



PENN
HYPERLOOP

NoDiggity V1

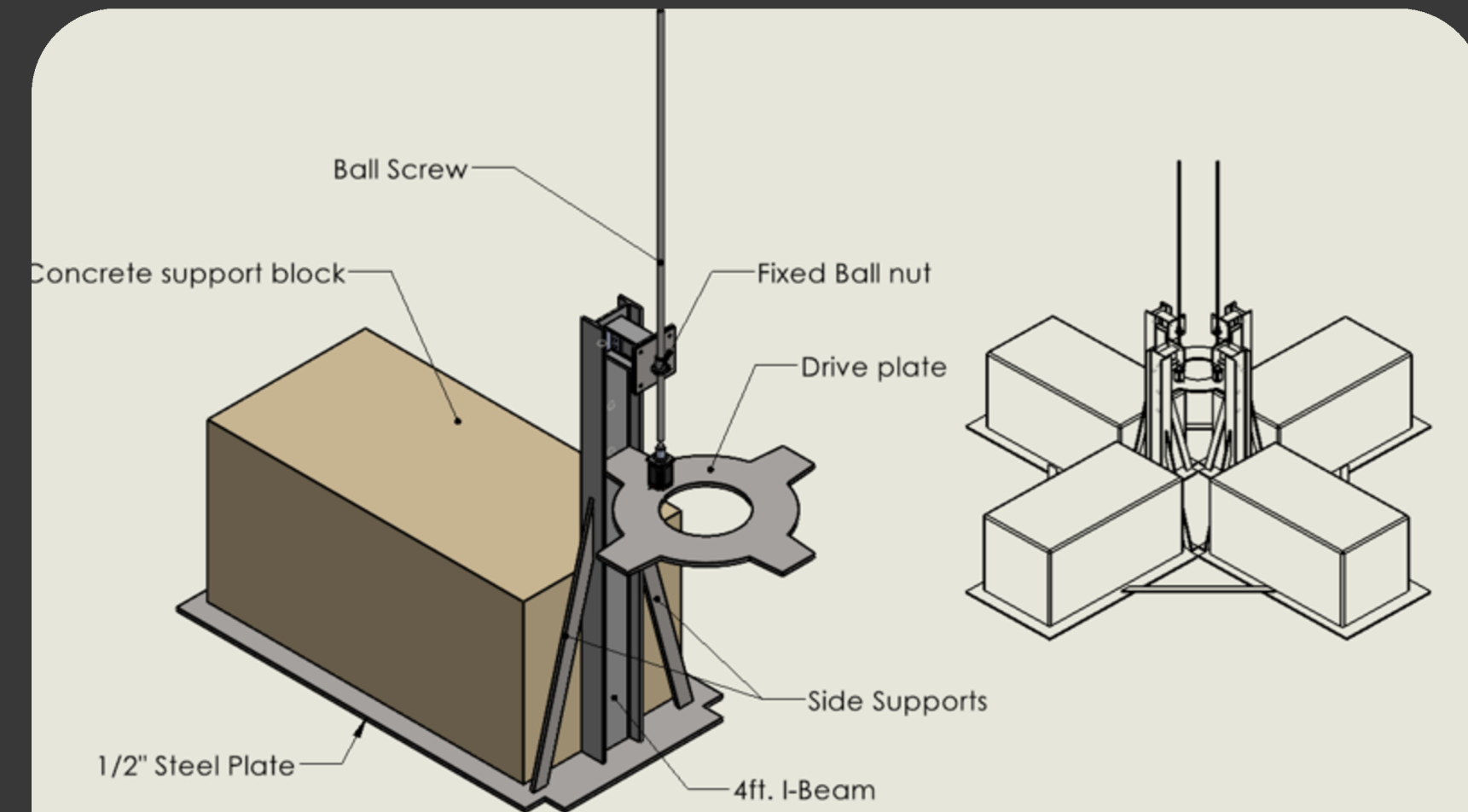
Founding member of what came to be the Penn Hyperloop team later. Our goal was to dig a 1 meter hole with a 0.5 meter diameter in Bastrop, Texas soil. I was the Propulsion System RE (responsible engineer) – an independent on-ground structure that would push the TBM vertically downwards as it excavated.

In addition, as 1 of 3 mechanical team members, I assisted in the machining of custom gearmotor keys, forming the machine's outer shell, and troubleshooting a host of competition safety related requirements.

Aggressive 2 month design phase + 3 week construction phase to win 1st place in our Digging Mini-Event at NaBC '24 (for the Boring Company).

