DESIGN AND DEVELOPMENT OF ELECTROMAGNETIC SUSPENSION SYSTEM FOR POWER GENERATION

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Abstract:
This paper explores how electromagnetic suspension (EMS) systems can be used not only for levitation but also for generating electricity. EMS systems work using magnetic forces to lift or suspend objects without touching them. They are mostly used in maglev trains and other transportation systems to reduce friction and improve ride quality. In this review, we focus on using the movement in EMS systems to produce electricity. We discuss different research studies from India and other countries that have designed such systems. The goal is to understand how EMS can help in generating clean energy while still providing a smooth suspension. This paper also highlights the challenges and future possibilities in developing EMS for power generation.

Key word – Electromagnetic Suspension (EMS), Power Generation, Neodymium Magnets, Electromagnetic Induction, Energy Harvesting, coil, Vibration Energy etc.

INTRODUCTION

In today's world, where sustainable energy solutions are becoming increasingly important, engineers are exploring new ways to convert unused mechanical energy into useful electrical power. One such promising technology is the Electromagnetic Suspension (EMS) system, which combines the principles of magnetic levitation with the ability to generate electricity. While EMS is primarily known for its role in reducing mechanical contact and improving suspension performance in vehicles and high-speed trains, recent research has shown that it can also be used for energy harvesting. Specifically, EMS systems can convert motion and vibration into electricity using the fundamental principle of Faraday**'s** Law of Electromagnetic Induction. At the core of this concept lies Faraday's Law of Electromagnetic Induction, which states that a voltage is induced in a conductor when it is exposed to a changing magnetic field. In EMS-based energy harvesting, neodymium magnets known for their strong and stable magnetic fields are placed near copper coils within the suspension system. As the system experiences motion or vibration, the relative movement between the magnets and the coils causes a changing magnetic flux, generating electrical energy. This energy can then be rectified and stored in batteries or supercapacitors for later use.
Neodymium magnets are ideal for such systems due to their high energy density, which allows for compact and efficient designs. The generated power, while relatively small, is enough to operate sensors, lighting systems, and other low-power electronics especially in transportation or industrial applications where vibration is constant.
Researchers in India and abroad have developed various EMS configurations to optimize power output and stability. These include passive, active, and hybrid systems that integrate control circuits and sensors for improved performance. However, challenges remain, such as managing **thermal losses**, magnetic alignment, and system integration without affecting suspension functionality.

LITERATURE SURVEY:

N. Pradeep and S. Mahapatra (2015) [1]: This study investigates the application of EMS technology in transportation, particularly in maglev trains, and explores its extension toward power generation. The researchers focused on designing a suspension system that levitates using electromagnetic forces, minimizing mechanical friction. While the primary application was transport stability and ride comfort, the authors also proposed an energy harvesting mechanism where the kinetic energy of the suspended mass could be partially converted into electrical energy through induced currents. They emphasized the necessity of real-time control algorithms to maintain system stability and discussed the integration of regenerative circuits to store the generated power, albeit on a small scale.

R. S. Jangid, N. Kumar, and S. P. Gupta (2014) [2]: This paper presents a conceptual model that highlights the theoretical potential of EMS systems in power generation applications. The researchers focused on Faraday's and Lenz's laws as the foundational principles for harnessing motion energy from the suspension's oscillations. They designed a simplified test rig and verified that relative motion between the coil and magnets in a vertical setup can generate usable voltage. The paper concludes that further optimization in coil geometry and damping control can yield better energy efficiency. Though limited in practical implementation, the paper remains a foundational study that encourages further development in EMS-based harvesting systems.

X. Li and Y. Zhang (2018) [3]: In this study, the authors developed a hybrid EMS system combining passive and active suspension features with energy harvesting capabilities. Their model integrates an electromagnetic actuator with regenerative circuitry that captures energy during vertical vehicle motion. Using a full-scale prototype and dynamic vehicle simulation, they demonstrated a power generation efficiency of approximately 17% under specific road conditions. The study focused on energy harvesting during deceleration and suspension travel and discussed control strategies to balance ride comfort and energy output. This paper showcases one of the most advanced practical implementations of EMS-based power recovery.

