Grenze International Journal of Engineering and Technology, Jul 2019

Conceptual Design of a Hyperloop Pod Traveling at High Speed inside a Vacuum Tube

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***Abstract*—Technological advancements has conceived a lot of research work in the field of transportation to make them faster, safer and economical. Hyperloop concept would be the preeminent solution that will revolutionize the mode of transportation. In this contemporary work a pod was designed and analyzed for various design iterations. The pod consists of C-shaped feet which comprises of magnets embedded in them. These feet levitate on the track consisting of electromagnets. The pod is propelled forward using an induction motor. The relative cross-section area of the tube and pod was resolved using the kantrowitz limit and was initiated that for a Mach number 0.6 the size of the tube was relatively smaller as compared to higher Mach number thus easing the economical and maintenance factor involved. The pod was them analyzed for coefficient of drag. It was assessed in a circumstance which generally endures at 10 to 12 km above sea level. It was designed according to the required aerodynamic shape and was iterated to get the optimum result.**

***Index Terms*— Hyperloop, pod, Kantrowitz limit, Drag Coefficient, Mach number, Magnetic levitation, Vacuum.**

I. Introduction

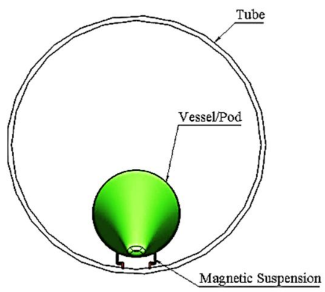
There's always a need for a faster, safer and economical mode of transport that enables everyday travellers to move from one place to another. The conventional modes of transportations tend to be either expensive or relatively slow so to overcome this, new technology is been proposed that may be fastest and safest mode of transportation Hyperloop concept might be the greatest leap transport infrastructure for the next generations this technology is developed by combining two concepts that is electric propulsion and magnetic levitation which promises to slash journey times from several hours to matter of minutes between major cities that would revolutionise our world. Hyperloop technology is a fastest mode of transportation that is designed for the high-speed ground transportation, which consists of a passenger capsule travelling at a speed of 1 Mach in a partially evacuated vacuum tube. This concept was first proposed by Elon musk which was published by SpaceX in the year 2013 [1]. This was basically designed as an alternative for the high-speed rail system that's currently been developed between San Francisco and Los Angeles [2]. To maintain the vacuum inside the tube vacuum pumps are installed to maintain the required pressure and air in the confined tube the main aim is to reduce the drag created by air resistance so for that we create a vacuum chamber so that pod can move at its top speed. Once we have achieved this then the pod is to be designed in a proper aerodynamic shape that will increase the efficiency

Grenze ID: 01.GIJET.5.2.501

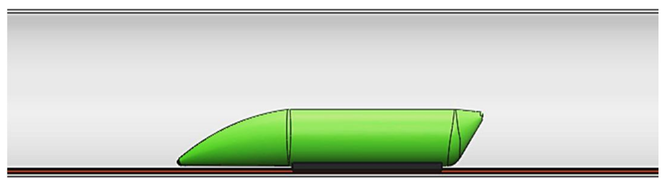
of the pod for that several designs has been proposed and analysis are been done in this field. We have designed a pod that a move up to a speed of 0.7 Mach in a pressure controlled tube. The pod is driven by linear induction motor and a compressor along with magnetic levitation, the tubes would create low pressure environment while surrounding the pod with the cushion of air that allows the capsule to move faster and safer [3].

II. Design of The Pod

The proposed model is based on the magnetic levitation. In this design the pod could be levitated easily using electromagnetic levitation and could be easily propelled forward. The pod is propelled forward using an electric motor. As witnessed, electric motor comprises of a rotor which is the rotating element and a stator which is stationary. The stator consisting of copper coils are energized there by creating a magnetic field which attracts the rotor consisting of magnets and there by rotating it in a particular direction. This basic principle is being applied in our design except the stator which is arranged linearly on the track. As the rotor tends to rotate, the pod moves forward because of the attractive force produced by the stator when they are energized by electromagnetic force. The pod also consists of wheels which helps it to maintain contact with the track inside the tube at low speed. At high speed these wheels, comes up so that there is minimum friction between the track and the pod. The pod inside the tube is shown in Fig 1.