Propulsion System - NoDiggity V1 - Penn Hyperloop

- Designed force reaction and torque reaction into the structure
- Switched from traditionally preferred linear actuators to ball screws to make a 5x cost reduction in this system.
- Learnt and performed weld shear calculations for key joints
- Conducted bolt shear analysis at fastened joints
- Identified and sourced metal from local vendors at discount rates and <1 week lead times.
- Attempted force testing to characterize ball screw movement as an actuator (with help of controls team)



- Propulsion Method: SFU1605 Ball Screw Linear Actuator
- Maximum Thrust Force: >1600 lbf
- Motor Type: NEMA23 DC Stepper Motors
- Torque Reaction Method: Slotting into I-Beam Webs and Ground Screws
- Thrust Reaction Method: Four Concrete Bunker Blocks on 1/2" thick steel plates

PROPULSION

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Phase A: Structure Testing

a. Objective
To assemble the propulsion stands in their entirety. This will involve welding and drilling various ordered components and also fabricating certain components at nextfab. The structure must be able to be assembled when required and immediately connected to an appropriate test setup and motor further testing.

b. Safety
I-Beams are heavy, keep them on stable surfaces and not slanted surfaces.
General caution to be exercised when using heavy machinery at Nextfab.
No safety concerns when assembling parts with fasteners

c. Materials Required
All required components to be ordered for the structure with quantity and sizing where applicable have been detailed in the **propulsion BOM (below)**.
Nextfab equipment is required to:
1. Bend steel plates - Metal Stock Bender
2. Drill holes into the I-beam, Steel plates - Drill Press
3. TIG-weld various components (described below) - TIG Welder
4. Bandsaw to cut threaded rod
5. Cut steel sheet into ring - CNC Mill
6. Tapping into steel sheet - Tap
All other assembly steps are to be done by hand/ using basic tools available in-house.

d. Steps
1. Steel Plates (2.75" x 3" plates) for Clip angles to be **beat** using the Metal Stock Bender at Nextfab across its length by 90 degrees (two sections of 2.75" x 1.5" each).
2. Remaining Steel Plates to be used as Connection Plates have M8 holes drilled on all 4 corners using Drill Press at Nextfab. Position: Center to be 0.8" away from two edges at every corner.
3. 3 M8 Holes drilled into one side of each Clip Angle using Drill Press at Nextfab. Position: drawing below.

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4. Drill 6 M8 holes in each Main I-Beam using a drill press. Drawing below for position of holes.

5. Weld every connection plate to the edge of the flat side of both sides of the 4 Side I-Beams. Rishu will weld at Nextfab.

6. Weld 4 connection plates to the other side of every side I-Beam. Connection plate to be centered. Illustrated below for reference.

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7. Weld all tie-down rings to the I-Beams as shown below. Position: centered from both sides, flush to the top of the I-Beam.

8. Cut threaded rods to 16 6" pieces.

9. Use the CNC Mill to cut into the aluminum sheet to make a ring of outer diameter 20" and inner diameter 10".

10. Tap 4 sets of 4 M4 holes 1" deep into 4 symmetrical edges of the sheet to mount the motors. Each set of 4 holes need to be exactly 47.14 mm apart from each other in a square orientation.

Assembly Plans, Test Plans and BOM's generated for owned system

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13. Thread the ball screws through all the ball nuts. Attach the motor to the coupler to the bottom of each ball screw. Attach motors to the tapped holes using the threaded rods and M4 nuts.

Phase B: Out of Box Testing

a. Test Objective

High level objectives are to establish the functionality of the:

- (x4) NEMA23 stepper motors
- (x4) DM542T motor drivers
- Power distribution block
- Signal ground block

So any defective products can be identified and returned ASAP.

The following specific objectives must be met:

- The DM542T drivers must send accurate and uniform commutation signals to the NEMA23 motors while not exceeding 40 degrees celcius (maximum allowable value as specified in the [datasheet](#))
- The motor shafts must rotate and change direction without the motor bodies exceeding 130 degrees celcius (maximum allowable value as specified in the [operating manual](#))
- The wires connected to the distribution blocks must be sufficiently rigid such that they will not lose contact during operation.

Since dig time is ~10 minutes, a 30 minute test for driver and motor functionality should suffice. To complete the specified objective, this test include:

- Acceleration
- Deceleration
- Direction changing

b. Outcomes / Dependent Variable

Variable	Value Constraints	Reason
NEMA23 temperature (C)	130C max	Maximum allowable value as specified in datasheet
DM542T temperature (C)	40C max	Maximum allowable value as specified as

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[operating manual](#)

c. Independent Variables

The knobs of control for this test is:

- The rotational velocity of the motor shafts.

