ME_Hyperloop @ IISc

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1. Introduction

One of the most promising technological innovations in the modern century is the Hyperloop. Deemed to be a new form of ground transport, the concept is an open-source vactrain design system currently under development. It involves passengers or freight transported by pods elevated by magnets, which travel within raised depressurized pipes. Although the idea of transporting goods and passengers in pneumatic tubes has been around since 1799, it was Elon Musk's 'Hyperloop Alpha' paper in 2013 that reignited the interest in this concept.

Hyperloop has garnered interest globally, with some of the world's leading organizations and research institutions already testing their respective prototypes in the US, Europe, and elsewhere. Here in India, Maharashtra's state government has approved Virgin Hyperloop One's plan to develop a high-speed line between Mumbai and Pune, which could also become the world's first hyperloop system.

On the occasion of the annual Open Day 2020 at IISc and the semi-sesquicentennial anniversary of the Department of Mechanical Engineering (ME), we presented a prototype of the Hyperloop to the public for the first time. This is in line with the department's tradition to ignite the minds of students, science and technology enthusiasts, by showcasing its various research activities. As our first attempt at designing and building a hyperloop system, we demonstrated the concept of magnetic levitation and air propulsion of our tethered pod. Please read the following sections to learn more about our efforts.

Components Used

- Magnets: Consists 24 Neodymium magnets (cubical N35 & cylindrical N52).
- Brushless DC Motor: Four 1100 kV BLDC
- Electronic Speed Controller: Four 30A ESC
- Potentiometer: 1Kilo ohm.
- Rotors: Four 3D printed (Ultimaker Polyjet) rotors with cutouts to firmly fix the magnets.
- Base Plate: 240x240x6 mm Polypropylene base.
- Aluminium track: Three sheets each of length 1m.
- Acrylic Board: As a channel for guiding the pod.
- Caster wheels: 4qty.

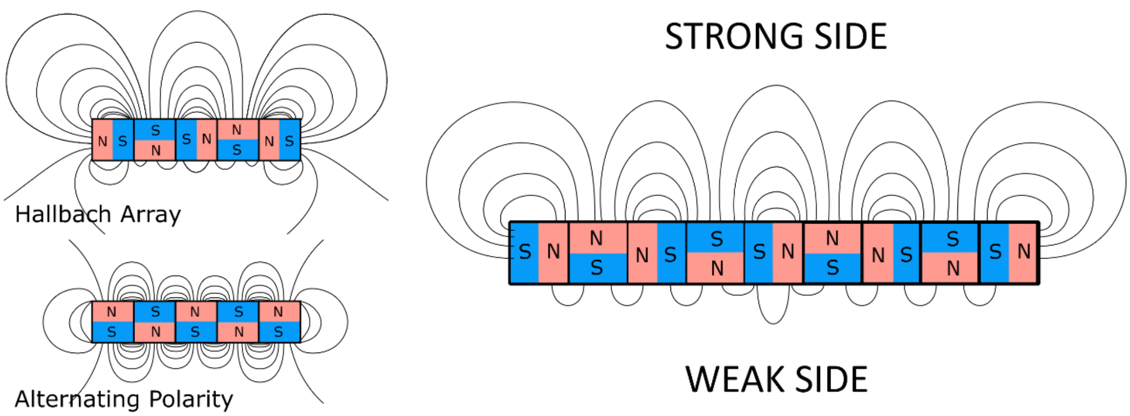
2. Concept

The two major aspects to any Hyperloop system are: *levitation* of the pod and its *propulsion*. Our approach to levitate the pod involved using the principles of magnetic levitation. Air propulsion in the form of a blower was used to propagate the pod through the chamber. While our current prototype was made to move in an open chamber, developing a low-pressure tube system, like the Hyperloop concept, is the end goal.

We implemented the following concepts while designing our prototype:

❖ Levitation Technique

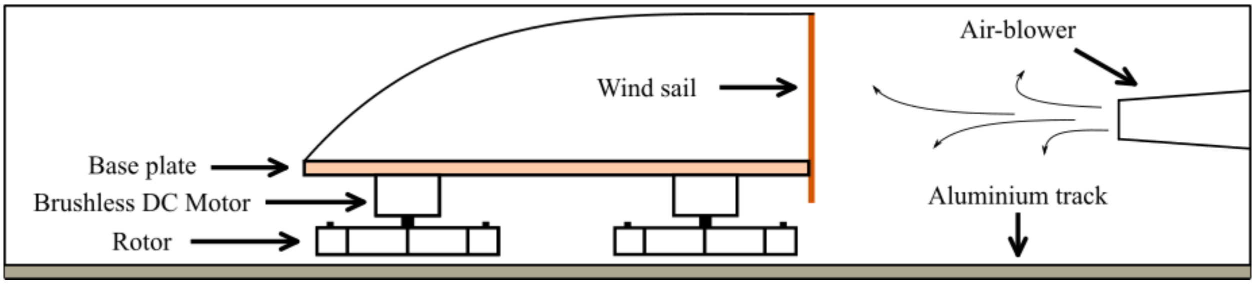
- ➢ Our pod levitates with the help of discs rotating under the pod, containing a special arrangement of permanent magnets called Halbach array. Unlike a regular array where the unlike poles of adjacent magnets are touching, a Halbach array has a spatially rotating pattern of magnetic field lines that produces larger, stronger uniform magnetic fields on one side whilst creating a small stray field on the opposite side. Thus, the force exerted by a Halbach magnet array on a conducting metal surface is greater than a conventional magnet arrangement with the same volume. The figure below indicates this.



- ➢ The operation is based on the principle of induction; and the levitation arises from the repulsive forces between the tracks induced magnetic field and the Halbach arrays permanent magnetic field. As the array is passed (or made to rotate) over the conductive metallic track, the variations in the magnetic field induce a voltage in the track. The changing voltage then generates changing current which induces a magnetic field in the track. And when this field aligns with the magnetic field produced by the Halbach array, it causes repulsion making the train levitate. It is similar to how the like-poles of two bar magnets repel when brought close to each other.

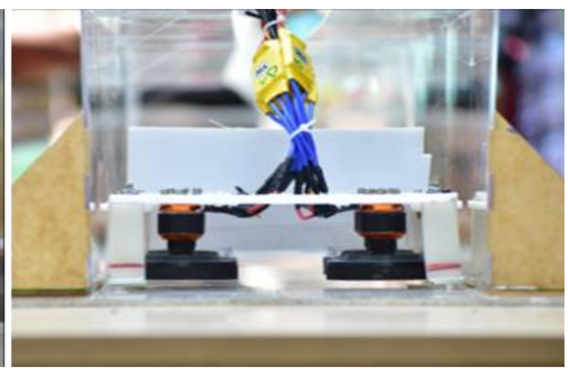
❖ Propulsion technique

- An Hyperloop pod levitates in air during motion either with air suspension or by electromagnetic levitation. The pod traverses in a sealed tube with low air pressure substantially reducing friction and air drag at high speeds. This allows the pod to carry high momentum throughout its journey after initial acceleration. Our prototype levitates in air at approximately 1.5 cm above a 3 m long aluminium track. The track is enclosed in an acrylic chamber and acceleration to the pod is given by exerting force by pressurized air from either end.



❖ Tethered power source

- Using the principle of *Pulse Width Modulation* (PWM) to control the speed of the motors, we operated the pod using a tethered power supply. PWM works by pulsating DC current and varying the amount of time that each pulse stays 'on' to control the amount of current that flows to a device such as a motor. By varying the 'on' and 'off' time of the motors, one can control the motor's speeds.



3. Design and Fabrication

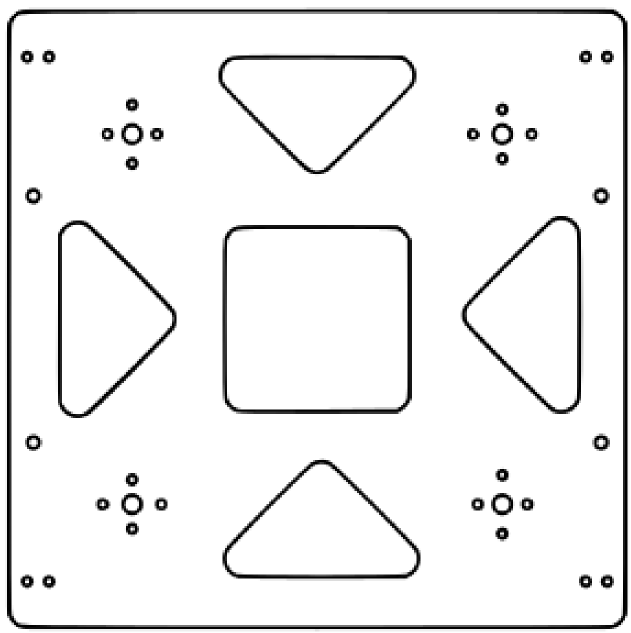
At present, our prototype has the following primary components:

a. The frame/chassis of the pod
b. A rotor retrofitted with cylindrical casings containing permanent magnets
c. An aluminium track

