PENN HYPERLOOP

NoDiggity V2

Overall goal was to dig a 30m long horizontal tunnel of 0.5m diameter. I was the Cutterhead and Main Drive systems RE (responsible engineer) for a system that generated 2.2 kNm of torque. Was the de facto mechanical–side team lead and coordinated between the propulsion system, soil removal and ground conditioning systems, to ensure delivery on the machine.

Not mentioned in this portfolio are the numerous hours (~50% of my time) spent planning the logistics of moving and testing ops, organizing a temporary build space, and fighting with school management for recognition, and fundraising talks.

Official dig length of 1.5m to win Rookie Award with smallest team and simplest TBM design (as per judges).

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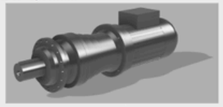
Meain Drive Torque Calculation

Utilizing the findings of Hu's 2011 paper* we can split up our torque contributions as seen below.

Torque Contribution	Torque (kNm)
T1 (Front)	1.169910308
T2 (Lateral)	0.5114362
T3 (Back)	0.389970103
T5 (Opening Shear)	0.13847143
T6 (Agitating torque)	0.2662796
Total Torque	2.476067639

Using a FOS of 2 we get a recommended Torque of ~5 kNm

Key System Metrics: (Rossi Group motor: **HB3 132 S 4**, Rossi Group planetary gear reducer: **EP R 3EL)**

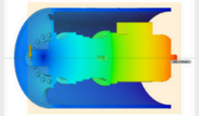


- Estimated Output Torque: 4780 Nm
- Nominal Output Speed: 8.1-11.9 rpm
- Mass: 221 kg
- Effective reduction ratio: 142.56-209.44
- Gearmotor configured for expected axial/thrust loads from manufacturer.

Coupling:

- Custom machined keyway two-piece coupling (Stafford)
- 316 Stainless Steel (for corrosion protection)
- 6 screws on each side
- Holding Torque: 3723 Nm

Mounting Plate:



- Assuming AISI 4340 242 HR steel with a Young's modulus a plate thickness of of 33mm would be needed to support the system. Considering a safety factor of 1.5, a plate thickness of 49.5mm (50mm) would be desirable.
- Mounting Strategy: Weld ring plate to outer body casing to create a flange mounting system for plate to be bolted to. This allows for removal of plate to make other components accessible.