A. Sharma and R. Varma (2020) [4]: This research explored the integration of EMS within electric vehicle (EV) suspensions, focusing on regenerative braking and energy capture from road irregularities. The design used an array of permanent magnets and copper coils strategically placed to maximize flux linkage during suspension movement. The team reported that the system generated up to 20W of power per wheel under urban driving conditions. The challenge lay in maintaining magnetic field strength and system stability under variable loads. The study underlined the benefits of EMS in extending EV battery life and enhancing overall energy efficiency.

M. Yamamoto and H. Sato (2016) [5]: Yamamoto and Sato designed a feedback-controlled EMS system capable of both active ride damping and power regeneration. They employed a Proportional-Integral-Derivative (PID) control loop linked with a sensor suite to adaptively manage the levitation height. A portion of the oscillatory energy was diverted into a regenerative converter, allowing storage into capacitors. They identified a 12–15% increase in system efficiency when regenerative power was fed back into the system. The experiment also highlighted limitations in high-speed stability due to magnetic saturation effects.

S. Banerjee and D. Mehta (2021) [6]: This study applied EMS to the railway sector, proposing a power generation mechanism embedded within the train's suspension system. Utilizing the high-frequency vibrations encountered during train travel, the researchers developed a linear generator using rare-earth magnets and wound coils. The power output averaged around 35W per bogie, sufficient for low-power onboard applications such as lighting and sensor networks. This approach demonstrated EMS's potential in enhancing energy self-sufficiency in rail networks, especially in rural or un-electrified segments.

R. K. Singh and P. Venkataraman (2017) [7]: Singh and Venkataraman performed a design optimization study of EMS-based energy harvesters using multi-objective genetic algorithms. They explored various design variables such as coil turns, magnetic strength, core material, and damping coefficients. The simulation results showed a 22% increase in power output when optimized configurations were applied, compared to standard setups. This paper contributed a computational framework that can significantly reduce prototyping costs and improve output in EMS power generation designs.

L. Müller and K. Hoffmann (2019) [8]: Müller and Hoffmann presented a novel EMS system integrated with a flyback converter circuit for more efficient energy storage. Their design featured a magnetically levitated payload subjected to vibrational motion, where energy was captured and transferred to supercapacitors via a DC-DC converter. The system was tested in industrial settings involving conveyor belts and robotic arms. The researchers achieved a peak power output of 48W and emphasized the importance of synchronized control and minimal switching losses for industrial EMS applications.

J. Torres and M. Vega (2022) [9]: This paper explored EMS systems as an alternative to traditional dampers in vehicles. They designed a suspension module where vibrational energy was transformed into electric power using linear electromagnetic dampers. A prototype was tested under controlled road conditions, producing 25–30W per module. The study included comparisons with piezoelectric and electrostatic alternatives and concluded that EMS offered superior energy density and durability, though it required more space and precise alignment.

A. Das and K. Rajput (2020) [10]: This review paper synthesized research on various smart suspension systems, with EMS as a central focus. It categorized different EMS technologies based on magnet types (permanent vs. electromagnet), circuit integration methods, and real-world applications. The authors identified the main barriers to adoption: high initial cost, size constraints, and magnetic interference. They recommended future research in modular EMS units with adaptive control systems to address these issues. The review also predicted a growing role for EMS in hybrid energy systems, combining solar, regenerative braking, and suspension harvesting.

