

Model Electromagnetic and Electrodynamic Levitation Trains

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My first proposal for my Honors Physics II Research Project was to create an electromagnetic suspension system using attractive forces like the ones used in The German Transrapid. As I began researching more, I realized that this was not possible with solely permanent magnets but instead needed to use computer motoring with electromagnets in order to keep the train car stable. My second thought was to create an electrodynamic system that used repulsive forces instead attractive like the Japanese Yamanashi. This uses the properties of permanent magnets, but the paper also discusses the properties of electromagnets that are involved in the electromagnetic system.

Samuel Earnshaw discovered in the 1860s that “it is impossible for a body to be held in stable equilibrium against displacements in all directions if the system is constituted of permanent magnets only.”^[1] Discoveries, such as this one, allows others to spend time elsewhere. This is the case only if he/she first researches the project thoroughly. This was my first problem.

I proposed building a magnetic levitation train using electromagnetic attractive forces (by using ceramic magnets). This allowed for a much more interesting project than the usual repulsive forces. After many failed attempts, the idea of researching more about attractive suspension came to mind. This research led to Earnshaw’s Theorem, which explained the trouble with the project – permanent magnets alone cannot create a stable magnetic field. This caused a change in the creation of the project, but not without further explanation of the theory behind my original project.

My prototype consisted of Lego’s, tape, and 8 small rectangular prism ceramic magnets (a cheaper version of what would hopefully be the final project). The train car created a U-shape (see Figure 1). Two magnets on each side (on the bottom and top part of the train car) with their

magnetic moments pointing in the same direction were taped to the train car. The other four magnets were placed below

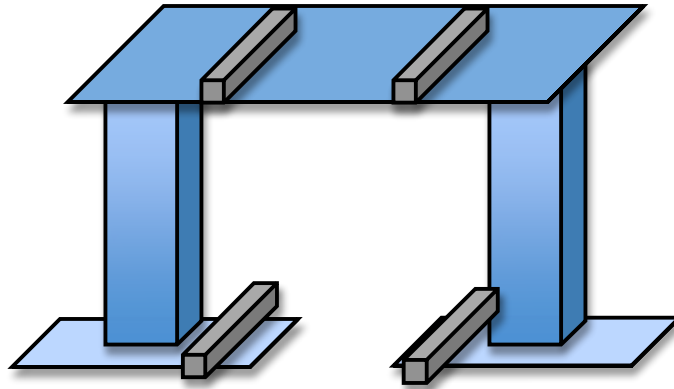


Figure 1:
Prototype train car
for original project

and above the guide rail (see Figure 2). The guide rail magnets were oriented with their moments in the same direction as each other but opposite the four magnets on the train car. When the train car was placed over the guide rail, the permanent magnets on the guide rail and the train car attracted each other to the point of touching. After many attempts, the train car still attracted to one of the magnets more than the other. No more attempts were tried or modifications after a very important detail was

discovered – permanent magnets do not create stable equilibrium forces.

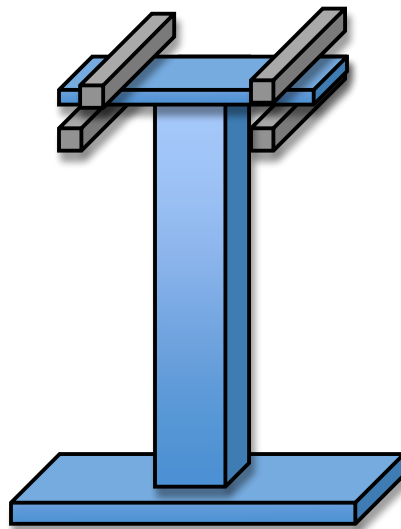


Figure 2:
Prototype guide rail
for original project.