❖ Chassis or Base Plate Design

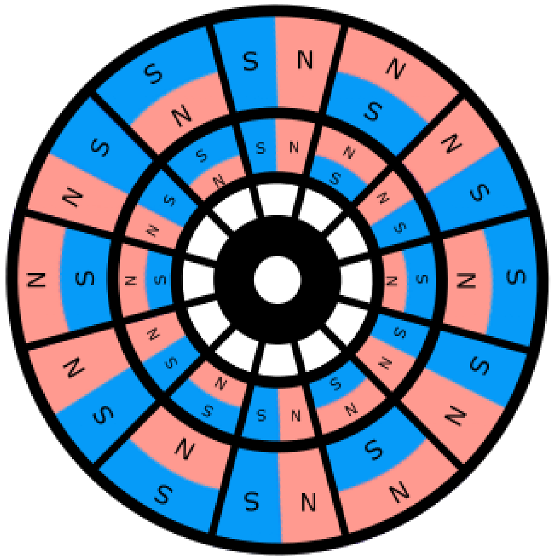
In the process of designing any mobile systems, the self-weight of the system plays a crucial role in the performance of the system. The chassis of the pod is also designed to absorb vibrations while reducing the self-weight.

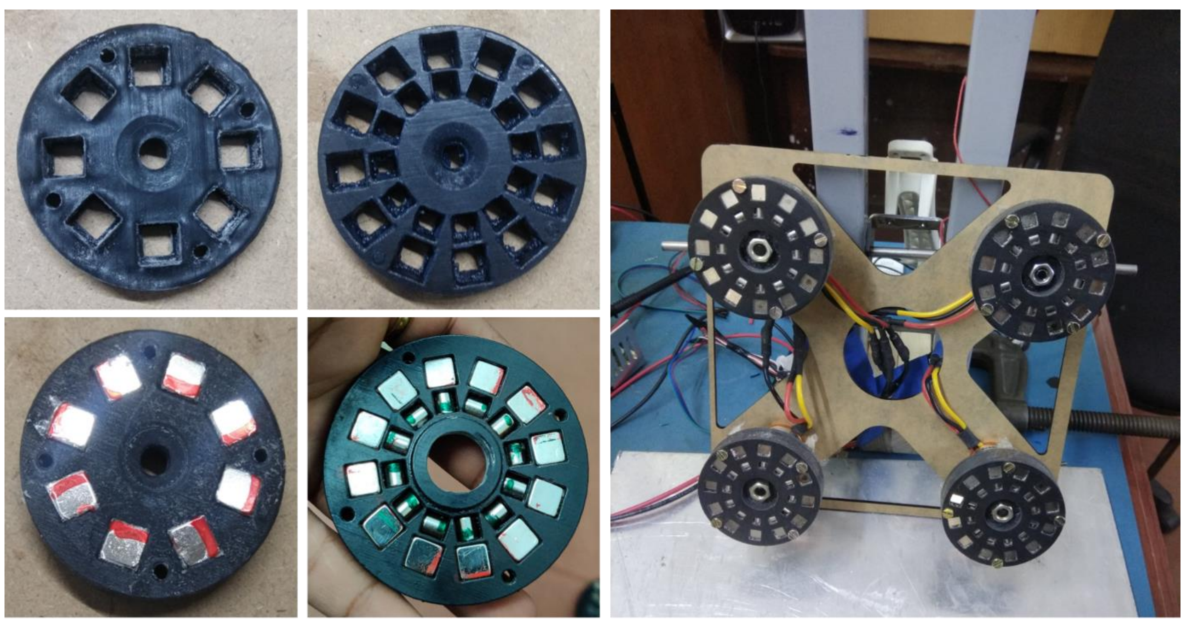
For our demonstration, we made preliminary design choices to ensure an even weight distribution of the base plate by introducing symmetrically positioned cutouts for mounting the motors, caster wheels and takeoff/landing frame. A centrally located circular cutout helps in ensuring that the wiring to the motors minimizes weight imbalance. To further reduce the weight, we also made four triangular cutouts close to the periphery of the frame. Our chassis is made of polypropylene sheet with a square geometry as shown in the figure below.



❖ Rotor Design

The rotor disc was designed to house an array (Halbach) of Neodymium magnets in a circular fashion. Two types of magnets were used in our demonstration; cubical N35 magnets and cylindrical N52 magnets. Symmetry in design was maintained to reduce vibrations and have an even weight distribution. The attachment of the rotor disc to the BLDC motor was designed considering failure due to shear while rotating at high speeds. The rotor disc was made of Vero Black material and printed using ‘Objet Polyjet 3D printer’.