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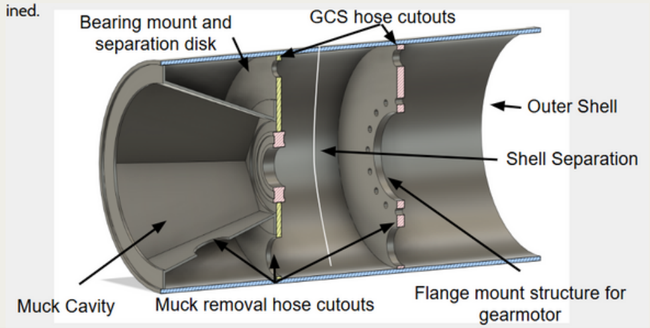
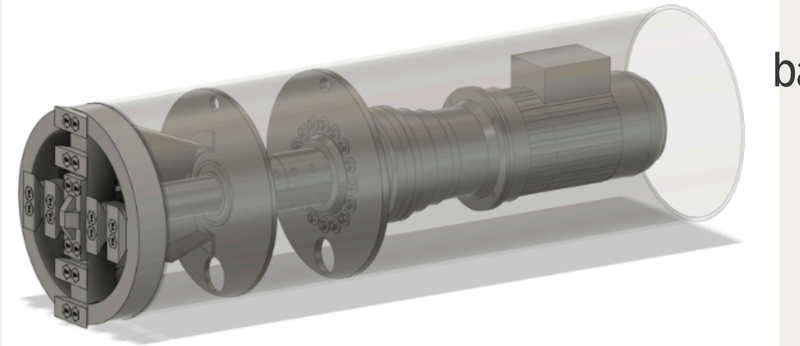
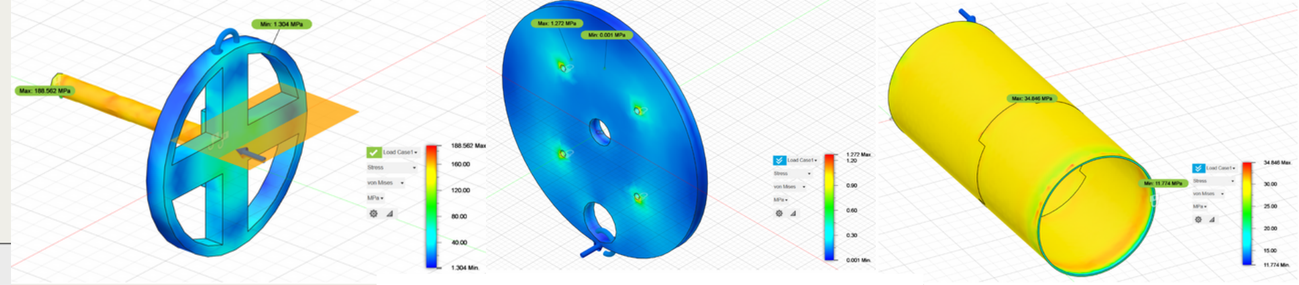
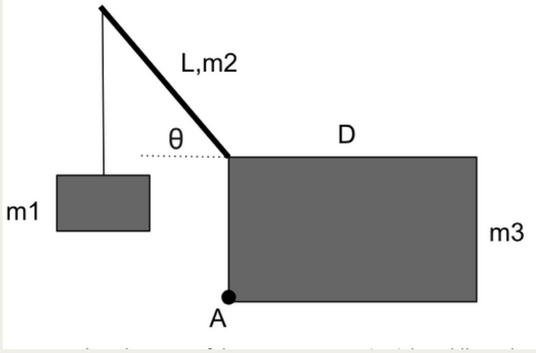


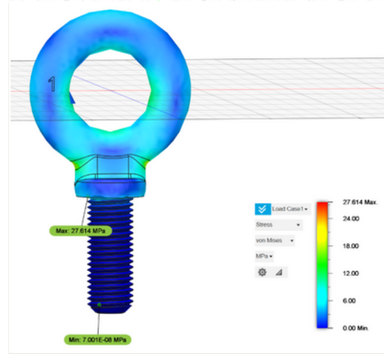
Initial Design – Started off with main physics requirement of torque needed. Accordingly, sourced sized a gearmotor + custom coupling system that fits into CAD modeled outer structure.



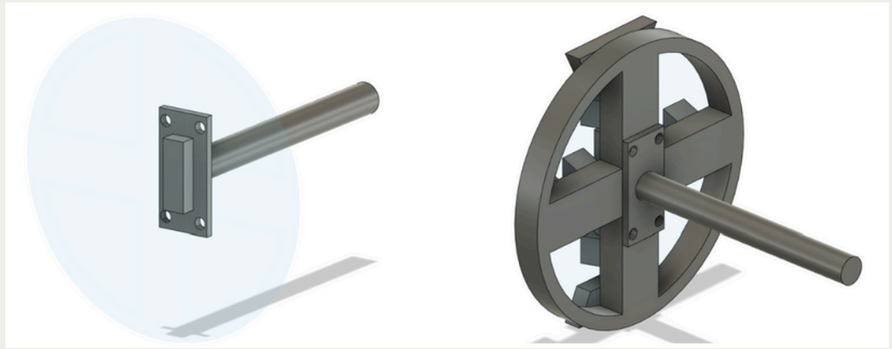


Improved design: Overall structural analysis shown for various failure modes.

