International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 04 | April - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Design of Prototype Hyperloop using Permanent Magnets

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Abstract

The project is centered on the development of an Hyperloop prototype magnetic levitation system, it harnesses the repulsive forces of permanent magnets to achieve magnetic levitation. It also incorporates a comprehensive review of maglev and hyperloop system technology, exploring their development and applications. The utilization of Aerodynamic technology in designing the capsule structure to facilitate smooth and efficient movement within the hyperloop. Applying the suction force of a vacuum cleaner to move the capsule easy and also conventional method of propulsion is implemented in the project. The challenges in the hyperloop prototype is to develop economical, energy-efficient, and environmentally friendly method of transportation for passengers without relying on fossil fuels or causing a significant carbon footprint in real-time.

Key Words: Magnetic levitation, magnetic propulsion, permanent magnets, Hyperloop, Capsule, Suction pressure, Lifting force.

1.INTRODUCTION

The role of transportation is vital in a developing economy, encompassing both daily travel and the movement of goods. However, the growth in population and the need for faster travel have raised concerns regarding air pollution and global warming. Recent data from 2020 revealed that nearly a quarter of greenhouse gas emissions worldwide are a result of transportation that relies on fuel. The future generation will encounter challenges related to energy security and climate change that require immediate attention. This article delves into the Hyperloop, an innovative form of transportation. Companies such as Virgin Hyperloop One, Trans pod Hyperloop, and Hyperloop are heavily investing in the research and advancement of this technology. The Hyperloop presents a promising option for traditional train travel, boasting enhanced safety, speed, reliability, and eco-friendliness [1].

The Hyperloop is an innovative form of transportation that utilizes a vactrain concept to move people and items. By creating a low-pressure environment within a tube, the Hyperloop aims to minimize air resistance and friction, allowing for incredibly fast travel speeds. Unlike typical train systems, the Hyperloop employs pods that glide through air-evacuated tunnels. These pods are equipped with air skis or magnetic levitation technology to reduce friction. The idea of utilizing vacuum tubes for transportation has a long history, with studies exploring the potential for levitation forces to improve the Hyperloop system. The pneumatic railway at the Crystal Palace, which was developed in 1864, made use of air pressure to move uphill and vacuum power for downhill travel. Since the late 19th century, pneumatic tube systems have been in use for the efficient transport of mail and packages between buildings. This practice is still common today in supermarkets and banks for the transfer of money. The Hyperloop, a revolutionary transportation system, is expected to surpass traditional trains and cars in terms of both speed and affordability. It is also considered more environmentally friendly than air travel and quicker to build than high-speed rail networks. This advancement could help reduce traffic congestion, making intercity travel easier and bringing significant economic benefits, such as job opportunities, while also offering budget-friendly ticket prices. Our project aims to create a smaller version of the Virgin Hyperloop concept using permanent magnets [1].

2. Components and Specifications

Capsule: The project is based on using transparent acrylic pipes as main components. Two pipes are welded together with the sides to enable the capsule to go and come back. The capsule is shifted into a tube horizontality

with low pressure air maintained at 100 pascals, which are 1000 times less than the pressure on earth. Such conditions decrease the drag forces and speed up the transport. The tubes are built above pillars freeing the traffic and getting much more space. Air bearings and suspension are designed to make the ride as smooth as possible for the passengers. The geometrical dimensions of the tube are outer diameter in 75mm, inner diameter in 69mm and 26 feet long. Plastic clamps are mounted to the pipes that rest on the wooden ladders. This project will attempt to make the capsule visible in this prototype and to also make it fully functional [2][3].

Tube:

The Hyperloop capsule consists of two main components: sealed capsules that can carry passengers and three full-size vehicles, and even larger structure that can transport three full-size vehicles within the capsule. These capsules are supported by air bearings using compressed gas reservoirs and aerodynamic force. The capsules are isolated inside the tube by around some km during operation. Two versions of the capsules are being considered: a passenger capsule with a traditional flight time of two minutes and a passenger plus vehicle capsule that can accommodate those vehicles. The capsules are designed to overcome air resistance and facility requirements [2].

Levitation:

The passive magnetic levitation of the Hyperloop train prototype is achieved by using permanent magnets in the train pod, a technology developed by physicist Richard Post. This makes use of the unpowered wire loops on the track and magnets within the train's pod thus avoiding complicated infrastructure upgrades. The magnets establish an electric field that prevents contact between the pods of trains even during power outage to ensure that they are still hovering. Consequently, this is a reasonable and secure levitating mechanism for swift transportation systems like Hyperloop [4].