The motor shafts are spun by using the four signal pins on the DM542T. Below are each of the signal and power lines, their purpose, and how they are connected:

Name	Purpose	Connection
Motor Wires (A+, A-, B+, B-)	Commutate the stepper motor phases	A+, A-, B+, B- pins on DM542T
PWR+, PWR-	24V power supply for the DM542T	Power Distribution Block terminals
PUL+, DIR+	Signal input pins on the DM542T for specifying motor direction and pulses	Arduino UNO or Teensy (test microcontroller)
PUL-, DIR-	Signal ground pins	Signal Ground Block terminals
Power Distribution Block	Supplies 24V for the four DM542Ts	Upstream 24V Full Bridge Rectifier supplies 24V to the four DM542Ts in parallel
Signal Distribution Block	Creates a common signal ground for all the DIR- and PUL- pins	All four pins of the DM542T's PUL- and DIR- pins are connected to the Arduino Uno's ground pin.

The [ArduinoStepper](#) library will be used for programming. The sequence of commands that will be sent to the NEMA 23's for testing can be found as part (g).

d. Data Gathering

Bill of (Assembly) Materials:					
Electronics					
Category	Name	Unit Cost	Quantity	Total Cost	Lead Time
Motors	NEMA23 340.oz in	\$26	4	\$104	~1 week
Motor drivers	DM542T	\$28	1	\$28	<1 week
Ball Screw + Nut	SEU 1605	\$75	4	\$300	~1 week
Coupler	10mm to 8 mm	\$3.6	4	\$14.4	~2 weeks
Power Distribution	Power Distribution Block	\$18	1	\$18	< 1 week
Power Distribution	Signal Ground Block	\$25	1	\$25	< 1 week
			TOTAL	\$489.4	

Structure				
Category	Name	Unit Cost	Quantity	Total Cost
Main I-Beam	S 6 x 12.5 lb (6.00" x .232" x 8.332") A36/A572-50 Standard Steel I Beam B16125, Custom size - 4.75 feet	\$178.26	4	\$713.04
Side I-Beam	S 4 x 7.7 lb (4.00" x .193" x 2.663")	\$18.09	4	\$72.36

There are very few safety risks associated with this stage of the test. However, the following precautions should be taken when the system is energized:

- Safety glasses worn
- No hands-on contact with components

f. Materials Required

Assembly Materials:

Name	Description
NEMA 23 Motors (x4)	Stepper motors
DM542T	Stepper drivers that control the NEMA 23s
Power Distribution Block	Distributes the 24V supply power (from upstream rectifier) to all the DM542Ts in parallel
Signal Ground Block	Creates a unified ground for all the DIR- and PUL- pins, requiring only one ground pin used on the Arduino
2x2" MDF board	For mounting the DM542Ts, Power Distribution Block, and Signal Ground block
3.5mm screws	Mounts the DM542T, Power Distribution Block, and Signal Ground block to MDF board
9 AWG copper wire	Connects 24V supply to the Power Distribution Block supply terminal

	A36/A572-50 Standard Steel I Beam B1477, Custom Size - 6 inches			
Tension Cable	304 Stainless Steel Wire Cable	\$34	1 (4 included)	\$34
Fasteners	M8 Bolt 30mm length	\$13.74	40 (2 packs of 25)	\$27.48
Fastener Nut	M8 Nut	\$9.67	40 (1 pack of 100)	\$9.67
Fastener Nut	M8 Larger Nut	\$11.58	40(1 pack of 50)	\$11.58
Pikes + Rope	Ground Anchor with Rope Pack of 8	\$28	1 (4 sets included)	\$28
Sheet Metal for Clip Angles	0.25" Carbon Steel Plate A36 Hot Rolled custom size 6"x6"	\$9.78	8	\$78.24
Sheet Metal for Connection Plates	0.25" Carbon Steel Plate A36 Hot Rolled custom size 2.75"x3"	\$3.07	8	\$24.56
Clip Angle	Manufactured in Nextfab Machine Shop by Rishu - Minimal Cost			
Connection Plate				
Tie-downs	Weld-On Tie-Down Rings	\$12.56	12	\$150.72
Threaded Rod	Threaded Rod	\$16.46	3 1m long rods (16 sets to be cut out)	\$49.38
Nut	M4 Nut	\$3.81	1 pack of 100	\$3.81
Nut	M4 Bigger Nut	\$7.14	2 packs of 50	\$14.28
Thrust Ring*	Aluminum 6061 Plate	\$1250	1	\$1250