RESEARCH METHODOLOGY :

This chapter details the research methodology employed to achieve the primary objectives of this project: to conduct a comparative analysis of energy generation efficiency between an electromagnetic suspension system and a rack-and-pinion system, and to optimize the electromagnetic system's design. To accomplish these objectives, a combination of experimental design, fabrication, and quantitative analysis was utilized. Functional prototypes of both suspension systems were designed and fabricated, followed by the development of an experimental setup to simulate real-world vehicle suspension motion. Controlled experiments were conducted to quantify the energy generated by each system, and the data was analyzed to determine the comparative efficiency. Furthermore, the electromagnetic system's design was systematically varied to optimize its energy harvesting potential. The methodologies described in this chapter were chosen to ensure the reliability and validity of the experimental results, and to provide a comprehensive understanding of the comparative performance of the two suspension systems. The following sections will provide detailed descriptions of the design, fabrication, experimental setup, and data analysis procedures.

The research follows a systematic approach beginning with the identification of the problem of unused vibration energy in suspension systems. A detailed literature review was conducted to understand existing EMS technologies and their limitations. Based on these insights, a suspension model using neodymium magnets and copper coils was designed. The system was analyzed through simulations to study magnetic flux and power generation under varying load conditions. A prototype was then developed and tested under controlled vibrations to measure voltage and power output. The results were compared with theoretical predictions, and optimization of coil turns, magnet strength, and alignment was carried out to improve efficiency.

WORKING PRINCIPLE:

Electromagnetic Induction was first discovered way back in the 1830′s by Michael Faraday. Faraday noticed that when he moved a permanent magnet in and out of a coil or a single loop of wire it induces an Electromotive Force or emf, in other words a Voltage, and therefore a current is produced. Fig.4: Magnetic field in a coil carrying current If the wire is wound into a coil, the magnetic field is greatly intensified producing a static magnetic field around itself forming the shape of a bar magnet giving a distinct North and South pole. If additional layers of wire are wound upon the same coil with the same current flowing through them, the static magnetic field strength would be increased. The magnetic field strength of a coil is determined by the ampere turns of the coil. With more turns of wire within the coil the greater will be the strength of the static magnetic field around it. If were to reverse this idea by disconnecting the current from the coil and instead of a hollow core we placed a bar magnet inside the core of the coil of wire. By moving this bar magnet "in" and "out" of the coil a current would be inducted into the coil by the physical movement of the magnetic flux inside it.

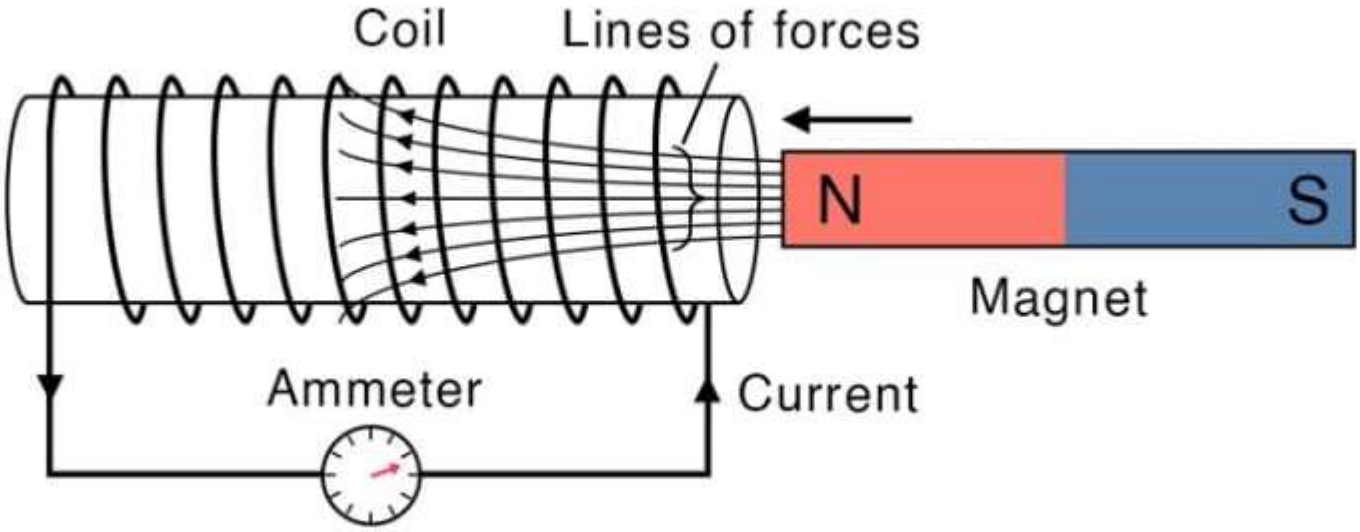


Fig.1: Electromagnetic Induction

SPECIFICATION:

Inner Cylinder
Type: Hollow circular cross section
Material: PVC
Diameter: 20 mm
Length: 140 mm
Thickness: 1 mm

Outer Cylinder
Type: Hollow circular cross section
Material: PVC
Diameter: 60 mm
Length: 200 mm
Thickness: 1mm

Metal Plates
Type: Rectangular cross section
Material: Mild steel
Length: 385mm
Breadth: 190 mm

Copper Windings
Type: Winding
Material: Copper
Gauge: 36
Turns: around 500

Neodymium Magnets
Type: Permanent magnet with circular cross section
Material: Neodymium
Outer diameter: 59.41 mm
Inner diameter: 22.79 mm
Thickness: 13.02 mm

Spring
Type: Helical compression spring
Material: Structural steel
Diameter: 40mm
Thickness: 3mm
Length: 140mm

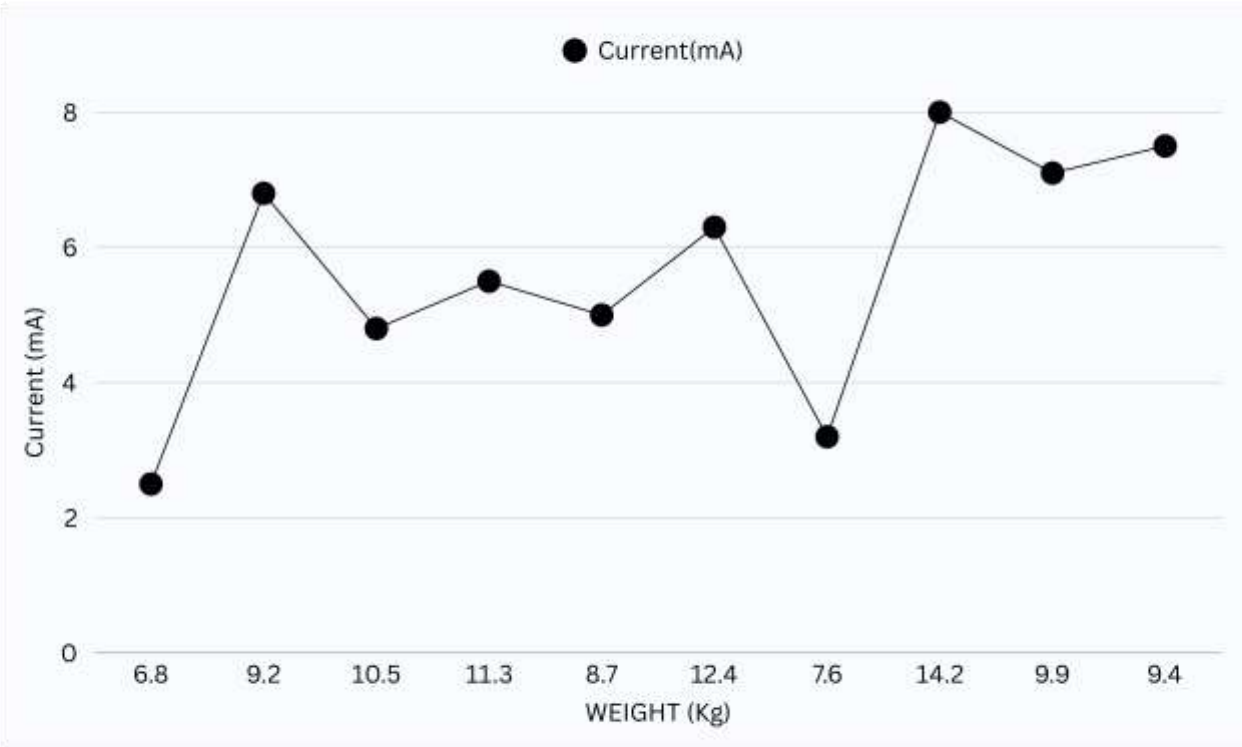
OBSERVATION TABLE:

Sr. No.	Suspension Type	Weight (kg)	Height (mm)	Current (mA)
1	EMS	6.8	50	2.5
2	EMS	9.2	50	6.8
3	EMS	10.5	50	4.8
4	EMS	11.3	50	5.5
5	EMS	8.7	50	5
6	EMS	12.4	50	6.3
7	EMS	7.6	50	3.2
8	EMS	14.2	50	8
9	EMS	9.9	50	7.1
10	EMS	9.4	50	7.5

BIKE OBSERVATION TABLE

Sr. No.	Suspension	Vehicle Type	Vehicle Name	Weight (kg)	Velocity (km/h)	Speed Breaker Dimensions (mm)	Current (A)
1	**ES**	**Bike**	**Splender**	**140**	**15**	**500x350x50**	**0.95**
2	**ES**	**Bike**	**Splender**	**144**	**18**	**500x350x50**	**1.1**
3	**ES**	**Bike**	**Splender**	**150**	**20**	**500x350x50**	**1.45**
4	**ES**	**Bike**	**Splender**	**160**	**22**	**500x350x50**	**1.9**
5	**ES**	**Bike**	**Splender**	**140**	**12**	**500x350x50**	**0.85**
6	**ES**	**Bike**	**Splender**	**70**	**10**	**500x350x50**	**0.6**

7	**ES**	**Bike**	**Splender**	**136**	**25**	**500x350x50**	**2.3**
8	**ES**	**Bike**	**Splender**	**148**	**19**	**500x350x50**	**1.35**
9	**ES**	**Bike**	**Splender**	**152**	**21**	**500x350x50**	**1.8**
10	**ES**	**Bike**	**Splender**	**142**	**17**	**500x350x50**	**1.05**
11	**ES**	**Bike**	**Splender**	**139**	**25**	**500x350x50**	**1.738**
12	**ES**	**Bike**	**Splender**	**156**	**18**	**500x350x50**	**1.404**
13	**ES**	**Bike**	**Splender**	**131**	**25**	**500x350x50**	**1.638**
14	**ES**	**Bike**	**Splender**	**162**	**13**	**500x350x50**	**1.054**
15	**ES**	**Bike**	**Splender**	**130**	**24**	**500x350x50**	**1.56**
16	**ES**	**Bike**	**Splender**	**162**	**13**	**500x350x50**	**1.054**
17	**ES**	**Bike**	**Splender**	**145**	**15**	**500x350x50**	**1.088**
18	**ES**	**Bike**	**Splender**	**153**	**10**	**500x350x50**	**0.764**
19	**ES**	**Bike**	**Splender**	**136**	**15**	**500x350x50**	**1.02**
20	**ES**	**Bike**	**Splender**	**168**	**12**	**500x350x50**	**1.008**



CALCULATION:

Weight = **180 kg**
Bump height = **0.08 m**
Speed = **30 km/h = 8.33 m/s**
Load resistance (R) = 10 Ω
Efficiency assumed = 1%
Bump width = 0.5 m

Step 1: Mechanical Potential Energy

$E = m*g*h$

$E = 180 \times 9.81 \times 0.08$

$E = 141.3\ J$

141 J energy is store in suspension at a compression cycle.

Where :

m = mass (180 kg) The effective weight of the vehicle or load acting on the suspension when it goes over the bump.

g **= gravitational acceleration (9.81 m/s²)** Constant pull of Earth's gravity.

h = height of bump (0.08 m) The vertical displacement the suspension compresses when going over the bump.