Propulsion:

The propulsion system using permanent magnets in the Hyperloop locomotive prototype operates by leveraging the magnetic fields generated by these magnets to achieve movement and acceleration. This system is based on the principle of electromagnetic propulsion (EMP), where the interaction between the permanent magnets on the train and the induced magnetic field on the track creates a repulsive force that propels the train forward as it moves above a critical speed. The use of permanent magnets in Hyper loop locomotive prototype, can lead to excellent efficiency and fuel savings, enhancing efficiency [5].

Permanent magnets:

Permanent magnets are used in the Hyperloop locomotive prototype to generate the magnetic field that enables levitation and propulsion. The magnetic field on the train is produced by either permanent magnets or superconducting magnets, with the induced magnetic field generated by wires or conducting strips on the track. The use of permanent magnets in the Hyperloop system provides a simpler design as it does not require a high electric power supply, although it is limited to applications for small systems due to the availability of high-powered permanent magnets. Passive magnetic levitation, utilizing permanent room-temperature magnets, is an alternative technology used in Hyperloop transportation systems to create levitation without the need for complex infrastructure upgrades like power sources along the track [6].

Compressor:

The compressor at the front of a capsule is essential for transferring air-to-air bearings that support the capsule's weight. It allows the capsule to move through a low-pressure tube without obstructing airflow. Compressed air, with 20:1 ratio, bypasses up to 60% of the air, traveling through a narrow tube near the capsule's bottom to the tail. A nozzle expands the flow to generate thrust, reducing aerodynamic and bearing drag. Air bearings support loads without metal-to-metal contact, offering advantages like high rotational accuracy, low vibration, dimensional stability, high speeds, stiffness, increased bearing life, improved surface finish, cleanliness, and ease of maintenance. Proper air quality and supply are crucial for optimal spindle operation.

3.PROJECT DESCRIPTION

Firstly, we have planned and make budget plan for our project. We have done the specific calculations for our prototype such as lifting force and suction force. According to that we bought all the components as per the grading, calculations, and power. We used neodymium 35 graded permanent magnets in our prototype which has a flux density of 1.8 tesla. Then we have used acrylic transparent pipes for the transparency of our project. Then we used vacuum cleaner to create a low pressure inside the tube for better levitation. Levitation force on the surface of two magnets are 23mm and distance between two magnets are 1.5 cm each up to 2 meters pipe which we placed 76 magnets on the track. Then we have designed capsule with a specific design and calculations. After that we placed the track and capsule inside the tube, we created a low pressure using vacuum cleaner and it worked.

4.CHALLENGES

- The project involves designing a low-pressure environment, managing high speeds, ensuring stability and control, and addressing potential safety concerns for Hyperloop locomotive prototype.
- Enhancing levitation, propulsion, and vacuum technologies, for rapid transportation.
- Acquiring support, for research, a design, and implementation.
- Carrying out thorough testing and validation to ensure safety, effectiveness, and dependability.

5.SAFETY

The safety of the hyperloop prototype for public transportation.

- One aspect that enhances the effectiveness of Hyperloop as a prototype is its safety aspect and vehicle safety is an issue that follows from it. Agreed.
- Risk Assessment: Due to the small confinement tube for people and goods transported at such high speeds, process safety management has been considered the best way to identify and control risk regarding Hyperloop technology use.
- Safety Measures: The security system design ensures passenger's protection are assured. This means that in terms of safety, the Hyperloop functions on the basis that it should be as safe as commercial airplanes across Europe.

To increase general level of safety, advanced safety procedures include semi-quantitative risk evaluation, auto pods control, communication systems, emergency evacuation plans, and scenarios RAM analysis stakeholder analysis security measures respectively.

7. THEORITICAL CALCULATIONS

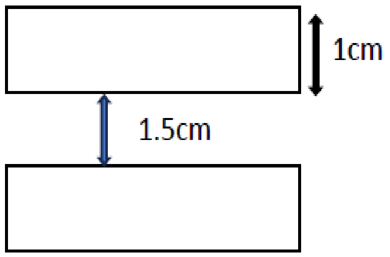
- Permanent magnet lifting force (or) magnetic levitation force calculation.
- Grade of the magnet is "Neodymium35".
- Magnet specifications: - [coated with nickel]

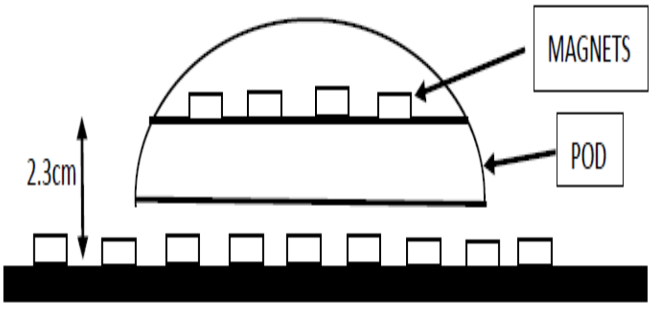
Magnetic grade	Flux density (B_r)	
	T (or) w/m²	KGs
N_{35}	1.18	11.8

