During Phase 2 commissioning of the End Cap MDTs, the chambers will be mounted in the Large and Small Sectors. The Lifting Tool, modeled on a tool used by CMS, will move MDT chambers from the floor to their mounted position in the sectors. The Grabber described here is a structure, mounted to the front of the Lifting Tool, which allows simple and quick connection to any of the large wheel MDT chambers. The Verticalizer is a complementary tool designed to pick a chamber up out of its transport container and move it into a vertical orientation so that the Lifting Tool and Grabber can be attached.

The Lifting Tool (see Muon Chamber Lifter/Positioner prepared by U of Wisconsin Physical Sciences Laboratory) is designed to lift chambers with a maximum weight of 4000 newtons with center of mass 0.42 meters from the front trunnion. The Atlas chambers will have a maximum weight of 3070 newtons at a distance of 0.40 meters from the front trunnion and a frame of 1500 newtons at 0.15 meter. Thus the strain requirements of the Lifting Tool are satisfied.

The sections of the U Wisconsin document numbered 2 (Physical Description), 3A (Attachment to the Crane) and 3B (Description of the Three Movements Possible on Lifter) are equally relevant for use of the Lifting Tool used by Atlas.
**Sequence of Operations**

The Grabber Frame used for MDT chambers accommodates all sizes necessary for use on the Big Wheel. The chamber must first be brought to a position where, in chamber coordinates, X is horizontal and Z is vertical. This is done with the Verticalizer Tool

1. Preparing the chamber
   MDT Endcap chambers are brought to the site shipped in wooden crates, with the chambers lying flat on foam pads. The box is placed on a set of rolling dollies, and the sides and top removed. Final preparation and photogrametry are done on the chamber at this time.

   The chamber is rolled up to the verticalizer with the long side nearest to the back beam, and the chamber centered under the hook.

2. Raising the chamber to a vertical orientation
   a. The arms on the back beam are slid toward the chamber until the pins are fully engaged in the kinematic mount bearings. The clamps on the arms are tightened slightly. The jacks are used to raise this long edge of the chamber by about 3 cm, until both arms are horizontal.
   b. The front beam is positioned and centered over the chamber so that its arms can be inserted in the KM bearings near the short edge of the chamber. The winch hook is attached to the slings.
   c. The winch is hand cranked to slowly raise the front beam and short edge of the chamber until the chamber is vertical. A latch from the gantry is fixed to the central beam of the chamber to lock it in this vertical orientation. Secure the ends of the front beam to stabilize it.
   d. Bottom side B sensors are mounted on the chamber and tested. Photogrametry measurements are made.
3. Attaching the Chamber to the Lifter
The four Grabber Arms are loosely mounted to the Kinematic Mount Blocks of the chamber, above the KM bearings. The Lifting Tool with Grabber is brought near to the chamber with the crane. The head is rotated to match the orientation of the chamber and the head locked in place. When the Grabber is near enough, bolts are inserted through the frame into the Arms. All bolts are then tightened. The Arms have heads with some rotational freedom to prevent over-constraining the shape of the chamber.

4. Rough Balance
After the chamber is attached the lifter should be brought into rough balance. This means getting the crane hook balance and the rotational balance approximately right while the lifter is close to the floor.

   a. The crane hook is raised until the main tube of the lifter is approximately horizontal (it will already be in this position if the chamber has just been attached to the lifter). The rotational head should already be locked to prevent rotation. Move the crane hook balance until the verticalizer jack is no longer bearing any weight. The crane hook balance is now close to the correct position. Put a small amount of tension on the winch wire and release the upper verticalizer arms from the chamber, sliding them outward till they are free. Release the lower verticalizer arms from the chamber, sliding them outward till they are well away from the chamber. Re-adjust the crane hook balance if necessary.