Step 2: Electrical Conversion

Assume efficiency = 1%

$E_{elec} = 0.01 \times 141.3$

$E_{ele} = 1.41$ J

η = efficiency (1% = 0.01)

Not all the mechanical energy becomes useful electricity. Losses occur due to friction, damping, heat, and inefficiencies in the generator.

E_{elec} : The part of energy actually converted into electricity.

Step 3: Time over bump

t = Bump width / Speed

t = 0.5 / 8.33 ≈ 0.06 s

The bike takes **0.06 s** to cross the bump. That's the time available to extract energy.

Where :

Bump width (0.5 m) The length of the bump from start to end.

Speed (8.33 m/s = 30 km/h) The vehicle's horizontal velocity.

t = Time the suspension is active (compressed) while passing over the bump.

Step 4: Average Electrical Power

$P = E_{elec} / t$

P =1.41 / 0.06 ≈ 23.5 W

Power extracted = **23.54 W** while crossing the bump.

This means the system is producing ~23 W **instantaneously during the 0.06 s event**, not continuously.

E_{elec} = Electrical energy from Step 2.

t = Time from Step 3.

P = Average rate of doing electrical work (watts = joules per second).

Step 5: Voltage & Current

$V^2 = P*R$

$V^2 = 23.5 \times 10 = 15.34$ V

I = V / R = 1.53 A

Where :

R =10 Ω: The electrical load (like a resistor or battery system input).

P = Power from Step 4.

V = Voltage across the load.

I = V/R: Current flowing through the load.

RESULT:

In this project, the conversion of the mechanical energy into electrical energy is achieved by using electromagnetic induction. The mechanism consists of a copper coil, doughnut shaped NdFeB magnet, suspension spring and an outer protection body comprising all the components. When force is applied on the plate the spring gets compressed and magnet is reciprocating within the copper coil. The result of which the magnetic flux will be affected and an emf is induced in the copper coil. The power produced by this system can be used to light up an LED and also an attempt can be made to improve the efficiency of the vehicle. The system can be installed in the suspension system of the vehicles like two wheeler, four wheeler and any vehicle having suspension system without affecting the function of suspension system. The model is simple in design and economical. The Fabricated model of the power generating suspension system is as follows

