A3_4 Speeding into the Future with Maglev Trains

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Abstract

In this paper we present our findings for the maximum theoretical speed of a maglev train. The maximum theoretical speed was calculated by finding the force acting on the train due to the magnets. Then using this in the equation for terminal velocity, where the weight is replaced by the magnetic force, the maximum velocity at sea level was found to be 280 ms^{-1}. Following this, we plotted a graph to show how the maximum velocity of the train would change at varying air densities. This graph shows that velocity rapidly increases as air density decreases.

Introduction

Maglev trains are one of the newest and most exciting forms of transportation. The name maglev is derived from the uniqueness of its design, as the trains magnetically levitate in order to reduce friction. Due to the reduced friction these trains have, it is possible to reach incredible speeds, resulting in the time of journeys being cut dramatically. In this paper we have calculated the maximum theoretical velocity of a maglev train and plotted how this maximum velocity would vary with air density.

Method

In order to find the maximum theoretical velocity we first needed to know the force that the superconducting magnets have on the train. This was calculated by using Newton's second law of motion, as seen in equation (1), which required the acceleration and the mass of the train. The acceleration was calculated by finding the speed of the train after a given time and using equation (2) where v is the final velocity, u is the initial velocity and t is the time taken to reach the final velocity. Only a short initial acceleration period was used in order to reduce the impact of air resistance on the calculation. When the train is at lower speeds, the majority of the force is due to the magnets, hence the resultant force could be used as an approximation for the magnetic force.

$$F = ma \qquad (1)$$

$$a = \frac{v - u}{t} \qquad (2)$$

This force due to the magnets is equal to the force due to air resistance when the train is at its maximum velocity. This could then be used in equation (3) to calculate the maximum velocity of the train, V_{max}. Along with the force, the area of the train, A, the drag coefficient, C_d, and the density of the fluid that the train is moving in, ρ, were all required.

$$V_{max} = \sqrt{\frac{2F_M}{\rho C_d A}} \qquad (3)$$

This gives the maximum velocity that a maglev train can reach while accounting for air resistance at sea level. We have also extended this investigation by analysing the change in maximum velocity with the change in air density.

Findings

The acceleration of the train was calculated to be 0.58 ms^{-2}. It was possible to calculate this by using equation (2) as the Shanghai maglev train reaches 250 kmh^{-1} in 120 seconds [1]. The force of the magnets on the train was calculated to be 3.7×10^5 N. To calculate this the mass of the train was assumed to be 6.4×10^5 kg [2].

As previously described it was then possible to calculate the maximum velocity. This was found to be 280 ms^{-1}. This was calculated by using the air density, ρ, as 1.2 kgm^{-3} [3], however, this will affect the maximum theoretical velocity as seen in figure (1). Another assumption made was the shape of the cross sectional area of the train as this cannot be accurately measured. We assumed this to be roughly circular and therefore equalled the drag coefficient, C_d, to 0.5. The cross sectional area of the train was approximated to be 15 m^2. These are very conservative approximations, as in reality a maglev train is designed to be much more aerodynamic than a circle forcing its way through air.

It was then possible to vary the air density to determine how the maximum theoretical velocity would increase. In figure (1) it can be seen that as the air density decreases the maximum velocity of the train increases. This was expected as with less air resistance the train can obviously travel at a greater velocity. In figure (1) it is clear that the velocity increases rapidly. At just a tenth of the air density at sea level the maximum velocity increases from 280 ms^{-1} to 900 ms^{-1}, this is shown by the red dotted line in figure (1). As the air density tends towards zero the maximum possible velocity tends towards infinity. Obviously this is impossible as special relativity shows us nothing with mass can go faster than the speed of light. However, theoretically incredibly high speeds would be possible through
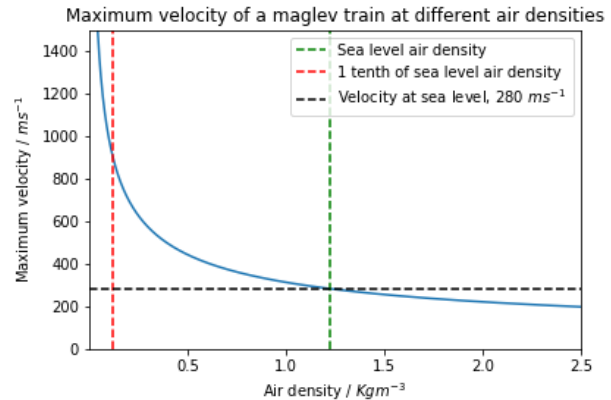

Figure 1: Graph showing how the maximum velocity varies with air density

the use of magnets in a vacuum tube.

Conclusion

In conclusion the maximum theoretical velocity of a maglev train was found to be 280 ms^{-1}, approximately 1000 kmh^{-1}. This is much greater than the maximum velocity a maglev train has reached to date, 170 ms^{-1} or 600 kmh^{-1} [5]. From figure (1) it is clear that as the air density decreases the maximum velocity rapidly increases. At 1 tenth of sea level air density the maximum velocity is 900 ms^{-1}. The trains do not reach this speed due to a number of reasons but most likely the fact that not all of the force is converted to the train's velocity and there is not 100% efficiency in this process.

References

[1] http://maglevgps.yolasite.com/[Accessed 19 October 2020]

[2] https://tinyurl.com/trainmass[Accessed 19 October 2020]

[3] https://tinyurl.com/airdens[Accessed 2 November 2020]

[4] https://tinyurl.com/dragshape[Accessed 19 October 2020]

[5] https://tinyurl.com/maxvel1 [Accessed 19 October 2020]