A Review of Principles and Illustration of the Physical Working Model of Magnetic Levitation

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Abstract
This work is a sequel to the authors' previous work [6]. A fast forward of all underlying principles and theories of levitation are included for comprehensive and quick understanding of the electromagnetic forces.(i) Static repulsive gravitational force to float the pay load, (ii) Needed propulsive or linear motoring forces for movement of pay load above the track are taken up for calculations. A working model details and specifications are shown in figures.

Keywords: Magnetic levitation, underlying electromagnetic forces, repulsive force that floats pay load, moving forces that help traction, pole windings of linear motor on track, control systems, working model

1. INTRODUCTION
Maglev (derived from magnetic levitation) is a transport method that uses the energy in magnetic levitation to move vehicles without touching the ground. With maglev, a vehicle travels along a guideway using magnets to create both lift and propulsion, thereby reducing friction by a great extent and allowing very high speeds.
Maglev trains were first proposed in the 1960s by two physicists at Brookhaven National Laboratory, whose vision led to large-scale research projects in Japan and Germany \[4\]. Since then, maglev test tracks have been built in countries all around the world, and the first commercially operating maglev train opened in Shanghai in 2004 \[4\]. Recent innovations in maglev technology, such as the Inductrack system, promise “fail-proof” operation.

The major advantage of maglev trains is speed (up to 580 km/h \[4\]), which increases the range in which rail travel is comparable to air travel. Other advantages include much greater energy efficiency, since levitation eliminates all friction normally created by rails; reduced noise pollution, again due to reduced friction; and faster acceleration, which further reduces the travel time. The major disadvantage, which has been the primary obstacle to maglev projects throughout the world, is cost, because unlike with conventional high-speed rail, completely new infrastructure must be built. The cost for this can reach $100 billion \[4\].

2. OBJECTIVE

The need for more sustainable and efficient mass transportation of people, commercial freight, and military applications has led to a rethinking of rail-based transit. The design for this paper’s maglev train was not based on any current maglev technology, nor does it seek to improve on any current technology. Rather, the pose of this project was to design a working model of a maglev train in order to better understand the principles behind magnetic levitation and propulsion \[1\]. The team produced a design for a small-scale proof-of-concept linear maglev system, measuring half meter in length, capable of levitating and accelerating a scale-model maglev train, in order to demonstrate to consumers, investors, and regulators that maglev systems fabrication is a feasible and efficient option for new transportation infrastructure development. The linear system designed is propelled by an AC Drive and is levitated by an array of permanent magnets.

The track was designed with ease of construction, stability of operation, and levitation efficiency as primary constraints. The final system has passive lateral stability, passive magnetic support with minimal friction for levitation, and user controlled speed. A demonstration of the system provides the observer insight into how maglev technology works and why it is a viable alternative to traditional rail transport.

3. LITERATURE

The basic requirements to be achieved for utilizing magnetic levitation for transportation are levitation (against gravity) and propulsion.
A. Levitation

Levitation is the process by which an object is held aloft, without mechanical support. To accomplish levitation an upward force that counteracts the pull of gravity should be provided, [8]. The team used magnetic levitation; a method by which an object or a system is suspended with no support other than magnetic fields.

Forces between the magnets depend on:

1. Strength of the magnetic field
2. Area of the magnets

By carefully studying these factors a force can be accomplished to magnetically levitate objects by simply utilizing two permanent magnets, but the real problem is to stabilise this levitated object.

Stability refers to ensuring that the object or the system does not flip or slide from its levitated position. Earnshaw’s theorem from [7] states that it is impossible for a static system to stably levitate against gravity.

1) Earnshaw’s theorem:

It states that collection of point charges cannot be maintained in stable equilibrium solely by electrostatic forces. The same applies to magnetic levitation. Hence some other means are to be used to magnetically lift a body. Usage of combination of forces like gravitational, electrostatic and magneto static forces enables static stability.