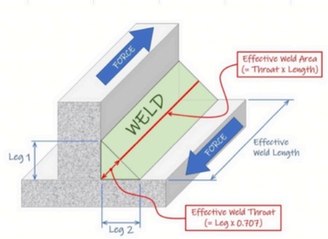


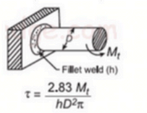


<u>Added</u>: lifting points, alignment peice to achieve concentrictiy and better torque transfer, switched out gearmotor based on updated assumptions.



	A	B
1	**Torsional Shear**	
2	Applied Torque (Nm)	2700
3	Shaft Radius (m)	0.0508
4	Weld thickness (m)	0.00635
5	Polar moment of inertia (m^4)	0.000006274
6	FOS	5
7	Torsional shear stress (N/m^2)	109311612.5
8		
9	**Normal Shear**	
10	Applied Force (N)	265748.0
11	Weld area (m^2)	0.001170
12	Normal shear stress (N/m^2)	227098227.4
13		
14	Filler material required max stress (psi)	36554.8574
15		
16	**Online model (w/ safety factor)**	
17	Weld fillet radius (m)	0.003175
18	Filler material required max stress (psi)	43053.69067
19		
20	ER 4340 max stress (psi)	168,000
21	FOS	3.902104497
22		
23		
24		
25		
26		





$$\tau = \frac{2.83\ M_t}{hD^2\pi}$$

τ = Shear Stress, MPa (psi)
M_t = Torque N-m (lbf-in)
D = Diameter, m (in)
h = Size of Weld, m (in)
π = 3.14157 (PI)

$$J = 2\pi a (r + a/2)^3$$

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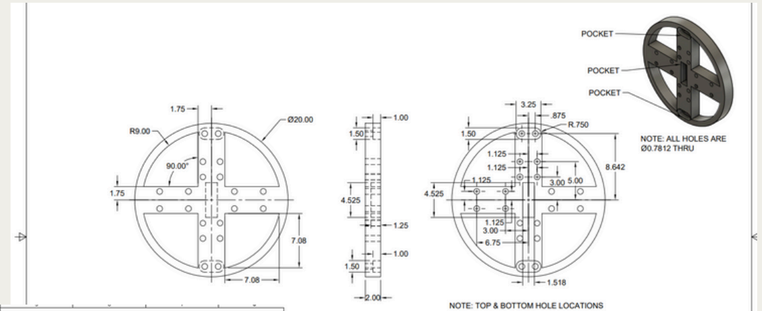
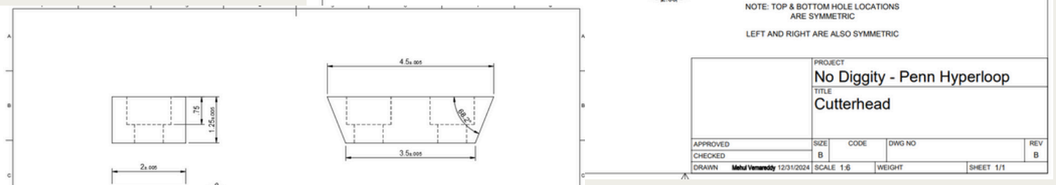
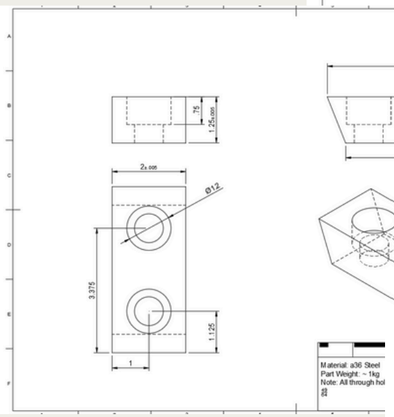
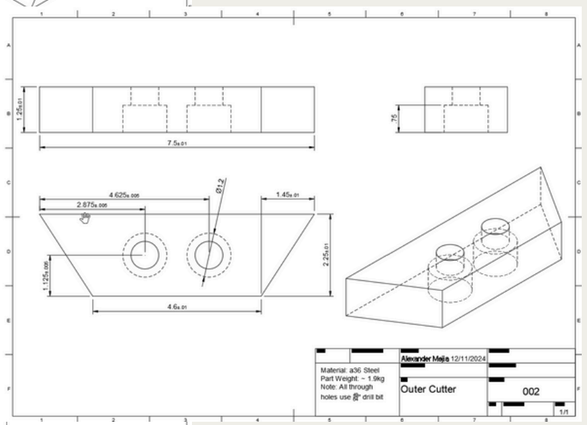
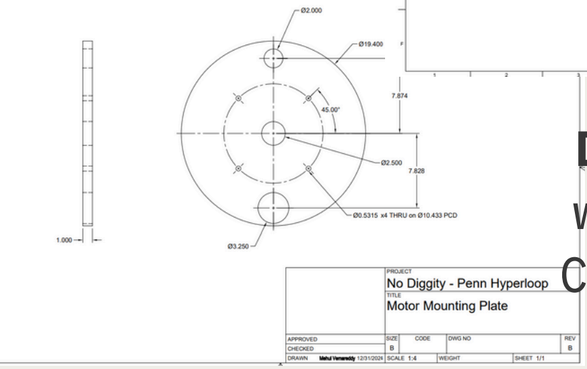