   b. Now release the rotational-head lock. The chamber will probably want to turn unless it is held by hand. Adjust the rotational balance screw to move the chamber horizontally until no hands are necessary to keep it from rotating. The chamber is now approximately balanced in this direction. The chamber may, however, still be unbalanced rotationally on the slide that moves the chamber vertically. With the rotational head locked, lift the crane hook until the chamber is about 0.5 meters off the floor. Carefully release the rotational lock and watch the behavior of the chamber when it is turned a little way from horizontal. If it tends to return to horizontal the center of mass is below the axis of rotation. If it tends to continue to move further away from horizontal when disturbed the center of mass is above the axis of rotation.
Note of Caution: Do not lift the chamber higher until this adjustment is as close as it can be gotten at this height. If the center of mass is balanced above the axis of rotation when the chamber is horizontal, it could feel balanced but start to move and then continue to move, increasing in speed as the center of mass swings around to the bottom.

c. When this adjustment is done as well as it can be near the floor, the chamber may be lifted higher for the fine adjustment.

5. Fine Balance
When the rough adjustment is complete lock the rotating head and finish adjusting the crane-hook balance. This consists of making small movements in the crane hook balance until the chamber is precisely vertical (or at some other small angle to the vertical if that is desired).
Unlock the rotating head and re-adjust the screw that moves the chamber horizontally until the chamber is balanced. Re-lock the rotating head. After that is finished the chamber should then be lifted to about 2m off the floor, high enough that the frame will clear the floor when rotated 90 degrees. Unlock the head and carefully rotate the head by 90 degrees. Adjust the other screw to achieve a balanced chamber. Re-check the balance in both positions and rebalance as needed until the chamber will stay in any position it is placed in without being held. When the fine balance is finished one must be sure to lock the rotational head with the tubes vertical so that it doesn’t drift while unattended.

6. Transfer to struts
Struts are fixed in 3 of the kinematic mounts. The crane moves the chamber to the sector and brings it slowly into position. There must be two operators positioned near the two opposite struts who can guide the chamber into final position. The lateral strut is the first to be fixed to the sector, then the axial strut opposite and then the final strut. Tighten all strut screws. The chamber is now fixed to the frame.

7. Removing the Grabber
The crane-hook balance must now be readjusted to the position where the tool is balanced with no chamber attached. Move the crane hook balance to its “home” position. The screws holding the arms to the Grabber Frame are first loosened, and then removed, checking that the Lifter/Grabber is balanced and not prone to sudden movement. There must be hands steadying the frame during this process. The crane then moves the Lifter/Grabber away from the sector. Finally the Grabber Arms are removed from the chamber by hand.
The operators who guide the chamber and fix it to the frame must be standing on a separate support approved for lifting or carrying personnel. At no time may the Lifter/Grabber be used as support for personnel.
Safety

The two main safety rules with this piece of equipment are:

a) Avoid situations where something can move quickly or unexpectedly.

b) Avoid situations where someone could get hurt or equipment damaged if there is an unexpected or sudden movement.

As with any piece of equipment on a crane hook people should never walk under it and should be cautious whenever approaching it. It is safest always to assume it could fall no matter how safely it is held.

The following are some safety guidelines specific to this piece of equipment:

- Make sure the slings are in good condition, long enough and are of adequate weight rating.
- Never walk under it, always around it, when it is on the crane hook.
- Keep the rotational head locked at all times except when performing a maneuver that requires it to be unlocked.
- The equipment should be operated by trained, qualified personnel.
- The crane should be operated by a qualified crane operator.
- If the equipment is hanging on a long crane cable be aware that the long cable combined with a heavy mass at the end will cause a significant delay in sideways movement of the lifter when the crane hook is moved sideways. This delay has the potential to create a swing with large amplitude that could endanger people and equipment.
- Pay attention to the balance of the chamber on the rotating head. If the chamber is lifted in a position where the chamber’s center of mass is directly above the rotation axis the chamber could appear balanced but then swing around picking up speed as the center of mass moves around to the bottom. The chamber is heavy enough that it could be damaging to people or equipment even rotating at low speed.
- Keep fingers and clothing away from the moving parts of the lifter. The motorized crane hook adjustment shouldn’t be operated when people are near the lifter.
- No workers should ever stand on the fixture to work on the chambers. It is designed only for lifting the chambers and should never be used to lift or carry people.
Grabber Strength Calculations

The following calculations evaluate the strength of welded joints of the frame and the strength of the screws holding arms to the frame.