Stability is thus needed to ensure that the levitated object stays in it’s fixed position, without flipping and sliding. From Earnshaw’s theorem at least one stable axis must be present for the system to levitate successfully and other axes can be stabilized using ferromagnetism.

2) Techniques to accomplish stable levitation:

- Mechanical constraint: Reference [8] shows that with a small amount of mechanical constraint, stability can be achieved. For example is two magnets are mechanically constrained along a vertical axis, and then it’s possible to achieve a stable levitation system.
This physical imperative or the damping can be defined in any of the 6 axis and the body will be stabilized. This is how the magnetically levitated bodies with permanent magnets are stabilized.

- **Servomechanisms (Electromagnetic suspension):** In this case the levitation effect is mostly due to permanent magnets, with electromagnets are only used to stabilize the effect. This stability for the object can be achieved by constantly altering the strength of a magnetic field produced by electromagnets using a feedback. As mentioned in [8], this servomechanism formed by continually changing the electromagnets to correct the object’s motion, are extensively used in Electromagnetic Suspension (EMS).

In EMS, magnetic attraction is the prime cause for levitation.

- **Induced currents (Electro dynamic suspension):** When the magnets attached on board move forward on the inducing coils or conducting sheets located on the guide way, the induced currents flow through the coils or sheets and generate the magnetic field.
While EMS uses attraction force, EDS uses repulsive force for the levitation. The team has utilized this technique to achieve levitation.

**B. Propulsion (Guidance)**

The Maglev train is a noncontact framework that requires a controlling power for the counteractive action of sidelong relocation. As in the case of levitation, the guidance is accomplished electromechanically by magnetic repulsive force or magnetic attraction force. A repulsive force and an attractive force induced between the magnets are used to propel the vehicle.

**4. FORCES BETWEEN MAGNETS**

Understanding and the ability to evaluate the forces between magnets are very essential for attaining stable magnetic levitation. The fundamental forces are due to microscopic currents of electrically charged electrons orbiting nuclei and the intrinsic magnetism of fundamental particles that make up the material. Since both these are modelled as tiny loops of current called magnetic dipoles, the most elementary force between magnets, therefore, is the magnetic dipole–dipole interaction. The study of which can be divided as the following:

**A. Gilbert model**

The Gilbert model assumes that the magnetic forces between magnets are due to magnetic charges near the poles. While physically incorrect, this model produces good approximations that work even close to the magnet when the magnetic field becomes more complicated. Gilbert model approximations are listed out as formulae for the following cases:

1) **Force between two magnetic poles:** If both poles are small enough to be represented as single points then they can be considered to be point magnetic
The force between two magnetic poles is given by

\[ F = \frac{\mu_0 q_1 q_2}{4\pi r^2} \]  

(1)

2) **Force between two bar magnets:** The force between two identical cylindrical bar magnets placed end to end is approximately:

\[ F = \frac{B_0^2 A^2 (L^2 + R^2)}{\pi \mu_0 L^2} \left[ \frac{1}{x^2} + \frac{1}{(x + 2L)^2} - \frac{2}{(x + L)^2} \right] \]  

(2)

3) **Force between two cylindrical magnets:** For two cylindrical magnets with radius \( R \) and height \( h \), with their magnetic dipole aligned and the distance between them greater than a certain limit, the force is approximated as

\[ F(x) = \frac{\mu_0}{4} M^2 R^4 \left[ \frac{1}{x^2} + \frac{1}{(x + 2h)^2} - \frac{2}{(x + h)^2} \right] \]  

(3)

