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Electromagnetic Force-Based Train

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Abstract

The swift advancement in transportation technology encouraged scientists to seek out faster and eco-friendly propulsion techniques. The majority of transportation systems depend on mechanical engines and wheel-axle setups that generate friction, noise, and energy dissipation. Because of these drawbacks there is potential for propulsion approaches. A contemporary technique is propulsion, which utilizes electromagnetic forces rather, than traditional mechanical movement. This research paper addresses the design and operation of a train system that uses propulsion. The system leverages the interaction principle, between electromagnets and permanent magnets to create movement. When current flows through the coils it generates a field. This magnetic field interacts with the magnets mounted on the train resulting in a linear force that propels the train along the track. Controlling the flow of current, to the coils allows for management of the train's speed and direction. The mechanical inefficiencies in the suggested system are significantly less than those, in trains that rely on combustion engines or frictional wheel contact. Because the system contains a limited number of moving elements deterioration is minimal leading to reduced maintenance. Key elements of the proposed design consist of coils, permanent magnets, driver circuits, power sources and a basic control unit to oversee its functioning. The practicality and efficiency of the electromagnetic propulsion mechanism are the main concerns in small-scale transportation systems. During testing, observed results have been smoother in operation, with less friction and better energy efficiency. Though the prototype is developed at a small scale, the concept can be extended to future applications such as high-speed railways, maglev trains, and advanced urban transport systems.

Keyword: Arduino-based control system, coil-based linear motion, electromagnetic propulsion, Lorentz force law, magnetic attraction and repulsion

INTRODUCTION

Transportation plays a very energetic role in modern society. Diesel or electric engines that convert rotational motion into mechanical energy power conventional trains. However, wear and tear, mechanical friction, energy losses, and environmental pollution are the disadvantages of these methods. Electromagnetic propulsion provides a promising alternative [1–5]. It is based on the fundamental laws of electromagnetism, particularly Faraday's law, Lorentz force law, and Fleming's left-hand rule. Instead of depending on a rotating motor, electromagnetic systems can produce direct linear motion. This linear movement is ideal for railway systems and can replace outdated wheels with a frictionless or low-friction mechanism [6–10]. The ability of Maglev (Magnetic Levitation) trains to move at extremely high speeds and float above the tracks has garnered attention in recent years. These trains use electromagnetic propulsion as their primary driving force. Encouraged by this concept, our project aims to develop a limited electromagnetic propulsion train model that establishes the same basic principles [11–15].

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The purpose of this research paper is to explain:

1. The concept of electromagnetic propulsion
2. The design of the propulsion system
3. The construction and working of the train model
4. The practical applications and advantages of this technology

LITERATURE REVIEW

Various studies have been conducted in the field of electromagnetic propulsion and maglev technology. In Japan and China, maglev trains have been tested at speeds above 600 km/h. These trains use linear induction and linear synchronous motors to generate thrust. Research has proven that electromagnetic propulsion significantly reduces friction because the train levitates above the track. Yamamoto et al. (2015) demonstrated that electromagnetic propulsion provides better acceleration than traditional DC motors [1]. Kumar and Singh (2018) determined that the maintenance cost of electromagnetic propulsion trains is lower than that of diesel engines because there are fewer moving parts [9]. However, a barrier to the general use of this technology is its high setup cost. Therefore, more research is required to develop low-cost and efficient electromagnetic propulsion systems. Our project is a small-scale approach for understanding and optimizing this advanced transportation system.

METHODOLOGY

The methodology of this project is divided into the following main parts:

Conceptual design of the train
1. Development of electromagnetic propulsion system
1. Circuit design and implementation
2. Testing and analysis

Electromagnetic attraction and repulsion between coils and permanent magnets affixed to the train's wheels or body form the basis of its operation. A magnetic field is produced when current flows through a coil. The polarity of the magnetic field can be changed by changing the polarity of the current. Motion can be produced by the ability of a shifting magnetic field to attract or repel adjacent permanent magnets. By placing a series of electromagnets along the track and permanent magnets on the train, a continuous forward force can be achieved [16–20].