(a)



(b)

Figure 1. (a) Front and (b) side view of the pod inside the tube

A. Kantrowitz Limit Contemplations

As the pod approaches the transonic speed, the flow around it tends to become Mach number 1, a condition of choke flow occurs which could slow down the pod. This condition is known as choked flow condition as the air gets choked at the frontal area of the pod. As the pod speeds up the mass flow that could easily pass around it is limited thus increasing the pressure at the frontal area of the pod. This is known as kantrowitz limit and is represented by (1).

$$\frac{A_4}{A_0} = M_0 \left(\frac{\gamma+1}{2+(\gamma-1)M_0^2} \right)^{\frac{\gamma+1}{2(\gamma-1)}} \left[\frac{(\gamma+1)M_0^2}{(\gamma-1)M_0^2+2} \right]^{\frac{-\gamma}{\gamma-1}} \left[\frac{\gamma+1}{2\gamma M_0^2-(\gamma-1)} \right]^{\frac{-1}{\gamma-1}} \tag{1}$$

The kantrowitz for the pod travelling through a tube is given by (2).

$$\frac{A_{bypass}}{A_{tube}} = \left[\frac{\gamma-1}{\gamma+1}\right]^{\frac{1}{2}} \left[\frac{2\gamma}{\gamma+1}\right]^{\frac{1}{\gamma-1}} \left[1+\frac{2}{\gamma-1}\frac{1}{M^2}\right]^{\frac{1}{2}} \left[1-\frac{\gamma-1}{2\gamma}\frac{1}{M^2}\right]^{\frac{1}{\gamma-1}} \tag{2}$$

Where A_{bypass}: The area inside the tube through which the flow is not restricted
A_{tube}: The total area of the cross-section of the tube.

M: Mach number and

γ: Isentropic expansion factor.

The speed limit that is set by the kantrowitz limit could be overcome by 2 possible methodologies. The first methodology is to place a compressor driven by an electric motor at the front of the pod. This compressor will suck the air in front of the pod is sent to a tube whose diameter reduces to a small tube, thereby compressing the air through that tube. At the back of the pod, the tube expands to considerable size which allows the air to escape through the other end consisting of a nozzle, there by producing a thrust which propels the pod forward. This air could also be sent through small holes at the bottom of the pod there by creating an air cushion that keeps it levitated [4]. The other method is to increase the diameter of the tube there by giving more bypass area for the air to flow. The second method was considered because there are risks involved using compressor in terms of designing, manufacturing and cost. Furthermore a lot of research is required for such compressors as they are not in use in aerospace applications these days [1].

B. Pod Design Considerations

The pod was designed after considering the max speed which lies between Mach number 0.6 to 0.7. At this Mach number the ratio of area of bypass to tube lies between 0.65 and 0.84. The tube diameter was assumed to be 3m, which gives us the diameter of the pod around 1.4m to 1.5m. The first pod (model 1) was designed to be a cylindrical pod with hemispherical front and back side. But this idea was rejected as the coefficient of drag (C_d) is quite high and will reduce the speed of the pod. Therefore in the next deign the frontal part was reshaped into a semi conical shape which is shown in Figure 2.