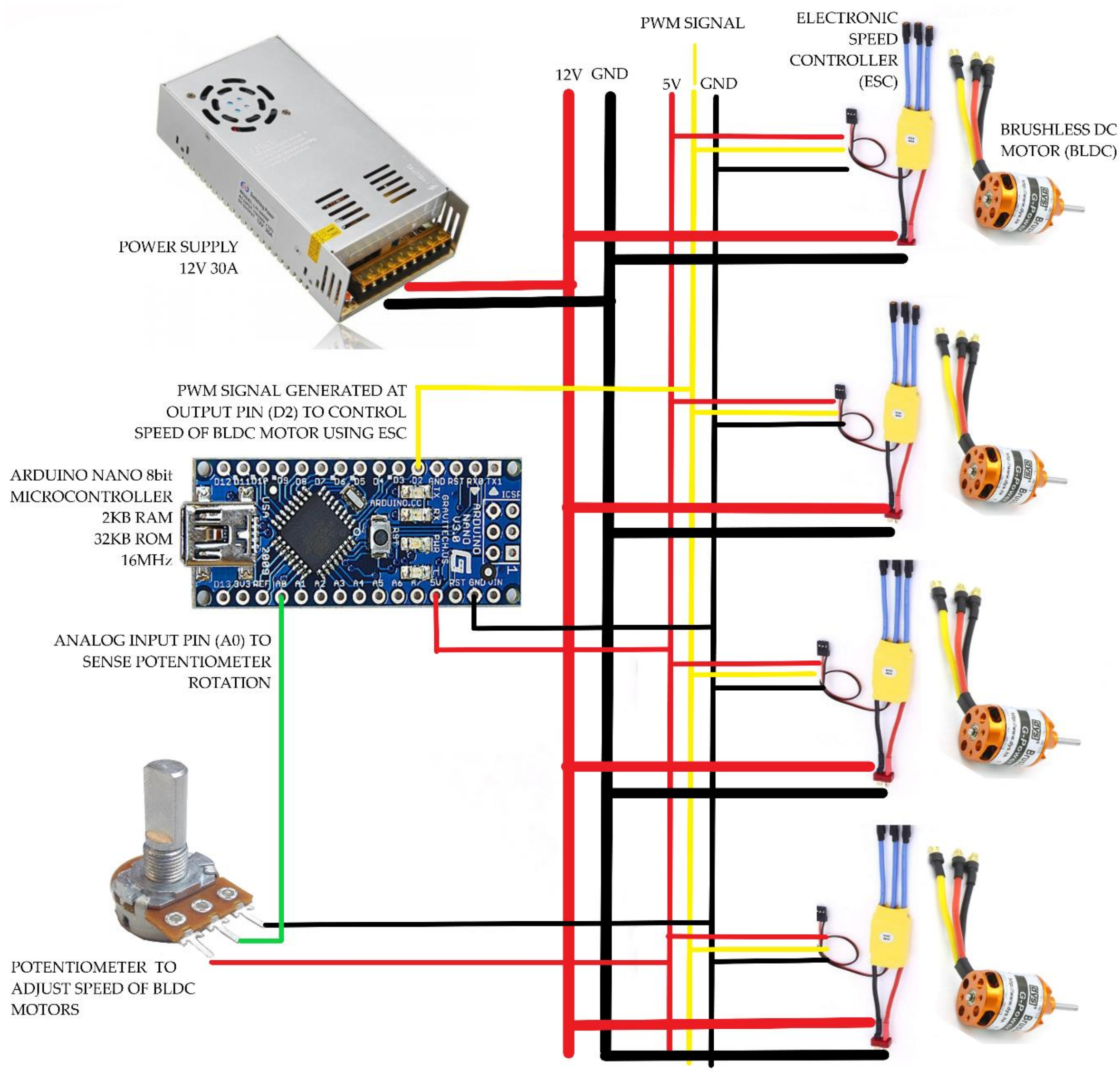




Design – 1 **Design – 2** **Assembled prototype**

4. Electronics Circuit Design

The pod is powered with a 12V 5A Switch Mode Power Supply (SMPS) which evenly divides power to the four electronic speed controllers (ESCs). A pulse width modulation (PWM) signal is sent to the ESCs to control the speed of rotation of the motors. The speed of the motors determines the rate at which the magnetic field changes, which in turn quantifies the magnitude of induced current. We use a potentiometer which interfaces with an Arduino microcontroller to vary the speed of the motors. All the components used in the project are off-the-shelf for ease of use and procurement.



