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A1 3 Steampunk Magnetic Rails

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Abstract

We investigated whether Victorian era steam trains produced enough power to levitate using maglev technology. The power required would be 40 MW, and the train would produce an average power of 864 KW, thus with the parameters we used the power was insufficient. We also note that with a few minor tweaks it could become possible, however impractical, and ultimately it would not be the power requirement that failed it, but rather the balancing act required.

Introduction

In recent years, interest in magnetic levitation trains has been on the rise aiming to find efficient, clean alternatives to traditional transportation options [1]. The Victorians were known for their trains, and this raised the question: would they be able to capitalise on this technology? The main concern was that, while energy was previously entirely going towards the acceleration of the train, it must now also support the weight of the train itself. Currently, this is not a problem, as the rails themselves can provide lift and power to the train, but here, we will assume that the train must instead provide its own power. There are two primary options in achieving magnetic levitation: electro-dynamic suspension, which requires the train to be moving at significant speed before the repulsive force generated by eddy currents is significant to hold the train; and electromagnetic suspension, which uses attraction by having the electromagnets underneath the track. We opted to look at Electromagnetic suspension as it is simpler, and does not require the train to already be moving.

Method

First, we needed to determine the force the magnets would be able to produce at a given distance. To do this we used the equation [2]

$$F = C\frac{B_0^2 A^2 (L_m^2 + R^2)}{\pi \mu_0 L_m^2}, \tag{1}$$

where B_0 is the magnetic field strength at the pole of the magnet, A is the cross sectional area of the pole of the magnet, L_m is the length of the magnet, R is the radius of the pole of the magnet, μ_0 is the permeability of free space, and where C is

$$C = \frac{1}{x^2} + \frac{1}{(x + 2L_m)^2} + \frac{1}{(x + L_m)^2}, \tag{2}$$

where x is the distance of the magnets from each other. This is a simplification for the force of bar magnets operating on each other, with the assumption that they are sufficiently far apart such that the radius of each magnet is significantly smaller than the distance between the magnets. This is not true in our case; however it was deemed a necessary simplification as no

simple equation for interactions between magnets as a function of their relative position has been derived [3]. Additionally, this force is for one magnet. We assumed that there would be 2 rows of electromagnets running the length of the train on either side, and that the forces of each magnet would sum to create a total force. To calculate B_0 we used the magnetic field of a solenoid [4],

$$B_0 = \frac{\mu_0 N I}{L_m}, \tag{3}$$

where N is the number of turns in the solenoid and I is the current in the wire. As we want to know power consumption, we use the equation

$$P = I^2 R, \tag{4}$$

where R is the resistance of the wire. This requires us to rearrange Eq. 3 for current and find the resistance of the electromagnet, which we can find using the equation

$$R = \rho \frac{L_w}{A_w}, \tag{5}$$

where ρ is the resistivity of copper at 20°C, and A_w is the cross sectional area of the wire. For ρ we used a value of 1.8 x 10^{-8} Ωm [4]. We took example electromagnets from [5]. These had 1300 turns, with an internal radius of the solenoid of 5 mm, a length of 40 mm, an external radius of 16 mm, and used wire of thickness 0.8 mm. With this, we were able to calculate the length of the wire using the equation

$$L_w = 2\pi r_s N, \tag{6}$$

where r_s is the average radius of the solenoid. Given a required force, we can then rearrange and combine all previous equations for a power required. We assumed the locomotive to be the Victorian Railways Y class steam locomotive [6]; with mass of 114.56 tons and a length of 18.43 m, allowing for a total of 920 electromagnets to be attached. Using the equations listed previously, we can calculate an expected required power output of 39.98 MW. To calculate the average power we took the tractive force of 97.1 kN and used $F = ma$ to calculate acceleration, and then calculated the total kinetic energy, and used the acceleration to determine the time taken to reach its top speed of 17.8 m/s. Combining these equations, gets us the equation

$$P_{gen} = \frac{v_{max} F_T}{2}, \tag{7}$$

where P_{gen} is the power generated by the engine; v_{max} is the max speed, and F_T is the tractive force. The result is a power of 864 kW, significantly less than the 40 MW needed.

Discussion and Conclusion

Based on these calculations, the Victorians were far from being able to benefit from maglev technology, however there are a few things that could be done to reduce the power usage. First, thicker wires can be used. As R is inversely proportional to A_w simply moving from 0.8 mm diameter wire to 8 mm diameter wire, means that, given the electromagnets have the same dimensions, the engine is now able to generate sufficient power to levitate. Additionally, P is proportional to I^2, but directly proportional to R. Combined with the fact that B_0 is directly proportional to both N and I; increasing the number of turns will decrease I required. This will increase R, but by less than I decreases, resulting in lower power. Both of these have limitations, eventually the copper wire will be limited in its transmission due to the skin effect, and eventually L added per turn will counteract any decrease in I. Regardless of whether the engine can generate sufficient power, a greater problem is that due to the nature of the system you need to supply the precise amount of power required to have a separation of 1 cm, for unlike a repulsive system, where you simply hover slightly higher if you have too great a force, with an attractive system, too great a force will pull you closer to the rails, and so increase the amount of force applied, creating a feedback loop that ends with the engine stuck to the tracks. Thus we conclude the Victorians would not be able to benefit from this technology.

References

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