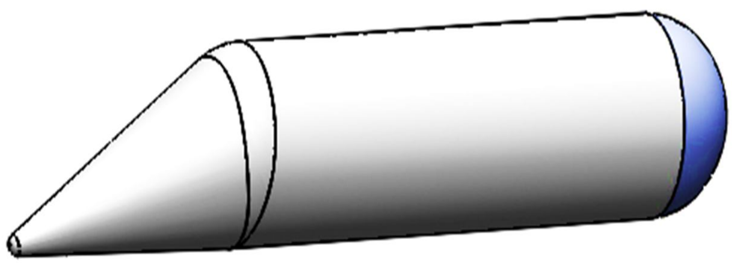
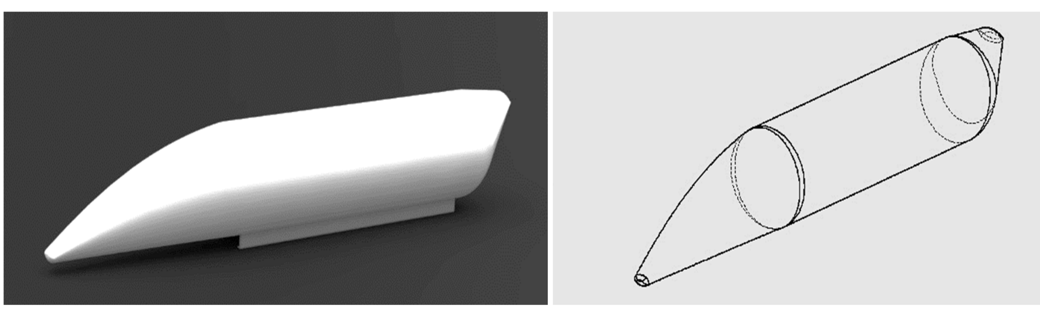


Figure 1. Model 2

This shape increases the surface area of the slant side there by assisting in easy air flow as well as less coefficient of drag compared to the hemispherical front. But the obtained coefficient of drag was quite high (above 0.05) when compared to a stream line body. This reduces the Mach number which was not acceptable and thus a better streamlined design was obtained. This design consists of a frontal end which was inspired from cockroach body structure. This structure reduces the coefficient of drag below 0.05 which is acceptable and is much lower than model 1. The new design has longer frontal part with a curved conical structure as shown in Figure 3.



(a) (b)

Figure 3. (a) Rendered image and (b) sketched view of the model 3.

C. Magnetic Levitation

The levitation was achieved by designing a track which comprises of electromagnets with similar poles facing out wards. The pod consists of feet in shape of C and have magnets attached on them. These magnets face the electro magnets of the track and produces a repulsion. But due to the design of the feet, it remains levitated in between the track as same poles of the magnets repels each other on both side of the track [5] [6]. This magnetic levitation of the pod is shown in Figure 4.

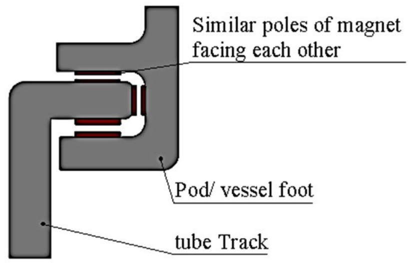


Figure 3. Magnetic levitation

III. Results And Discussions

A. Diameter of the Pod

The Kantrowitz limit for the vehicle was obtained using Equation 2 for Mach number 0.6, 0.7 and 0.8 which gives the ratio of the area of by pass to the area of tube through which the air flow takes place. The various limits for various Mach number was tabulated in Table I.

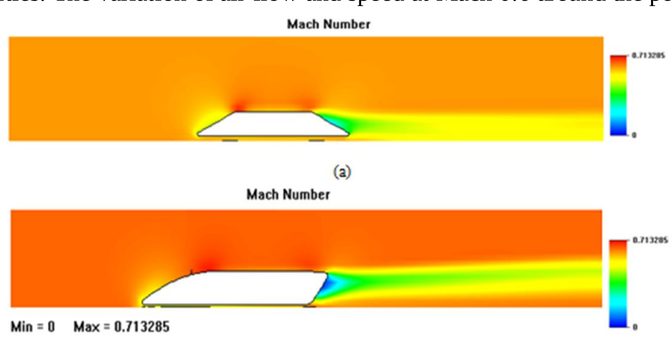
TABLE I. Kantrowitz Limit For Various Mach Number

Mach number	A_{bypass}/A_{tube}
0.8	0.942
0.7	0.844
0.6	0.65

The Mach number 0.6 was chosen as the ratio is less compared to other Mach number. Thus the size of the tube could be reduced such that the pod size is relatively half the diameter of the tube diameter. Assuming the tube sixe to be 3m diameter the pod size was calculated and found to lie between 1.4m To1.5m at 0.6 Mach number such that there is negligible choking of the air at the front of the pod.

