{preload1}} > \tau_{\text{thread1}} \\ \tau_{\text{thread1}} & \text{otherwise} \end{cases} = 3600 \text{ psi} \]

Maximum shear stress in female threads

\[ SF_{\text{thread1}} = \frac{\sigma_{\text{yield,2}}}{\sqrt{3} \tau_{\text{maxthread1}}} = 4.811 \]

Factor of Safety for Female Threads

1.3 Recommended Torque:

\[ F_{\text{bolt, yield1}} = \sigma_{\text{allow1bolt}} A_{m1} = 942.478 \text{ lbf} \]

Maximum force allowed on SS bolt

\[ F_{\text{thread, yield1}} = \frac{\sigma_{\text{yield,2}}}{\sqrt{3}} A_{n1} = 2721 \times 10^3 \text{ lbf} \]

Maximum force allowed on female threads

\[ F_{\text{max_torque1}} = \begin{cases} F_{\text{bolt, yield1}} & \text{if } F_{\text{thread, yield1}} > F_{\text{bolt, yield1}} \\ F_{\text{thread, yield1}} & \text{otherwise} \end{cases} = 942.478 \text{ lbf} \]

Maximum force allowed on Bolt / Female Threads

\[ K_1 = 0.20 \]

Friction factor for threads, per EDSS table 1.2-1, section 1.2.4.2, rev 1 (Female threads = Stainless Steel, Male threads = Stainless Steel, Friction = Lubricated - Silver Plated)

\[ T_{1.3} = K_1 D_{m1} F_{\text{max_torque1}} (0.6) = 28.276 \text{-in-lbf} \]

Recommended torque for bolt (60% of material yield strength used, per EDSS section 1.2).
Appendix C – EPPS Drawings
Title  Electron Positron Proton Spectrometer
NOTES: UNLESS OTHERWISE SPECIFIED

1. APPLICABLE STANDARDS/SPECIFICATIONS:
   ASME Y14.5M–1994, DIMENSIONING AND TOLERANCING
   ASME B46.1–2002, SURFACE TEXTURE
   ASME Y14.38–1994, SURFACE TEXTURE SYMBOLS
   ASME Y14.38–2007, ABBREVIATIONS AND ACRONYMS

2. BREAK EDGES .005 – .015 R OR CHAMFER.

3. PROTECT PART AND FINISHED SURFACES DURING
   SHIPPING AND HANDLING.

4. FABRICATION AND HANDLING OF COMPONENTS SHALL CONFORM
   TO LLNL SPECIFICATION MEL08–001 (FABRICATION OF NF
   LASER COMPONENTS AND STRUCTURES). ANY DEVIATION FROM
   THIS SPECIFICATION SHALL BE SUBMITTED TO LLNL FOR
   APPROVAL.

5. CLEANING OF COMPONENTS SHALL CONFORM TO LLNL
   SPECIFICATION MEL09–009 (GROSS CLEANING OF NF LASER
   COMPONENTS AND STRUCTURES). ANY DEVIATION FROM THIS
   SPECIFICATION SHALL BE SUBMITTED TO LLNL FOR
   APPROVAL.

6. WEIGHT 1.4 LBS.

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U.S. DEPARTMENT OF STATE SECTION 3B OF THE EAR MONITORING LIST.
VIOLATIONS ARE SUBJECT TO PENALTY UNDER:
SECTION 11 OF THE EXPORT ADMINISTRATION ACT OF 1974
SECTION 3B OF THE ARMS EXPORT CONTROL ACT

CLASSIFICATION: UNCLASSIFIED

EPPS SUPPORT PLATE / A 6681–76

EPPS MODIFICATION TIM MOUNT ASSEMBLY
MODIFIED SUPPORT PLATE

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Title: Electron Positron Proton Spectrometer

NOTES: UNLESS OTHERWISE SPECIFIED

1. APPLICABLE STANDARDS/SPECIFICATIONS:
   ASME Y14.5M–1994, DIMENSIONING AND TOLERANCING
   ASME B46.1–2002, SURFACE TEXTURE
   ASME Y14.5M–1994, SURFACE TEXTURE SYMBOLS
   ASME Y14.38–2007, ABBREVIATIONS AND ACRONYMS

2. BREAK EDGES .005 – .015 R OR CHAMFER.

3. PROTECT PART AND FINISHED SURFACES DURING SHIPPING AND HANDLING.

4. FABRICATION AND HANDLING OF COMPONENTS SHALL CONFORM TO LLNL SPECIFICATION MELS–001 (FABRICATION OF NIF LASER COMPONENTS AND STRUCTURES). ANY DEVIATION FROM THIS SPECIFICATION SHALL BE SUBMITTED TO LLNL FOR APPROVAL.

5. CLEANING OF COMPONENTS SHALL CONFORM TO LLNL SPECIFICATION MELS99–009 (GROSS CLEANING OF NIF LASER COMPONENTS AND STRUCTURES). ANY DEVIATION FROM THIS SPECIFICATION SHALL BE SUBMITTED TO LLNL FOR APPROVAL.

6. WEIGHT 10 LBS.

THIS IS A NON ENGINEERING DRAWING
Title: Electron Positron Proton Spectrometer
NOTES: UNLESS OTHERWISE SPECIFIED

1. APPLICABLE STANDARDS/SPECIFICATIONS:
   ASME Y14.5M-1994, DIMENSIONING AND TOLERANCING
   ASME B46.1-2002, SURFACE TEXTURE
   ASME Y14.35M-1996, SURFACE Texture SYMBOLS
   ASME Y14.58-2007, ABBREVIATIONS AND ACRONYMS

2. 🔴 ALL MACHINED SURFACES.

3. BREAK EDGES .005 → .015 R OR CHAMFER.

4. PROTECT PART AND FINISHED SURFACES DURING
   SHIPPING AND HANDLING.

5. CALCULATED WEIGHT = 0.8 LB.

6. FABRICATION AND HANDLING OF COMPONENTS SHALL CONFORM
   TO LLNL SPECIFICATION N567-12-01 (FABRICATION OF NF LASER COMPONENTS AND STRUCTURES). ANY DEVIATION FROM
   THIS SPECIFICATION SHALL BE SUBMITTED TO LLNL FOR
   APPROVAL.

7. CLEANING OF COMPONENTS SHALL CONFORM TO LLNL
   SPECIFICATION M568-12-09 (GROOVE CLEANING OF NF LASER
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