B. Ampere’s Model

In Ampere’s model the calculations are done by considering the microscopic or atomic currents in the object, hence this is difficult. The force between two permanent magnets is given by:

\[
\vec{F} = \frac{\mu_0}{4\pi} \int_{(V)} \left( \int_{(V_o)} \frac{\vec{m} \cdot \vec{M}_o + m_c m_{oc}}{(\Delta r)^5} \Delta \vec{r} dV_o \right) dV \\
- \frac{\mu_0}{4\pi} \int_{(V)} \left( \int_{(V_o)} \frac{5[\vec{m} \cdot \Delta \vec{r}][\vec{M}_o \cdot \Delta \vec{r}]}{(\Delta r)^7} \Delta \vec{r} dV_o \right) dV \\
+ \frac{\mu_0}{4\pi} \int_{(V)} \left( \int_{(V_o)} \frac{3[\vec{m} \cdot \Delta \vec{r}]}{(\Delta r)^5} \vec{M}_o dV_o \right) dV
\]

(4)

Where,

- \( \mu_0 \) is permeability of free space
- \( \vec{m} \) is magnetic momentum between permanent magnets
- \( m_c \) is magnetic momentum of magnet 1
- \( m_{oc} \) is magnetic momentum of magnet 2
- \( \vec{r} \) is position vector of magnet
- \( \vec{M}_o \) is magnetization of permanent magnet
Gilbert’s model has formula relating to magnets being as poles, for two bar magnets and for two cylindrical magnets whereas Ampere’s model has intrinsic calculations, which are difficult. The model designed by the team is based on a bar magnet and disc magnet. So Gilbert’s model isn’t applicable.

Given the limitation of the time and scope of our project, the team has decided that the calculation of the exact force and later the levitation gap between magnets is a time taking and cumbersome process. The team has decided that such calculations can be eliminated, when while assembling, we can use trial and error method and vary the weight and design of the body to achieve the required levitation with the track.

5. MECHANICS

To design the linear propulsion system, two things had to be achieved; levitation and propulsion. A body made of wood and magnets has to be levitated. Propulsion requires the body to move across a 50 cm linear track. To meet these requirements the design was made in such a way that propulsion is achieved in the centre and levitation on either sides of the propulsion track. (Fig. 11)

Levitation has been designed to be achieved through Alnico bar magnets which are arranged in an array, parallel and on either side to the line of propulsion.

Propulsion has been achieved using the electro magnetism. A three phase lap winding along the length of the central track with 18 gauge insulated copper wire is selected. When the winding is connected to AC power source, it produces an alternating magnetic field. The center of the body with three neodymium magnets is synchronously locked with the travelling magnetic flux and is hence propelled.

<table>
<thead>
<tr>
<th>Object</th>
<th>Type of magnets</th>
<th>Dimensions (cm)</th>
<th>No of magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>Alnico</td>
<td>4x2.5x1</td>
<td>16</td>
</tr>
<tr>
<td>On body</td>
<td>Neodymium(Nd$<em>2$Fe$</em>{14}$B tetragonal crystalline structure)</td>
<td>2.5 dia x 0.2cm</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 2. Specifications for propulsion

<table>
<thead>
<tr>
<th>Object</th>
<th>Type of magnets</th>
<th>Dimensions</th>
<th>No of magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track</td>
<td>Copper wounded electromagnet</td>
<td>18 gauge</td>
<td>1</td>
</tr>
<tr>
<td>Body</td>
<td>Neodymium (Nd2Fe14B tetragonal crystalline structure)</td>
<td>2.5cm dia, .2cm thick</td>
<td>3</td>
</tr>
</tbody>
</table>

6. MAGENTICS

The repulsion force between two permanent magnets with same poles has been used for levitation.