MATHEMATICAL MODELING OF ELECTROMAGNETIC PROPULSION

The electromagnetic propulsion mechanism can be explained mathematically using the Lorentz force law. When a conductor carrying a current is placed in a magnetic field, it experiences a mechanical force expressed as follows:

$$F=BIL$$

Where:
F is Force acting on the conductor (Newtons)
B is Magnetic flux density (Tesla)
I is Current flowing through the conductor (Amperes)
L is Length of conductor in the magnetic field (Meters)

This equation shows that the propulsion force increases directly with the magnetic field strength and current magnitude. In the proposed system, each phase contains eight coils, which increases the effective magnetic field (B) owing to the superposition of fields. Therefore, a larger thrust is generated at each activation step [21–23].

The switching sequence implemented using the Arduino and BTS7960 driver modifies the direction of the current (I), which in turn alternates the direction of the force (F). By controlling the timing and polarity, a travelling magnetic wave is generated along the track. The permanent magnets on the train respond to this dynamic field, resulting in continuous forward motion. The mathematical principle confirms the feasibility of using coil groups for linear propulsion [24–28].

WORKING PRINCIPLE

The electromagnetic propulsion train operates based on the Lorentz force law and Fleming's left-hand rule. When a current-carrying conductor is placed in a magnetic field, a force is applied to it. The direction of the force is indicated by Fleming's left-hand rule:

- First finger → Magnetic field (N to S)
- Second finger → Current (Positive to Negative)
- Thumb → Force (Motion of the train)

In our model:

- Electromagnets are placed on the track
- Permanent magnets are placed on the train
- A power supply energizes the coil
- A microcontroller or switching circuit controls the current sequence

As the coils are energized sequentially, they create a moving magnetic field. This acts like a wave that pulls the train forward [29, 30].

HARDWARE COMPONENTS USED

The following major components are used in this system (Table 1)

Each coil was carefully wound to produce a sufficiently strong magnetic field when energized. The driver module controlled the polarity and current flow in each coil.

CIRCUIT DESIGN AND PHASE-BASED CONTROL LOGIC

Continuous linear propulsion is achieved in the proposed electromagnetic propulsion train system, in which a phase-based multicoil structure is used, wherein each phase consists of a group of eight coils (left and right sides combined). These coils are placed symmetrically on both sides of the track to produce a stronger and more uniform magnetic field. An Arduino microcontroller together with an BTS7960 dual H-bridge motor driver is used to control the direction and sequence of current supplied to each phase [31, 32].

Permanent magnets are attached near the wheels or bottom surface of the train. The mutual magnetic field of the eight coils in a particular phase interacts with the permanent magnets to generate attractive or repulsive forces when the coils are energized. A traveling magnetic field produced along the track by successively energizing the phases pulls and propels the train forward [33, 34].

Table 1. Hardware and components.

Component	**Description**
Copper Coil	Creates electromagnetic field
Permanent Magnet	Provides constant magnetic field
BTS7960 Motor Driver	Controls current to coils
Bridge Rectifier	Convert AC to DC
Arduino	Controls sequencing
DC Power Supply (12V/24V)	Provides power
Train Model	Prototype vehicle
Wooden Track	Base for train

Coil Arrangement per Phase

The track is divided into different sections, and each section is treated as one electrical phase. Coils are placed on both the left and right sides of the track to provide better thrust and identical force distribution.

- Each phase = 8 coils (left + right combined)
- Normally, four coils are placed on the left side and four coils on the right side.
- These eight coils are connected in a parallel or series– parallel combination so that they behave as a single electromagnetic unit.
- All coils belonging to one phase are connected to one output channel of the BTS7960 H-bridge motor driver.

Therefore, although there are multiple coils on the track physically, they work as one phase unit electrically and are controlled together by the Arduino.