Given data:

- \( W_{ch} = 3070 \) (N)-max.chamber weight
- \( L_{arm} = 0.25 \) (m)-arm length
- \( 0.076 \times 0.038 \times 0.0031 \) (m)-cross beam section sizes

A. Strength of the Grabber when in the horizontal position

1) Strength of welded joints of the frame with the highest load.

The arms are 250 mm long and the weight of the chamber, \( W_{ch} \), will exert a torque, \( M \), on the frame (see fig.1).
There are max internal bending moments of 0.22 M in the first and last cross beam welding joints due to torque \( M \).
The weld is penetrated into at least half of the wall thickness.
We will predict a stress greater than the actual one, by not taking into account the reinforcement due to the thicker weld.

![Fig.1](image)

\[
M = W_{ch} \times L_{arm} \quad \text{(Nm)-max. moment on the frame}
\]

\[
M = 767.5
\]
Zx = $4.8 \cdot 10^{-6}$ (m$^3$)-section modulus of cross-beam welding joint
Sjoint = $0.22 \frac{M}{Zx}$ (Pa) – max. tensile strength in the welding joints

\[ S = 35 \cdot 10^6 \]

Sy = $360 \cdot 10^6$ (Pa)-min yield stress of weld metal
SF = Sy/Sjoint (non-dimensional)-safety factor against yield
SF = 10.3

2) Strength of the screws holding arms to the frame

The forces on the screws are exerted by a quarter of the weight of the chamber which is applied to the arm. (see fig.2)

![Diagram of forces on screws](image)

Hflange = 0.076 (m)-height of the arm flange
N = 2 (non-dimensional)-number of the bolts holding arm
Fbolt = $\frac{Wch \cdot Larm}{2 \cdot Harm \cdot N}$ (N)-tensile force in the bolts exerted by a quarter of chamber weight
Fbolt = 2525

FC = 1 (non-dimensional)-friction coefficient between flange knurled thrust and frame pipe
SF = 3 (non-dimensional)-safety factor preventing flange sliding
Ftight = W*SF/(2*FC)  
\text{(N)-tightening force of the bolt to prevent flange sliding} 
Ftight = 4605 

Fbolt total = Fbolt + Ftight 
\text{(N)-total force on one bolt} 
Fbolt total = 7130 

FminM12 = 98500 
\text{(N)-minimum tensile strength of a single M12 class 12.9 screw} 
SF = FminM12/Fbolt total 
\text{(non-dimensional)-safety factor against tensile strength} 
SF = 13.8 

\textbf{B. Grabber strength in the vertical position} 

1) \textbf{Strength of the welded joints of the frame with the highest load} 

The weight of the chamber will exert a torque $\mathbf{M}$ and vertical force $\mathbf{Wch}$ applied to the mount plate (see fig.3) 
Due to the force $\mathbf{Wch}$ there are internal vertical forces $\mathbf{Wch}/4$ in the welding joints of the central cross beams. 
Actually, due to torque $\mathbf{M}$ there are both torque and horizontal force in these joints. 
The ratio between torque and force depends of the joint flexibility. Assume the worst case when there is just a torque $\mathbf{M}/4$. 
We do not take into account any reinforcement of the welding and crossbeams.
Fig. 3

\[ M = W_{ch} \times L_{arm} \]  (Nm)-max. torque on the frame

\[ M = 767.5 \]

\[ Z_p = 8.7 \times 10^{-6} \]  (m³)-polar section modulus of the cross beam welding joint.
Ssh1 = \frac{M}{4Zp} \quad \text{(Pa)} \quad \text{max. shearing stress in the welding joint due to torque}

Ssh1 = 22 \cdot 10^6

A = 1.8 \cdot 10^{-4} \quad \text{(m}^2) \quad \text{area of the section of welding joint}

Ssh2 = \frac{Wch}{4A} \quad \text{(Pa)} \quad \text{max. shearing stress in the welding joint due to vertical force}

Ssh2 = 0.43 \cdot 10^6

Ssh2 stress is negligible in comparison with Ssh2, so we do not take it into account.