The linear system has two guide ways on the either sides of the propulsion track. These guide ways consist of an array of Alnico bar magnets. The body has strong Neodymium disk magnets placed symmetrically at the corners of the body to attain a stable lift. This body when placed on the track, fits into the guide ways and also levitates over the bar magnets. A stable levitation for the body can be achieved owing to its weight and symmetric design. (Fig. 10)

The propulsion track is an electromagnet. A three phase lap winding has been selected for the primary rotor windings. A 4 slots one pole machine has been selected. The 50 cm linear track could accompany 36 slots with 3cm as pitch. Therefore a 6 pole linear synchronous system was achieved. [3]

The strength of magnetic field depends upon number of turns per coil which is also called as active slot, calculated as follows:

Area of active slot = 8mm*10mm

= 80mm²(1 mm²=0.00155 inch²)

= 0.124

Maximum current turns / active slot = 1000 AT / inch²

An active area of 0.124 can have maximum current turns of 124 AT

Taking nearest active turns as 150 AT,

A maximum coil current is 6 A.

Therefore, required turns is 150 AT / 6A = 25 turns

For optimal results, eliminating loses and unseen errors 40 turns/coil have been
decided.

**Table 3. Magnetic Levitation Heights**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height over LSM</td>
<td>3mm</td>
</tr>
<tr>
<td>Height over track</td>
<td>2cm</td>
</tr>
</tbody>
</table>

**Table 4. Variation in magnetic levitation heights to be achieved**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Desirable displacements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Stability</td>
<td>Operating Elevation Height +/- 5mm</td>
</tr>
<tr>
<td>Horizontal Stability</td>
<td>Lateral Variation +/- 0mm</td>
</tr>
</tbody>
</table>

**Table 5. Parameters for magnetic levitation (levitation)**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>On track</td>
</tr>
<tr>
<td></td>
<td>On body</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For track</td>
</tr>
<tr>
<td></td>
<td>For body</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On track</td>
</tr>
<tr>
<td></td>
<td>On body</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>AlNiCo 5</td>
</tr>
<tr>
<td>On body</td>
<td>NdFeB Grade N52</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For track</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For body</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On track</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On body</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Max B Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>10900 Gauss; 1.1 Telsa</td>
</tr>
<tr>
<td>On body</td>
<td>14,800 Gauss; 1.48 Telsa</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On track</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On body</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Dimensions of magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>4x2x1 (cm)</td>
</tr>
<tr>
<td>On body</td>
<td>4.0” x 1.0” x 0.1” [4 Thick Disc Magnet Array]</td>
</tr>
</tbody>
</table>

**Table 6. Parameters for magnetic array (propulsion)**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>On track</td>
</tr>
<tr>
<td></td>
<td>On body</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For track</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For body</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On track</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On body</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>Linear Synchronous Motor (Three phase winding)</td>
</tr>
<tr>
<td>On body</td>
<td>NdFeB Grade N52</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For track</td>
</tr>
<tr>
<td>Max B Value</td>
<td>For body</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On track</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On body</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Max B Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>1.48 Telsa</td>
</tr>
<tr>
<td>On body</td>
<td>14,800 Gauss; 1.48 Telsa</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On track</td>
</tr>
<tr>
<td>Dimensions of magnets</td>
<td>On body</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Dimensions of magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>On track</td>
<td>Down the length of track, 50cm</td>
</tr>
<tr>
<td>On body</td>
<td>4.0” x 1.0” x 0.1” [3 Thick Disc Magnet Array]</td>
</tr>
</tbody>
</table>
Table 7. Parameters for performance of linear synchronous motor

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Design Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Interacting primary (LSM) &amp; Secondary (Train Body)</td>
</tr>
<tr>
<td>Wire Material</td>
<td>Copper</td>
</tr>
<tr>
<td>Parameter</td>
<td>Field Strength $B=1.2T$</td>
</tr>
<tr>
<td>Lorentz Force</td>
<td>$F=I\times(B\times L)$</td>
</tr>
</tbody>
</table>

7. ELECTRICS

The electrical component in the system is the propulsion system consisting of linear synchronous motor. This has been decided after careful study of research paper [2], which has similar problem statement as ours. Linear motors do not use mechanical coupling for rectilinear movement. Therefore, its structure is simple and robust as compared to rotary motor.