5. FAQs on the day

Q: **How is Hyperloop different from a Maglev train?**

A: Hyperloop is designed to run in partial vacuum tubes, while the conventional Maglev train operates in a normal open-air environment. This allows Hyperloop to travel faster due to the lesser air drag experienced by the pod. In terms of operation, this is the main difference between the two. Other differences may arise in propulsion technology used, cost of operation, and passenger capacity. We must also note that Hyperloop is still a concept under development: several teams across the world are still working on refining the technology used to realize a hyperloop system.

Q: **What is the maximum load your model can take?**

A: Our current prototype can take up to a 1.2 kg load. It can be increased by adding more permanent magnets fixed to the pod and also by rotating the rotors at a higher RPM. We can also improve the load carrying capacity by using copper (instead of aluminium) for the track.

Q: **What is the maximum gap between the rotor and the conducting surface?**

A: Our prototype can currently levitate at a maximum height of 1.5 cm from the top surface of the track.

Q: **If Hyperloop operates in vacuum, why did you not use a vacuum chamber here?**

A: As our first attempt, our approach was to arrive at a successful levitation and propulsion technique, before proceeding to vacuum operations. As we were unable to meet the standards required for safety demonstration of the pod, we opted to propel the pod in a regular (not vacuum) chamber. One issue which we could not address was the safe operation of our pod in a depressurized chamber. Given the high speed of the rotors, vibrations experienced by the pod, and the absence of a monitoring system, the rotors and pod could break at any point, scattering the magnets and broken parts in all directions. Nonetheless, our next goal is to test an automated, redesigned, and untethered pod in a partial vacuum chamber.

Q: **What is the speed of the rotors?**

A: When levitating at no load, our rotors rotate at around 8000 RPM.

Q: **It looks like you are pulling the pod by the wire connected to it. Is that the case?**

A: The pod does not use the wire when moving forward. However, we used the wire to bring the pod back to its initial position. This can be seen in the video where, as the pod levitates and moves forward (due to the air propulsion from the blower), we see that the wire is slack. As we used a tethered power source, we held the wire by hand to prevent it from obstructing the motion of the pod.

Q: **What is the reason behind using polypropylene as a base material?**

A: Polypropylene has a high strength to weight ratio. Moreover, it is ductile in nature. Thus, it acts as a damper against the vibrations generated due to the high rotor speeds and gives us a prior visual indication as the frame tends towards breakage.

Q: **What is the most challenging task while making this prototype?**

A: We faced several challenges in every phase of making the prototype: modifying the rotor design, powering the pod etc. to achieve sustainable levitation and propulsion speeds. But, the biggest challenge was ensuring the safety of the audience during the demonstration. There is a fair chance that the pod and/or the rotor can break due to high vibration and high speed. This may cause the magnets and plastic pieces to scatter randomly and injure the spectators. This risk can only be minimized but never eradicated.

Q: **What is the making cost of your prototype?**

A: It cost us less than Rs. 25,000, including the service charges.

Q: **Can we make our own prototype like this in our home?**

A: Yes, you can definitely make one in your home. We would suggest choosing an isolated place for building one.

6. Acknowledgement

We sincerely thank the Mechanical Engineering Department, IISc for providing us the opportunity to showcase our model on Open Day-2020. We express our heartfelt gratitude to Prof. G. K. Ananthasuresh and the M2D2 Lab for funding the project. For all the invaluable suggestions and support we received during our 14-day project, we thank all the members of M2D2 & Biomechanics lab, Anshul, Mihir, Sudhanva, Raghuram, and the departmental organizing committee. Without their timely support, we would not have achieved this milestone. A special thanks to Sachin Arya for designing the ME ‘Hyperloop’ logo for the event. We thank Anshul, Atanu, Nisheeth, Raghvendra for capturing all the key moments during our demonstrations. Last but not the least, we thank the audience who visited, appreciated and gave us valuable feedback which serves as motivation for our next attempt.

The “H – Team”

The “H – Team” with the Chair of Mechanical Engg. Dept. IISc. (From right to left): 1. Sundaram, 2. Praneet, 3. Vageesh, 4. Prof. G. K. Ananthasuresh, 5. Akshay, 6. Ankur, 7. Chaitanya, 8. Priyabrata.

Links:

- Link to vactrain: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwje6emNn7frAhXUbX0KHaJiCYQQFjAAegQIAhAB&url=https%3A%2F%2Fen.wikipedia.org%2Fwiki%2FVactrain&usg=AOvVaw3jd-xoW932g2XVNUu07Jcp
- https://www.kjmagnetics.com/blog.asp?p=halbach-arrays