Area of magnet is $=2(lw + lh + wh)$
Size of magnet is length (l) =20mm
Width (w) = 10mm
Height (h) = 5mm
Area of magnet is $= 2(lw + lh + wh)$
$= 2((20*10) + (20*5) + (10*5))$
Area of magnet is = 700mm² (in mm²)
Total lifting force = 0.0007m² (in m²)

Distance between magnets:

- Magnetic track
- Distance between magnets in track = 1.5cm
- Levitation height = 2.3cm





Strength of magnet:
Nickel coated neodymium magnet

- Thickness of coating layer = 15μm to 30μm

- It is antiferromagnetic but only at low temperatures below 19k (-254.2°C or -425.5°F)
- Magnetic field strength (H_A) ≈ 7T

Magnetic moment in $A.m^2$
Saturation magnetization (J_S) ≈1.6T or 16kg
BH_{max} (magnetic energy) ≈ 512 KJ/m^3 (or) 64MG.Oe

Inverse square law of magnetism force of attraction or repulsion:

- The force of attraction or repulsion between the two poles between the two poles of a magnet is directly proportional to the product of their pole strengths and inversely proportional to the square of the square of the distance between them

$$F = \frac{m1 * m2}{r^2}$$

Force of attraction or repulsion depends on

1. Pole strength
   Pole strength is more attraction and repulsion force is more
2. Distance between magnets
3. Magnets between magnets

$$F = K\frac{m1 * m2}{r^2}$$

$$k = medium\ constant$$

$$K = \frac{\mu}{4\pi}$$

$$F = \frac{\mu}{4\pi} * \frac{m1 * m2}{r^2}$$

Magnetic pole strength (M) = 1.4T
Ratio of pole strength = M_1: M_2 = 1:1

$$B_1 = B_2 = \frac{M_1}{r^3} = \frac{M_2}{(2.3 - r^3)}$$

$$[B = \frac{\mu}{4\pi} * \frac{2m}{r^2}]$$

$$\frac{1}{r^3} = \frac{1}{(2.3 - r)^3}$$

$$r = 2.3 - r$$

$$2r - 2.3$$

$$r = \frac{2.3}{2}$$

$$r = 1.15cm$$

Hence the magnetic field will be zero.

Lifting force of magnet:

Lifting force (f) = $\frac{1}{2} * \frac{B^2}{\mu} * A$ (N)

- F = Lifting force (or) Magnetic levitation force
- B = Flux density in air gap (in T) = 1.18T
- A = Area of magnet in m^2 = 0.0007m^2
- μ = Permeability of free space = $4\pi * 10^{-7}$

Lifting force of magnet (F) = $\frac{1}{2} * \frac{B^2}{\mu} * A$ (N)

Force (F) = 387.81N

To convert this newton to kg we will divide that "9.8"

Force (F) = $\frac{387.81}{9.8}$ (N)

F = 39.57kg

- Hence Lifting Force per unit area

$P_m = \frac{1}{2} * \frac{B^2}{\mu} (\frac{N}{m^2})$

$P_m = \frac{1}{2} * \frac{1.18^2}{4\pi * 10^{-7}} (\frac{N}{m^2})$

P_m = 554018.3 $\frac{N}{m^2}$

Convert it into kg-m^2

$P_m = \frac{\frac{1}{2}}{9.8} \frac{B^2}{\mu}$ kg/m^2

$P_m = \frac{0.051 * 1.18^2}{4\pi * 10^{-7}}$ kg/m^2

P_m = 56509.87 kg/m^2

- Vacuum cleaner suction lift Force Calculation: - (For Contant place)

power Consumption. = 700w
High suction power = 1734mm
Vacuum cleaner pressure = 14PSI
1PSI = 6894.76 Pa

14PSI = 14X6894.76 Pa
Vacuum cleaner pressure = 96526.6 Pa
Atmosphere pressure = 101, 325 Pa

Suction Lift Force:

F = P_{atm} A_o – $P_{suction}$ A_i
F = Upward Force the suction cup exerts on the pipe (N)
P_{atm} = Atmospheric pressure in absolute units (Pa)
A_o =Area of the outer of the Suction Cup
$A_o = \frac{\pi}{4} * D_o^2$ (in^2, m^2)
D_o = Diameter of the suction Cup outer circle (in (or) m)
$P_{suction}$ = The suction pressure, the cup cavity in absolute units (pa)
A_i = The Area of the inner of the Suction Cup lip
$A_i = \pi/4 * D_i$ (in^2(or) m^2)
D_i = diameter of the Suction Cup lip circle.
D_o = 3.2 cm = 0.032 m
D_o = 3cm = 0.030m
$A_o = \pi/4 * (D_o^2)\ m^2$
$A_o = \pi/4 * (0.032)^2 = 8.042 * 10^{-4}$ (m^2)
$A_i = \pi/4 * (D_i)^2\ m^2 => \pi/4 * (0.030)^2$
$A_i = 7.068 * 10^{-4}\ m^2$
Force (F) = P_{atm} A_o – $P_{suction}$ A_i
when pipe both ends are open then the pressure in pipe is equal to atmosphere pressure.
P_{atm} = 101, 325 pa
$P_{suction}$ = 96526.6.pa
A_o = 8.042x10m^2
A_i = 7.062x104 m^2

F = (101,325) *(8.042x10^-4) - 96526.6 (7.062×10^-4)
F = 13.31 N
To Convert This into kg
F = 13.31/9.8 kg
F= 1.35 kg

Calculation For pressure of vacuum cleaner:

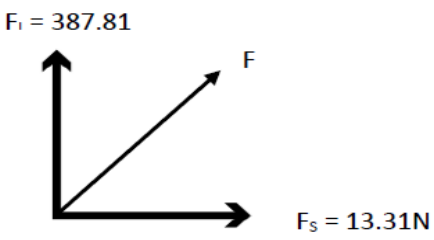
pressure in pipe (p) = $\frac{2*T*S}{D}$
P = pressure
S = Allowable stress=180F
t = wall thickness = 3mm = 0.003m
D = outside Diameter = 75mm = 0.075m
pressure (p) = = 2*0.003*$\frac{180}{0.075}$
P = 14.4 PSI

Relationship between force and acceleration:

F=ma
a = rate of change of velocity with respect to time
F=m*a

Resultant force:

F_L = Levitational Force
F_S = suction Force
$F^2 = F_L^2 + F_S^2$
$F^2 = (387.81)^2 + (13.31)^2$
F = 388.03 N



resultant Angle (Θ)= tan $(\frac{F_L}{F_S})$

Θ = tan $(\frac{387.81}{13.31})$

Θ = 0.55°
We considering Suction Force only
F = F_S, m=0.5kg, F=ma
13.31 = (0.5) *a
a=2.6.62 $\frac{m}{s^2}$
We Know the acceleration
We calculate "time"
Distance (D) = length of the pipe = 8m
a=26.62 $\frac{m}{s^2}$
Distance (D) = $ut + \frac{1}{2}at^2$
u=initial velocity
a=acceleration
t=time
8 = 0*t + $\frac{1}{2}$ (26.62) *t²
8 = $\frac{1}{2}$ (26.62) *t²
8 = 13.31xt²
$t^2 = \frac{8}{13.31}$
t = 0.775 s

speed calculation by using: -

Speed = $u + at$
u = initial velocity
a = acceleration
t = time
Speed = 0 +(26.62*0.77)
Speed = 20.49m/s
Speed = 73.76 km/hr.

8.Advantages:

- It saves traveling time.
- There's no problem with traffic.
- It can travel in any reasonably weather.
- Cost of travelling in hyperloop is low.
- Less disturbances compared to other transportations.

Disadvantages:

- Turnings are critical.
- Less movable space for the passenger.
- High speed might cause dizziness in passengers.
- The punctured tunnel could cause shockwaves.

9.Budget Planning:

The all expenses of our hyperloop prototype design as sketched out is under 25,900/-

Components	**Cost**
ACRYLIC PIPE	12000/-
HIGH POWER MAGNETS	8850/-
VACCUM CLEANER	3500/-
Plastic beadings	400/-
Plastic Sheet	300/-
Clamps and Base (Wooden pieces)	850/-
Total	25900/-

10. future extension:

Plans, for Advancing the Hyperloop Train Prototype,

- Speed Boost; Improving the Hyperloop technology to achieve speeds, for more effective travel.
- Extended Routes; Expanding the Hyperloop infrastructure to link distant cities and regions.

- Passenger Convenience; Upgrading passenger comfort through seating, entertainment choices and facilities.
- Sustainable Energy Use; Prioritizing energy efficiency in the Hyperloop design to lower harm and promote eco-friendly transportation.

CONCLUSION

Finally, our project concludes that, by using permanent magnets we can levitate and propel the capsule which we can make own and drag that capsule in a transparent acrylic tube by using suction force of vacuum cleaner with required components and necessary calculation. In this way the design and prototype of Hyperloop should be made as per our results.

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