Sallowable = 180 \cdot 10^6 \quad \text{(Pa)} \quad \text{min. allowable shearing stress of weld metal}

SF = \frac{Sallowable}{Ssh1} \quad \text{(non-dimensional)} \quad \text{safety factor}

SF = 8.2

2) Strength of the screws holding arms to the frame

The calculation scheme is shown on the fig. 4.

Supporting force $F_{support} = F_{bolt}$ (see following calculations) is exerting friction between knurled flange thrust and frame pipe that will prevent arm sliding.

\[ D_{bolts} = 0.066 \quad \text{(m)} \quad \text{distance between bolts holding arm} \]

\[ F_{bolt} = \frac{Wch \cdot Larm}{4 \cdot D_{bolts}} \quad \text{(N)} \quad \text{tensile force on the top bolt exerted by half} \]
The weight of a chamber

\[ F_{\text{bolt}} = 2910 \]  
(N)-tightening force of the bolt remains the same as for the horizontal grabber

\[ F_{\text{tight}} = 4605 \]  
(N)-tightening force of the bolt remains the same as for the horizontal grabber

\[ F_{\text{bolt total}} = F_{\text{bolt}} + F_{\text{tight}} \]  
(N)-total force on one bolt

\[ F_{\text{bolt total}} = 7515 \]

\[ F_{\text{minM12}} = 98500 \]  
(N)-minimum tensile strength of a single M12 class 12.9 screw

\[ SF = \frac{F_{\text{minM12}}}{F_{\text{bolt total}}} \]  
(non-dimensional)-safety factor against tensile strength

\[ SF = 13.1 \]

**Strength of the arm flange welded joint**

The size of the welding joint section of the arm pipe to flange is 0.05x0.05x0.005 (m).

For calculations, we do not take into account the welding reinforcement and the influence of the rib that will reduce the actual stress in comparison with calculated one.
\( M_1 = 166 \quad \text{(Nm)} \) - bending on the flange moment exerted by the force \( W_{ch/4} \).

\( M_2 = 98 \quad \text{(Nm)} \) - torque on the flange due to force \( W_{ch/4} \).

\( Z_x = 12.5 \cdot 10^{-6} \quad \text{(m}^3\text{)} \) - section modulus of the welding joint.

\( Z_p = 20.6 \cdot 10^{-6} \quad \text{(m}^3\text{)} \) - polar section modulus of the welding joint.

\[ S = \frac{M_1}{Z_x} \quad \text{(Pa)} \] - max. tensile strength in the welding joint due to bending moment \( M_1 \)

\[ S = 13.3 \cdot 10^6 \]

\[ \text{Shearing} = \frac{M_2}{Z_p} \quad \text{(Pa)} \] - max. shearing stress in the welding joint due to torque \( M_2 \)

\[ S_{sh1} = 4.8 \cdot 10^6 \]

\[ S_{equiv} = \sqrt{S_{stensile}^2 + 4 \cdot S_{shearing}^2} \quad \text{(Pa)} \] - equivalent tensile strength in the welding joint

\[ S_{equiv} = 16.4 \cdot 10^6 \]

\[ S_y = 360 \cdot 10^6 \quad \text{(Pa)} \] - min yield stress of weld metal

\[ S_F = \frac{S_y}{S_{equiv}} \quad \text{(non-dimensional)} \] - safety factor against tensile strength

\[ S_F = 22 \]
Strength of the Verticalizer

The maximum load on the verticalizer winch is 2500 N when using a single cable directly to the lifting bar. During operation we plan to have the cable doubled back to halve the load. The cable is rated at a breaking strength of 31000 N, and the winch is rated for safe operation up to 3350 N. All hardware has been chosen to match or exceed these specifications.