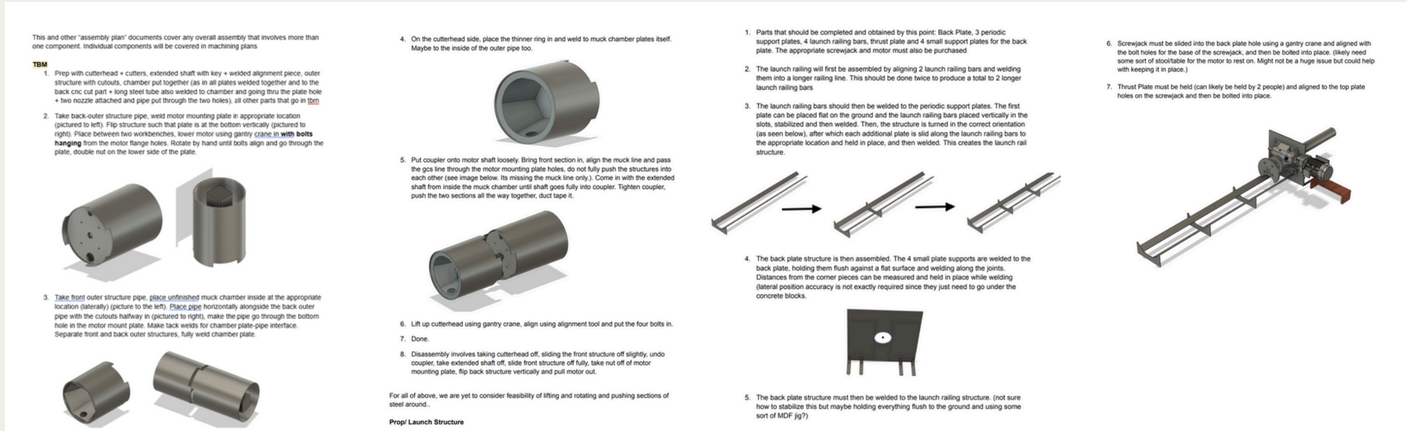




Drawings – Large plates plates were sent out for waterjet/ laser CNC cutting. Rest were machined in-house.

Assembly and Machining Plans generated:

(Test Plans were skipped due to lack of funding early enough into our process.)



This and other "assembly plan" documents cover any overall assembly that involves more than one component. Individual components will be covered in machining plans

TBM

1. Prep with cutterhead + cutters, extended shaft with key + welded alignment piece, outer structure with cutouts, chamber put together (as in all plates welded together and to the back cnc cut part + long steel tube also welded to chamber and going thru the plate hole + two nozzle attached and pipe put through the two holes), all other parts that go in then
2. Take back-outer structure pipe, weld motor mounting plate in appropriate location (picture to left). Flip structure such that plate is at the bottom vertically (pictured to right). Place between two workbenches, lower motor using gantry crane in **with bolts hanging** from the motor flange holes. Rotate by hand until bolts align and go through the plate, double nut on the lower side of the plate.