Example connection

- Phase A (8 coils) → BTS7960 Channel 1 (OUT1–OUT2)
- Phase B (8 coils) → BTS7960Channel 2 (OUT3–OUT4)

If more phases are needed (C and D), another L298 driver can be used.

Phase-Based Alternate Sequencing of Coil Groups

The input pins of the BTS7960 driver receive control signals from the Arduino. At this moment, the driver modifies the polarity of the voltage applied to the entire eight-coil group. Consequently, both attractive and repulsive forces are generated.

The working sequence is shown in Table 2.

In each step, all eight coils of the active phase are energized simultaneously, thereby creating a strong and uniform magnetic field. The previous phase is turned OFF before the next phase is triggered, thereby preventing any backward force. This produces one-directional thrust and smooth motion of the train. This working principle is similar to that of a linear synchronous motor, wherein the stator is spread along the track and energized in a sequence to generate a moving magnetic wave.

Arduino and BTS7960 Control Logic (Concept Code)

The following theoretical code shows how the Arduino controls one phase (8-coil group) through the L298 driver. Electrically, it is one phase; physically, it represents eight coils connected together.

Step	Phase/Coil Group	Current Direction	Effect
1	Phase A (8 coils)	Forward (+)	Train is attracted
2	Phase A	OFF	Magnetic field removed
3	Phase B (8 coils)	Forward (+)	Train pulled forward
4	Phase B	Reverse (–)	Repulsion provides extra push
5	Phase B	OFF	Phase reset
6	Phase C (if used)	Forward (+)	Attraction
7	Phase C	Reverse (–)	Push
8	Phase C	OFF	Reset
9	Phase D (if used)	Forward (+)	Pull
10	Phase D	Reverse (–)	Push
11	Phase D	OFF	Reset
12	All phases	Repeat cycle	Continuous motion

Table 2. Working sequence based on attraction and repulsion.

```
   int A1 = 8;
   int A2 = 9;
   int B1 = 10;
   int B2 = 11;

void setup() {
   pinMode(A1,OUTPUT);
   pinMode(A2,OUTPUT);
   pinMode(B1,OUTPUT);
   pinMode(B2, OUTPUT);
}

void loop() {
   // Phase A group (8 coils) – Forward

(Attraction)
   digitalWrite(A1,HIGH);
   digitalWrite(A2, LOW);
   delay(100);

// Phase A OFF digitalWrite (A2,LOW);
   digitalWrite(A1, LOW);

// Phase B group (8 coils) - Forward (Pull)
   digitalWrite(B1,HIGH);
   digitalWrite(B2,LOW);
   delay(100);

// Phase B group - Reverse (repulsion push)
   digitalWrite (B1, LOW);
   digitalWrite (B2,HIGH);
   delay (100);

// Phase B OFF
   digitalWrite(B1,LOW);
   digitalWrite(B2, LOW);

// The same pattern can be repeated for Phases C and D.
}
```

This control logic confirms that

- 8 coils in one phase.
- Each phase is controlled as a single unit.
- Arduino + BTS7960 performs alternate forward–reverse sequencing.
- A travelling magnetic field is generated.
- Continuous linear propulsion is achieved.

POWER CONSUMPTION AND EFFICIENCY ANALYSIS

In electromagnetic propulsion systems, electrical energy is directly converted into linear motion without any intermediate mechanical conversion. Thus, such a system is inherently more efficient.

The overall efficiency is determined by.
$\eta=F\cdot v/Pin$ Where:
η = System efficiency
F = Generated force
v = Velocity
P_{in} = Input power

The major losses in the proposed system include.

1. Copper losses (I^2R losses) in coils.
2. Core losses due to alternating magnetic fields.
3. Switching losses in the driver circuit.

Despite these losses, electromagnetic propulsion exhibits better performance than mechanical propulsion, especially at high speeds. The absence of frictional losses from wheels and gears is a major factor for improved efficiency. Coil heating was observed during the tests at higher voltage levels. This is primarily due to resistive heating and can be minimized by using a thicker copper wire, better insulation, and improved cooling mechanisms.