After further research I found that this phenomenon could be explained using some

calculus. In order for the train car to be in equilibrium, the net force must be equal to zero. If the train is at the point (x,y,z) and the force of the static field (the field created by the permanent magnets) is represented by $F(x_0,y_0,z_0)$. Two equations must be true for this system to be in stable equilibrium: (1) $F(x_0,y_0,z_0) = 0$ and (2) $\nabla \cdot F(x_0,y_0,z_0) < 0$. The first equation, the force

must be equal to zero, is needed for the system to be in equilibrium; the second equation, the divergence of the force must be less than zero, is the condition for stability. The electromagnetic field equations are as followed, $\nabla \cdot E(x,y,z) = 0$ and $\nabla \times E(x,y,z) = 0$. Using the equation that the force of an electric field is equal to the charge of the particle multiplied by the electric field, $F=qE$, a vector for the electric force can be created: $F(x,y,z) = qE(x,y,z)$. The divergence of this function is zero ($\nabla \cdot F(x_0,y_0,z_0) = 0$). This violates the equation required to allow for stability of the system ($\nabla \cdot F(x_0,y_0,z_0) < 0$); therefore, it is impossible to suspend an object using permanent magnets alone (Jayawant 1981).

Because permanent magnets do not work, other methods for suspension are required. The most common way is to continually monitor and regulate the gap size between the train car and the guide rail. This can be done using a L, C, R circuit, which resonates to determine the gap size. If the gap becomes too small the current going through the circuit decreases causing decrease in the force lowering the train car back to a safer position. These trains allow high-speed travel, but because of their instability, many governments are hesitant to build these systems.

Whether or not an electrodynamic (repelling levitation) or an electromagnetic (attractive suspension) system is used, the propulsion of the train car is usually the same. Both systems use variable electromagnets to move. Variable electromagnets switch the polarity of electromagnets when needed.

At first, the train car accelerates because the electromagnets attract the magnets on the train car. Once the train is almost in line with the electromagnets, the current running through the coils switch off. At that point, the momentum of the train car carries itself forward enough to be affected by the attraction and/or repulsion of the electromagnets. This process repeats until the train has reached its destination. The current in the coil must switch in order for the train car to

continue in its forward motion. Without switching the current of the coils, the train car would stop after aligning with the first electromagnet.

I created just the levitation portion of the magnetic levitation electrodynamic system. I was unable to attempt the creation of the coils that would allow the train car to move through electricity because of the shortcoming of time.

In order to create a more interesting project than just floating a magnet, only Lego's, superglue, and ceramic magnets were used. The thought process in using only these material was to create a project that parents could easily reconstruct with simple, laying-around-the-house items. By doing this, parents would be about to demonstrate fascinating physics to their kids with spending much money.

First, the guide rails were created. These guides were six-Lego-blocks high with a space of eight Lego-blocks wide. Next, thirty-nine, three-fourths inch, 1.9 centimeters thick, ceramic discs were used to line the track in three columns of thirteen. The two outer columns have the same orientation with their North poles facing upward. Because the magnets were in the same orientation, they repelled each other. To fix this, the magnets were glued in place. Knowing the magnets were strong, the first glue used was tacky glue. This glue did not work. The magnets immediately repelled each other after the pressure on the magnet (my hand) was released. The next glue worked: "Loctite Super Glue." After finishing the two outer columns, the next step was to create the inner column. The sole purpose of this column was an attempt to advance the train car with other means than pushing the train car or alternating a current through a solenoid. Every other magnet switched orientation. For example, if the first magnet's North pole was facing upward, the second magnet's North pole would face downward and so on (see Figure 3 for diagram of guide rails). Last, the train car was designed. The train car consists of two 4 by 8

(Lego-block) flat Lego's, two 2 by 4 (Lego-block) flat Lego's and five, three-fourths inch, 1.9 centimeter thick, ceramic discs. The two larger flat Lego's were attached together to create a wider train car. Four of the ceramic discs were glued to the four corners of the flat Lego's. Then, the last magnet was glued in the middle back of the flat Lego's (see Figure 4a and 4b).