3. Take front outer structure pipe, place unfinished muck chamber inside at the appropriate location (laterally) (picture to the left). Place pipe horizontally alongside the back outer pipe with the cutouts halfway in (pictured to right), make the pipe go through the bottom hole in the motor mount plate. Make tack welds for chamber plate-pipe interface. Separate front and back outer structures, fully weld chamber plate.

4. On the cutterhead side, place the thinner ring in and weld to muck chamber plates itself. Maybe to the inside of the outer pipe too.

5. Put coupler onto motor shaft loosely. Bring front section in, align the muck line and pass the gcs line through the motor mounting plate holes, do not fully push the structures into each other (see image below. Its missing the muck line only.). Come in with the extended shaft from inside the muck chamber until shaft goes fully into coupler. Tighten coupler, push the two sections all the way together, duct tape it.

6. Lift up cutterhead using gantry crane, align using alignment tool and put the four bolts in.
7. Done.
8. Disassembly involves taking cutterhead off, sliding the front structure off slightly, undo coupler, take extended shaft off, slide front structure off fully, take nut off of motor mounting plate, flip back structure vertically and pull motor out.

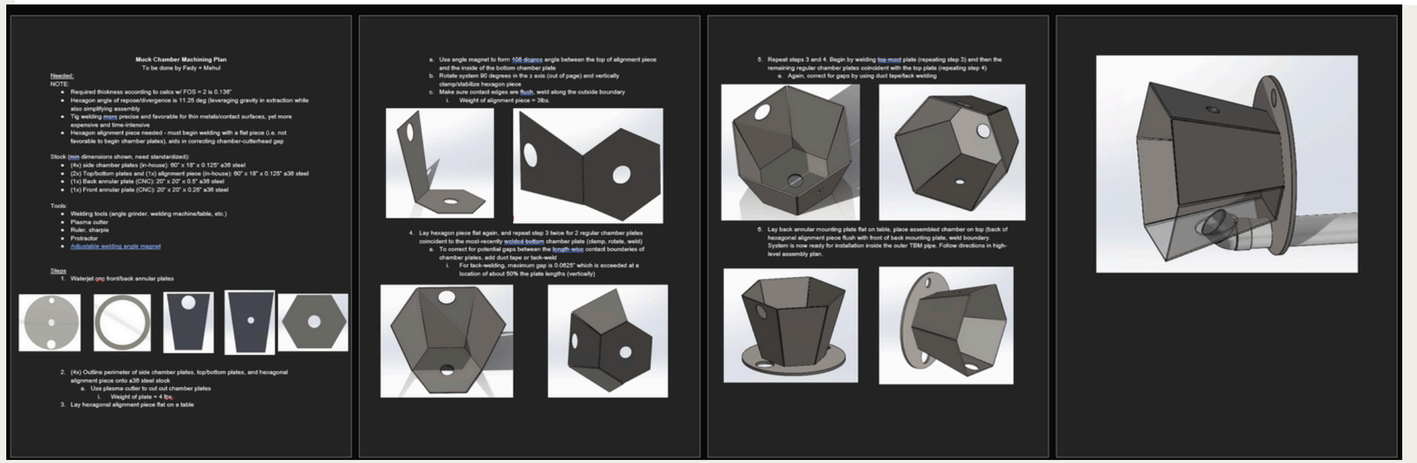
For all of above, we are yet to consider feasibility of lifting and rotating and pushing sections of steel around..