A travelling flux will move along the length of the primary rotor. The magnets on the secondary will be synchronously locked with the travelling wave and move at a velocity $V_s$

$$V_s=2\times\text{pole pitch}\times\text{frequency of the track}$$

The pole pitch of a single magnet is equal to its diameter; 0.025m. Therefore for 0.025m pole pitch and 50Hz, (output frequency of a Lab Volt) the magnet array attempted to accelerate from 0-2.5m/s instantaneously. This rapid acceleration caused vibrations in the body, restricting its forward motion.

A slower acceleration was needed and this would be done by ramping up the frequency and smoothening the sinusoidal electric signal (Discussed in $X, A$).

8. DESIGN OF LINEAR SYSTEM

Based on the earlier work done by our team, we designed a linear system for magnetic levitation vehicle. By citing our work from [6], following are the SolidWorks 2013 designs of the body, track and assembly.
Fig. 4 The body made of balsa wood with neodymium magnets array for levitation and a central array for propulsion.

Fig. 5 The track.

Central track with 6 pole lap winding linear synchronous motor. Two guidways on either side of the central track to house the array of alnico magnets for levitation.

Fig. 6 Assembly
The body has its legs correctly fitting into the slot for levitation and the central array of magnets on the body are locked with the electromagnetic wave from the linear motor.

**Fig. 7** Levitation over the track

9. MODELLING OF LINEAR SYSTEM

A. Levitation and stabilization

The track is responsible for levitation and stabilization.

**Fig. 8** The track with LSM, Alnico array and body
B. Propulsion system

1. The linear synchronous motor (LSM), which behaves like the primary rotor

Fig. 10 LSM as primary motor

2. The magnet array on the train car, which behaves like the secondary. Three permanent magnets were arranged into an array with alternating north and south poles.

Fig. 11 Magnetic array, train car
These three magnets interact with the LSM that runs down the middle of the track and are crucial for propulsion. The alternating magnetic field induced in the LSM due to the high current flowing through the wires interacts with the magnetic field provided by these permanent magnets. As a result, the train car is propelled down the track.

10. CHALLENGES FACED

The significant challenges in implementing our particular design are as follows:

- Smoothing out the current waveform from the AC Drive to be more sinusoidal
- Achieving very low friction between the magnetic rails and disc magnets
- Winding the LSM by hand evenly and precisely enough to function properly.

Overcoming the challenges:

Efforts were made to reduce the challenges to the problem statement most efficiently with the available tools and machinery within the speculated time.

A. Smoothing the current waveform from the AC Drive to be sinusoidal:

Initially, a Lab Volt variable voltage three phase power source in Power electronics Laboratory was used to test the LSM. It was capable of providing 8 amps of current to the track windings, and a noticeable interaction was detected between the track and a magnet array.

However, since the output frequency of the Lab Volt source was fixed at 50Hz, linear motion of the magnet array was unachievable. Instead of sliding down the track, the array instead moved back and forth a small distance.

The speed at which the secondary, or magnet array, moves relative to the track windings is given by the following formula:

\[
\text{Secondary Speed} = 2 \times \text{pole pitch} \times \text{frequency of track current}
\]

The pole pitch of a single magnet is equal to its diameter, which is 0.025m

Therefore, when the 50 Hz current was applied to the track, the magnet array attempted to accelerate from 0-2.5m/s instantaneously. This rapid acceleration would require a large force from the track windings in order to overcome the inertia of the stationary magnets.

In order to lessen the amount of force required from the track windings, a slow acceleration is needed. This can be achieved by gradually ramping up the frequency of the current supplied to the track windings.

To fulfill this requirement, a PWM was chosen with a frequency of 15Hz and a voltage of 25V. This meant the body will accelerate between 0-0.75m/s. Which meant the body will have lesser vibrations and a controlled linear motion.
B. Achieving low friction between magnetic rails and disc magnets:
For achieving levitation, guideway was designed with magnetic rails arranged on the base and horizontal support on either side for horizontal stability. Disc magnets were places on the body with opposing poles as the magnetic rails so as to achieve levitation.