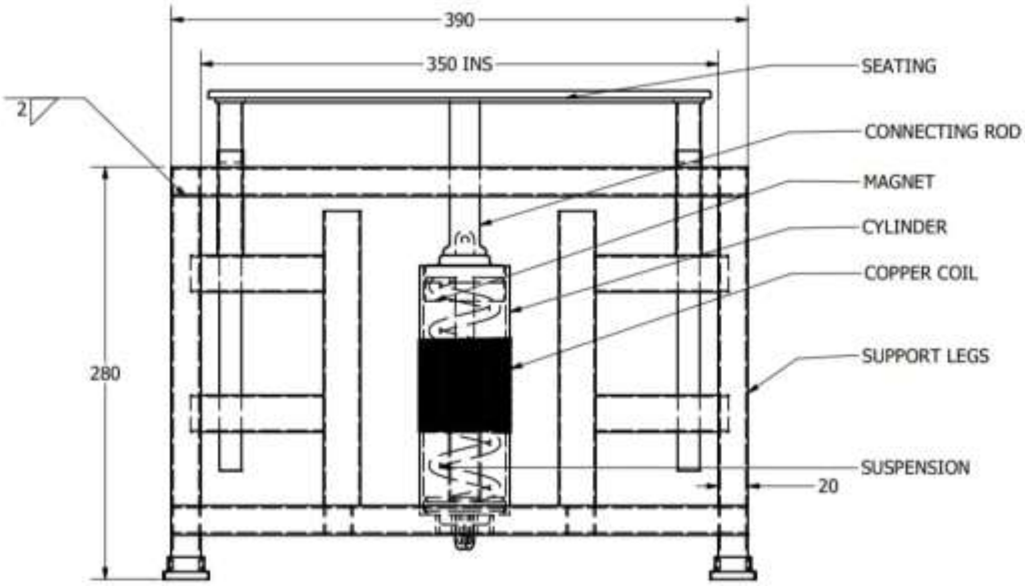


Fig.2: 2D Drafting of Electromagnetic Suspension

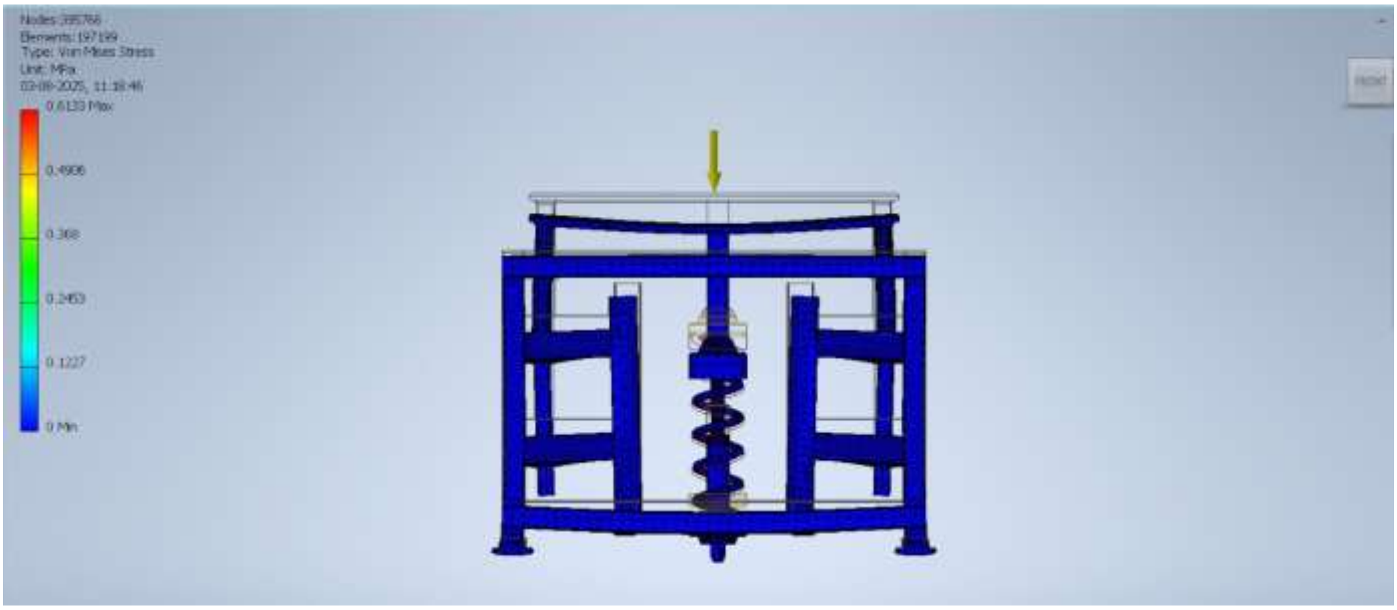


Fig.3: 3D Assembly of Electromagnetic Suspension

Fig.4: 3D Simulation of Electromagnetic Suspension

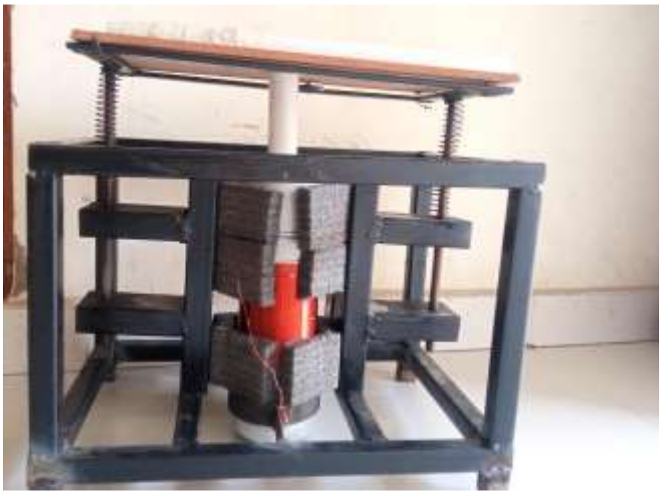


Fig.5: Electromagnetic Suspension

COMPARISON:

Aspect	Mechanical Suspension Energy Harvesting	Electromagnetic Suspension Energy Harvesting
Working Principle	Converts mechanical motion into electricity via rack and pinion, gears, and a generator.	Uses electromagnetic coils and permanent magnets to induce current via electromagnetic induction.
Energy Source	Captures vibrations and movements.	Utilizes magnetic fields and controlled resistance.
Efficiency	Generally lower due to mechanical losses in gears and friction.	Higher efficiency since electromagnetic induction has fewer mechanical losses.
Complexity & Cost	Simpler and cheaper to implement using basic mechanical components.	More complex and expensive, requiring precise control systems.
Application	Suitable for conventional vehicles with passive or semi-active suspension.	More suitable for advanced vehicles, including high-tech electric and hybrid cars.

CONCLUSION:

The concept of generating power through systems presents a significant opportunity to make mechanical systems more energy-efficient and sustainable. By integrating the principles of Faraday's Law of Electromagnetic Induction and using neodymium magnets for strong, compact magnetic fields, researchers have demonstrated that EMS systems can serve a dual purpose providing levitation or damping and simultaneously harvesting energy from motion or vibrations. From the literature reviewed, it is clear that this technology has been explored in both academic and applied settings across India and globally. Various configurations such as passive, active, and hybrid EMS systems have been tested and proven to generate electrical power from suspension movement, especially in transport systems like electric vehicles and railways. The use of neodymium magnets has proven especially effective due to their high energy density, enabling efficient energy conversion even with small displacements.

In conclusion, electromagnetic suspension systems for power generation represent a forward-thinking approach to energy efficiency. With further research and development, these systems can contribute significantly to cleaner energy practices in automotive, rail, and industrial applications.

REFERENCES:

[1] N. Pradeep and S. Mahapatra, "Design and Development of EMS for Transportation Systems," *National Institute of Technology (NIT), Rourkela, India*, 2015.

[2] R. S. Jangid, N. Kumar, and S. P. Gupta, "Electromagnetic Suspension for Power Generation: A Conceptual Framework," *Indian Institute of Technology (IIT), Roorkee, India*, 2014.

[3] X. Li and Y. Zhang, "Development of Hybrid Electromagnetic Suspension with Energy Harvesting," *Tsinghua University, China*, 2018.

[4] A. Sharma and R. Varma, "Regenerative Electromagnetic Suspension for Electric Vehicles," *Indian Institute of Science (IISc), Bangalore, India*, 2020.

[5] M. Yamamoto and H. Sato, "Electromagnetic Suspension with Regenerative Feedback Control," *University of Tokyo, Japan*, 2016.

[6] S. Banerjee and D. Mehta, "Energy Harvesting in Railway Suspension Systems Using EMS," *Indian Railways Research & Design*, India, 2021.

[7] R. K. Singh and P. Venkataraman, "Design Optimization of Electromagnetic Energy Harvesters in Vehicles," *Indian Institute of Technology (IIT), Madras, India*, 2017.

[8] L. Müller and K. Hoffmann, "Electromagnetic Suspension System with Flyback Converter Integration," *Technical University of Munich, Germany*, 2019.

[9] J. Torres and M. Vega, "Vibration-Based Power Generation Using Electromagnetic Dampers," *Universidad Politécnica de Madrid, Spain*, 2022.

[10] A. Das and K. Rajput, "A Review on Energy Harvesting Techniques in Smart Suspension Systems," *Delhi Technological University, India*, 2020.