COMPARISON WITH CONVENTIONAL PROPULSION SYSTEMS

A comparison of electromagnetic propulsion with conventional mechanical propulsion systems is shown below to clarify the benefits of electromagnetic propulsion.

This comparison demonstrates that electromagnetic propulsion offers notable advantages in terms of high-speed capability, efficiency, and noise reduction. Long-term dependability and minimal maintenance are the outcomes of eliminating mechanical components (Table 3). In terms of efficiency, noise reduction, and high-speed capability, electromagnetic propulsion has substantial advantages. Long-term dependability and minimal maintenance are the outcomes of eliminating mechanical components.

Safety Considerations

Safety is very important in any train system. In this electromagnetic propulsion train, some basic safety points were considered. The magnetic field near the track is maintained in a safe range because it is mainly around the coils. To prevent the coils from overheating, a temperature limit was set so that the system automatically turned off if the heat became too high. The BTS7960 motor driver also helped protect the circuit from incorrect connections. In an emergency, all the coils can be switched off at once using a main switch, and the train will gradually come to a stop. Proper insulation was also used for all coils and wires to prevent electric shock or short circuits. Owing to these safety measures, the system can operate in a safe and controlled manner.

RESULTS AND OBSERVATIONS

The model was established at different voltage levels (6 V, 9 V, and 12 V) (Table 4).

Table 3. Comparision between conventional train and electromagnetic propulsion train.

Parameter	Conventional Train	Electromagnetic Propulsion Train
Propulsion Method	Engine, motor, gears	Magnetic attraction and repulsion
Mechanical Friction	High (wheels & axles)	Very low
Noise	High	Extremely low
Maintenance	Frequent	Minimal
Acceleration	Limited	High (no mechanical inertia)
Speed Potential	< 200 km/h	> 500 km/h (Maglev standards)

Energy Losses	Mechanical + thermal	Mainly electrical (resistive)
Environmental Impact	Pollution depending on engine	Environment-friendly

Table 4. Results and Observations between voltage and speed.

Voltage	Speed	Observation
6V	Low	Train moves slowly
9V	Medium	Stable movement
12V	High	Fast but slight heating

The best performance was achieved at 9–12 V. The system produced smooth vibration-free motion. There was no direct physical contact between the coils and train body for movement, which significantly reduced the friction. Some heating of the coils was observed after prolonged use. This can be reduced by:

- Using heavier wire
- Adding heat sink
- Providing cooling gap

ADVANTAGES OF ELECTROMAGNETIC PROPULSION

- Very low friction
- Silent operation
- Higher speed capability
- Less mechanical wear
- Environment friendly
- More efficient than combustion engines
- Suitable for high-speed trains

APPLICATIONS

- Maglev trains
- Hyperloop systems
- Metro and bullet trains
- Industrial conveyor systems
- Automated directed vehicles (AGV)
- Future electric transportation

LIMITATIONS

- High initial cost
- Requires advanced control system
- Needs strong magnetic materials
- Heating problem at high current
- Not yet commonly used in all countries

FUTURE SCOPE

The electromagnetic propulsion system can be further improved in the future. If superconducting coils are used, energy losses can be reduced because their electrical resistance is almost zero, which will also increase the thrust. Artificial intelligence can be used to control the switching arrangement and speed automatically. IoT-based sensors can be used to easily observe the temperature of the coils, current flow, and overall system conditions.

In addition, regenerative braking can be applied to improve energy during braking. Wireless power transfer coils can be embedded in the track such that the train does not require a separate onboard battery. If this system is designed on a larger scale for real railways, it can become a strong and effective solution for future transportation.

CONCLUSION

This study successfully demonstrates how electromagnetic propulsion can be used to move a train model without conventional engines. The system exhibited efficient, smooth, and controlled motion using electromagnetic interactions. The model demonstrates that this technology can replace traditional mechanisms in the near future, especially for high-speed and intelligent transportation systems. Electromagnetic propulsion is not merely a concept but a practical and powerful solution for next-generation trains.

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