Prop/ Launch Structure

1. Parts that should be completed and obtained by this point: Back Plate, 3 periodic support plates, 4 launch railing bars, thrust plate and 4 small support plates for the back plate. The appropriate screwjack and motor must also be purchased
2. The launch railing will first be assembled by aligning 2 launch railing bars and welding them into a longer railing line. This should be done twice to produce a total to 2 longer launch railing bars
3. The launch railing bars should then be welded to the periodic support plates. The first plate can be placed flat on the ground and the launch railing bars placed vertically in the slots, stabilized and then welded. Then, the structure is turned in the correct orientation (as seen below), after which each additional plate is slid along the launch railing bars to the appropriate location and held in place, and then welded. This creates the launch rail structure.

4. The back plate structure is then assembled. The 4 small plate supports are welded to the back plate, holding them flush against a flat surface and welding along the joints. Distances from the corner pieces can be measured and held in place while welding (lateral position accuracy is not exactly required since they just need to go under the concrete blocks.

5. The back plate structure must then be welded to the launch railing structure. (not sure how to stabilize this but maybe holding everything flush to the ground and using some sort of MDF jig?)
6. Screwjack must be slided into the back plate hole using a gantry crane and aligned with the bolt holes for the base of the screwjack, and then be bolted into place. (likely need some sort of stool/table for the motor to rest on. Might not be a huge issue but could help with keeping it in place.)
7. Thrust Plate must be held (can likely be held by 2 people) and aligned to the top plate holes on the screwjack and then be bolted into place.



Muck Chamber Machining Plan

To be done by Fady + Mehul

Needed:

NOTE:

- Required thickness according to calcs w/ FOS = 2 is 0.136"
- Hexagon angle of repose/divergence is 11.25 deg (leveraging gravity in extraction while also simplifying assembly
- Tig welding more precise and favorable for thin metals/contact surfaces, yet more expensive and time-intensive
- Hexagon alignment piece needed - must begin welding with a flat piece (i.e. not favorable to begin chamber plates), aids in correcting chamber-cutterhead gap

Stock (exp dimensions shown, need standardized):

- (4x) side chamber plates (in-house): 60" x 18" x 0.125" a36 steel
- (2x) Top/bottom plates and (1x) alignment piece (in-house): 60" x 18" x 0.125" a36 steel
- (1x) Back annular plate (CNC): 20" x 20" x 0.5" a36 steel
- (1x) Front annular plate (CNC): 20" x 20" x 0.25" a36 steel

Tools:

- Welding tools (angle grinder, welding machine/table, etc.)
- Plasma cutter
- Ruler, sharpie
- Protractor
- Adjustable welding angle magnet

Steps

1. Waterjet cnc front/back annular plates

2. (4x) Outline perimeter of side chamber plates, top/bottom plates, and hexagonal alignment piece onto a36 steel stock
   a. Use plasma cutter to cut out chamber plates
      i. Weight of plate = 4 lbs.
3. Lay hexagonal alignment piece flat on a table
   a. Use angle magnet to form 106 degree angle between the top of alignment piece and the inside of the bottom chamber plate
   b. Rotate system 90 degrees in the z axis (out of page) and vertically clamp/stabilize hexagon piece
   c. Make sure contact edges are flush, weld along the outside boundary
      i. Weight of alignment piece = 3lbs.

4. Lay hexagon piece flat again, and repeat step 3 twice for 2 regular chamber plates coincident to the most-recently welded bottom chamber plate (clamp, rotate, weld)
   a. To correct for potential gaps between the length wise contact boundaries of chamber plates, add duct tape or tack-weld
      i. For tack-welding, maximum gap is 0.0625" which is exceeded at a location of about 50% the plate lengths (vertically)

5. Repeat steps 3 and 4. Begin by welding top most plate (repeating step 3) and then the remaining regular chamber plates coincident with the top plate (repeating step 4)
   a. Again, correct for gaps by using duct tape/tack welding

6. Lay back annular mounting plate flat on table, place assembled chamber on top (back of hexagonal alignment piece flush with front of back mounting plate, weld boundary. System is now ready for installation inside the outer TBM pipe. Follow directions in high-level assembly plan.