B. Coefficient of Drag

The coefficient of drag was considered only for model 2 and model 3 as they are more likely to have less drag because of their surface design. The highest velocity was given around 221.9 m/s which is about Mach number 0.6. Since total (100%) vacuum is not possible, the tube was assumed to be 80% vacated using vacuum pump. Hence the inside pressure becomes 20% of the total atmospheric pressure and air density becomes 20% of density of air at sea level. These conditions are similar to the atmosphere present at 10km to 12km above sea level. These conditions also reduces the friction between air particles and the body of the pod. The main objective was to reduce the coefficient of drag below 0.05 such that there is less resistance to the movement of the pod at higher velocities. The variation of air flow and speed at Mach 0.6 around the pod is shown in Figure 5.



(b)

Figure 5. Variation of speed of airflow around the pod: (a) model 1 and (b) model 2

It was observed that model 3 frontal shape has least effect on the air flow and speed with respect to the model 2. The variation of the pressure of air is shown in Figure 6.

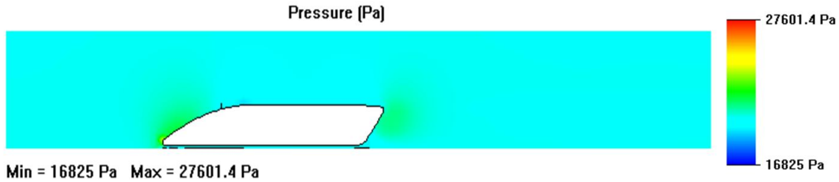


Figure 6. Variation of pressure around the pod for model 2 and model 3

The pressure at the frontal part came least for model 3, effecting less surface area as compared to model 2. The drag force for the frontal surface area is observed and tabulated along with the coefficient of drag for the respective pods. The coefficient of drag was calculated using:

$$c_d = \frac{2F_d}{\rho u^2 A} \tag{3}$$

F_d: Drag Force,
ρ: Density Of Air,
u : Velocity Of The Pod/ pod,
A: Surface Area.
The obtained coefficient of drag (Cd) for the models is given in Table II.

TABLE II. COEFFICIENT OF DRAG FOR VARIOUS MODELS

Model Number	Drag Force (N)	Surface Area (m^2)	Coefficient of Drag (C_d)	Average Mach Number
2	3813.76	9.9	0.0579	0.64
3	2799.85	10.6	0.0398	0.64

Since the coefficient of drag for model 3 is less compared to model, therefore it was taken into consideration for further development.

IV. CONCLUSION

The Kantrowitz limit for both the model were calculated. For Mach No. 0.6, it was found that Area of Bypass/Area of Tube was found to be 0.65. The diameter of the tube was decreased so that it could lead to an optimized size for the whole arrangement thus concurring to the economic angle. The Coefficient of Drag was found to be 0.0579 for the second model and 0.0398 for the third model thus implying that the third model will experience less drag force and it will be able to achieve greater speed. For both the model the average Mach No. was found to be 0.64. It is also evident that the air pressure experienced by the first model will be more thus encountering more resistance during transit. All these pertains to the supposition that the second model of the Hyperloop is more efficient and complies with the best interest of its implementation.

ACKNOWLEDGMENT

The authors of this paper wish to thank the Research and Development Centre, Mechanical Engineering Department, Siddaganga Institute of Technology, Tumakuru for supporting and completion of this work.

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