- Initial magnetic rail design:
Blocks of wood were placed giving equal gaps between the bar magnets so as not to weaken the magnetic strength of the magnets due to opposing poles being together.

Fig.12 Initial magnetic track design

After designing the track as shown it was observed that the poles of the bar magnets in the wooden gaps are opposite to that of the disc magnet moving over it and this caused vibrations in the motion of the body vertically.

To avoid these vibrations and to achieve vertical stability, though the strength of the magnets weaken by bringing opposite poles together, they stuck forcibly keeping in mind the high strength of the bar magnets.

The friction between the disc magnets on the body and the guideway was reduced by sticking a highly polished sheet on the inner sides of the guideway.

C. Overcoming challenges in track windings:
A three phase three pole winding was selected for the primary rotor windings. A 4 slots one pole machine was selected.
For winding the coils evenly, wooden strips were nailed into the base for the windings of one phase were wound around it as shown.

**Fig. 13** One phase windings around wooden strips

A coreless type of motor is selected, so reducing in the air gap means increase the strength of the magnetic flux produced by the primary coil. To reduce the air gap, the wooden strips nailed to the base were removed and each phase was slowly removed from their slots. After removal, each winding was taped with cloth insulation.

**Fig. 14** Removed wooden strips and coils are taped with insulation

After taping each winding of each phase, the coils were hammered closely. This hammering caused the coils to come closer and reduce the air gap.

To further prevent these coils to remove on the base, holes were drilled and each winding was tied together with the adjacent using a thread. This ensured that the coils were held steadfast on the base.

**Fig. 15** Coils of three phases, taped, hammered and held together by thread
11. SUMMARY
After going through the design and modelling processes it is clear that any approach to this technology must be taken with much attention paid to the underlying theory, mathematical justification, and all the specifications of the materials used. The team has produced a design which uses an effective linear synchronous motor and has mechanics and geometry which allows this to be constructed into a full-length track. If magnetic strips were used as rails more robust results would have been achieved against vertical stability, they could continue to be incorporated in the design for stability and levitation.

In the future one could also improve the circuit, possibly using sensors and a microcontroller, to regulate energy use. The microcontroller could tell the electromagnets to turn off once a certain velocity is reached and turn back on again only when needed to maintain the velocity. Future projects could add these features to the track and train.

12. CONCLUSION
The project is a modest effort in understanding the principles in magnetic levitation, the magnetic materials and its properties, the chronological history of magnetic levitation, the propulsion systems used in magnetic levitation and its working.

Studying these, the team has come up with probable design for a body to levitate and propel over a track with magnetic levitation for a linear path.

The work has lead the team in understanding the magnitude of the problem and its wide scope applications.

A suggestion has been made among the team that for the progressive growth of the problem statement, the members should specialize in or who have heavy resources in:

• Electromagnetics
• Embedded Design
• Systems & Controls

The study is involved one due to the multiple disciplines and a clear outlook and understanding of them. Any team needs to have a good back-up of all components. The power electronics part is not included in this work. Figures in inch and centimetres are deliberately given. This is certainly a technology worth reconsidering in view of the present manufacturing seen even at toy level levitation. Economics of it may be seen in a different perspective if bulk transportation, pollution freeness and speed become overweighing factors.
ACKNOWLEDGMENT

The team would like to thank E. Bhargava Sai, P. Aravind, P. Pradeep for their contributions in understanding and working though the concepts and fundamentals of magnetic levitation. We would also like to thank the Power Electronics Department Laboratory staff, whose expertise helped in practically realizing our model. Finally, we would like to extend our sincerest and most humble thanks to our guide and mentor Professor A.S.R. Murty who has continued to inspire us to strive for more and to achieve the better. He has been the greatest source of information required for our project and has helped us to see the project all the way through.

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