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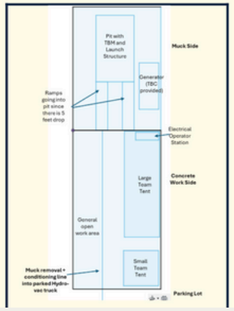
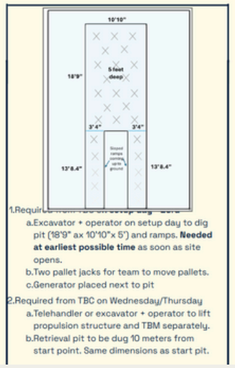
Section 3

Launch Setup

Site Layout





1.Requir[illegible]

a.Excavator + operator on setup day to dig pit (18'9" ax 10'10"x 5') and ramps. **Needed at earliest possible time** as soon as site opens.

b.Two pallet jacks for team to move pallets.

c.Generator placed next to pit

2.Required from TBC on Wednesday/Thursday

a.Telehandler or excavator + operator to lift propulsion structure and TBM separately.

b.Retrieval pit to be dug 10 meters from start point. Same dimensions as start pit.

Retrieval Plans

- Retrieval pit is dug for our max possible dig length of 11 meters. Once tbm surfaces, all pipes/wires will be disconnected, removable eye bolts will be screwed into the top and lifted out.
- In the event of machine failure before finishing dig, excavator will be required to dig to the depth of tunnel crown, team will dig around the pit to reveal full TBM for lifting.

Section 2

Ready to mine?: No

Cutterhead & Main Drive

Biggest Risks

1. Reaction torque causes TBM to spin
   a. Mitigation: Gearmotor can spin in both directions. Will switch if IMU indicates excessive TBM rotation
   b. Unlikely to happen since TBM is heavy + friction between back of TBM and clay pipe resists rotation
2. Outer scrapers tool wear
   a. An overcut is present where the outer cutters furthest point leads to an effective 20.5" OD (above the 20" of TBM itself)
3. Leakage of oil from venting hole on gearmotor
   a. Mitigation: Oil leakage point is placed facing up, gravity will not act to cause a leakage.
4. Motor mounting plate-outer structure weld failing (since made by amateur student welders)
   a. Failure does not harm humans. It is safe.

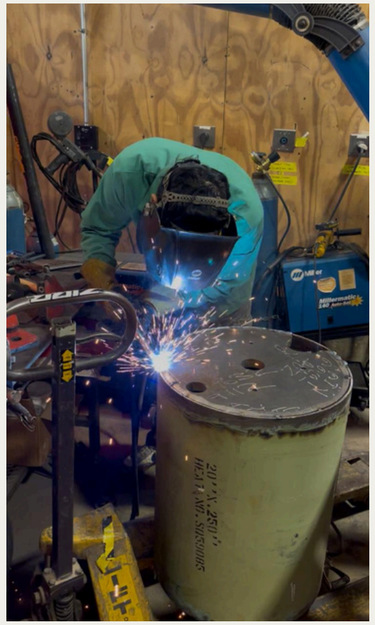
Subsystem Single Points of Failure

1. Weld at shaft-alignment plate interface fails
   Both parts are made of stronger 4340 steel + professionally TIG-welded with appropriate 4340 wire.
2. Coupler fails
   Unlikely since coupler is rated for max-torque expected (with FOS). This torque is likely not required at initial stages of dig either.

Open Action Items

1. Fasten cutters on cutterhead
   Done at comp to minimize cutter damage.
2. Mount motor into TBM structure
   Will be done on Monday, Tuesday latest
3. Mount coupler, shaft, cutterhead onto TBM
   Will be done on Monday, Tuesday latest
4. Spin Test:
   Will be done once TBM is assembled and high power on is approved

Evaluated mining readiness across mechanical systems to present to overseeing organization (Boring Company)



Manufacturing + Assembly at Nextfab (makeshift workspace for the machine)

Learnt and applied flux-core MIG Welding up to 1/4" thickness on Mild Steel.

Coordinated site prep, lifting ops, troubleshooting dig/ demo day failures