The middle column of magnets on the track and the middle magnet on the train car was an attempt of creating

a system that would propel the train forward. Before placing discs in the center, large rectangular prism magnets were glued

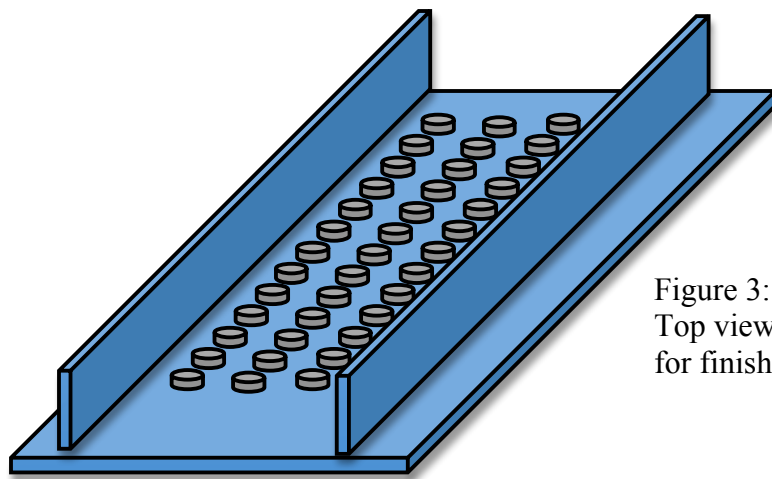


Figure 3:
Top view of guide rail for finished project

for the middle column. This caused more problems; the middle magnets were so much stronger than the discs that it off set the outer magnet columns and caused the train car to tip over and connect to the large middle column. Because of this, the middle column had to be changed to the

same sized discs that composed the outer columns of magnets. The attempt with the

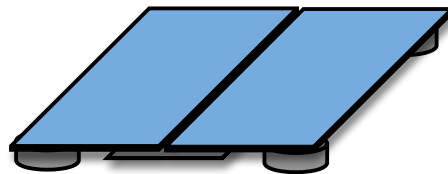


Figure 4a:
Top view of train car of finished project

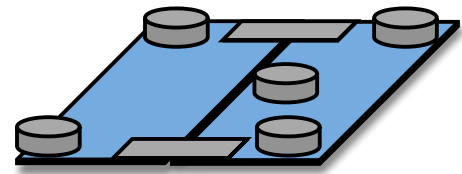


Figure 4b:
Bottom view of train car of finished project

discs failed as well. The failure was due to the dipole orientation of magnetic fields. When first

placed on the track, the train car moved forward but only until it reached the next magnet whose magnetic field was opposite of the magnet before. The magnetic field overcame the momentum the train car had gained from the force of the first magnet. The next two magnets were responsible for this overcoming magnetic field. The second magnet was attracting the middle magnet, which created drag when the train car was trying to move past it, and the third magnet's magnetic field was creating a repulsive force in the direction of the second magnet due to the dipole orientation. This causes the train car to stop its forward progress and just levitate.

Instead of using permanent magnets to move the train car down the track, copper coils wrapped around steel nails should have been used. The solenoids that would have been created by the copper coil would have been placed where the middle magnet column is now. Two solenoids would have been crossing so that north and south poles could be created. Then, using a switch, the solenoids could have been switched on and off. The switch is one of the most important parts in that it allows the train car to move without being stopped by the dipole orientation of magnetic fields. Using a switch with two solenoids, would allow the train car to be pushed by the magnetic fields until the net force from two neighboring magnets equaled zero just before it the net force became negative (The negative direction is the direction of force which would push against the velocity of the train car). At that moment, the switch would be turned off, and the train car would continue moving from its momentum until the theoretical net force from the next two neighboring magnet fields is greater than or equal to zero (Theoretical because the solenoids should be turned off before that time.). This process would be able to continue until the end of the track.

Magnetic Levitation systems that are being used today use advanced computer systems equipped with sensors and detectors that are able to tell when the current running through the

solenoids should be turned off. Current systems also employ superconductors, which gives these trains much more stability and reliability. By using superconductors, the engineers do not have to worry about the dipole orientated magnetic fields that permanent magnets create. This project gave me much more incite on the ideas of the different systems of magnetic levitation system and on permanent magnets and electromagnets. Along with understanding the physics behind these principles, I gained valuable lessons on research and time management.

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