

A Practical Model of the Mutual Induction Effect for Student Learning and Application

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ABSTRACT

This paper presents a simplified and practical model of the mutual induction effect tailored for student understanding and academic use. The model demonstrates the fundamental principles of mutual induction using basic circuit components and mathematical relationships, allowing students to explore the physical phenomena and its engineering relevance. This approach bridges theoretical knowledge with hands-on experimentation, providing a valuable educational tool. Mutual induction, the phenomenon where a changing current in one coil induces a voltage in a neighboring coil, is a foundational concept in electromagnetism and electrical engineering. Despite its importance, students often struggle to grasp its physical interpretation due to the abstract nature of electromagnetic fields and flux linkages. Traditional teaching methods typically rely on complex mathematical formulations, which may overshadow the intuitive understanding of the concept. To address this gap, the proposed model simplifies the visualization of mutual induction by using easily accessible components such as coils, resistors, and voltage sources, making the learning process more interactive and relatable. Furthermore, this model allows students to experiment with key parameters such as the number of coil turns, distance between coils, and current variations to observe their direct impact on induced voltage. Such experimental activities not only reinforce theoretical concepts but also develop critical thinking and problem-solving skills among students. The hands-on nature of the model encourages curiosity and active participation, fostering a deeper engagement with the subject matter. In addition to its educational benefits, the model provides a practical foundation for understanding real-world applications of mutual induction, such as transformers, wireless charging systems, and inductive sensors. By connecting classroom learning with industrial applications, students can appreciate the relevance of mutual induction in modern technology.

Keyword : - *Mutual Induction, Electromagnetic Induction, Educational Model, Hands-on Experimentation, Engineering Education, Simplified Circuit Model, Induced Voltage, Coil Interaction, Magnetic Coupling, Conceptual Understanding,*

1. INTRODUCTION

Mutual induction is a fundamental concept in the study of electromagnetism and electrical engineering, where a changing current in one coil induces a voltage in a neighboring coil through magnetic coupling. This principle forms the basis of essential devices such as transformers, inductors, wireless chargers, and various sensing technologies. Despite its widespread applications, the underlying theory of mutual induction often poses a challenge for students due to its abstract nature involving magnetic fields, flux linkages, and time-varying currents. Traditional pedagogical approaches primarily emphasize mathematical derivations and theoretical explanations, which can limit students' intuitive understanding of the physical phenomena involved. In engineering education, there is a growing need to bridge the gap between theoretical knowledge and practical application. Hands-on learning methods and interactive models have proven to be effective tools in enhancing conceptual clarity and student engagement. Simplified physical models that demonstrate complex concepts in an accessible manner are invaluable in fostering deeper learning and promoting analytical thinking among students. This paper proposes a simplified and practical model to demonstrate the effect of mutual induction, specifically designed for educational purposes. Using basic circuit components such as coils, resistors, and voltage sources, the model provides a clear and tangible visualization of mutual induction principles. It allows students to actively explore the relationship between current changes in a primary coil and the induced voltage in a secondary coil, thereby reinforcing their theoretical understanding through experimental observation. Furthermore, the model serves as a foundation for understanding the real-world significance of mutual induction in engineering applications. By integrating theoretical concepts with practical experimentation, this approach not only improves student learning outcomes but also enhances their ability to apply knowledge in solving engineering problems. The proposed educational model thus represents a valuable addition to teaching strategies aimed at simplifying complex electromagnetic concepts.

2. THEORETICAL BACKGROUND

Mutual induction is a phenomenon in electromagnetism where a change in current flowing through one coil induces an electromotive force (EMF) in a neighboring coil due to the changing magnetic flux linkage between them. This principle was first experimentally demonstrated by Michael Faraday in 1831, laying the foundation for modern electrical engineering applications such as transformers, inductors, and wireless power transfer systems. According to Faraday's Law of Electromagnetic Induction, the induced EMF (ϵ) in a coil is directly proportional to the rate of change of magnetic flux (Φ) through it

$$\epsilon = -N \frac{d\Phi}{dt}$$

Where:

- ϵ is the induced EMF (volts),
- N is the number of turns in the coil,
- $D\Phi/dt$ is the rate of change of magnetic flux through the coil.

In the case of mutual induction, the changing current in the primary coil generates a time-varying magnetic field, which links to the secondary coil and induces a voltage across it. The magnitude of the induced voltage depends on factors such as the number of turns in each coil, the core material's permeability, the distance between coils, and the rate of change of current in the primary coil. Its value of mutual inductance depends on the physical arrangement of the coils, the number of turns, and the magnetic permeability of the medium between them. Coils wound around a common ferromagnetic core exhibit stronger mutual inductance due to enhanced magnetic coupling. In practical applications, understanding mutual induction is critical for designing efficient electrical machines, transformers, inductive sensors, and wireless power systems. For students, visualizing this invisible electromagnetic interaction poses a challenge. Hence, simplified models that allow observation and manipulation of mutual induction parameters are essential for effective learning. This theoretical background forms the basis for developing a practical educational model that simplifies mutual induction for student exploration, as discussed in the subsequent sections.

3. PROPOSED MODEL

The proposed model aims to provide a simplified yet effective demonstration of the mutual induction phenomenon, specifically designed for student understanding and academic experimentation. The model utilizes basic and easily accessible electrical components, making it a cost-effective and practical tool for classroom demonstrations and laboratory sessions.

3.1 Components Used

The following components are used in the proposed model:

- Primary Coil (Excitation Coil): A copper wire wound into a coil, connected to an AC voltage source.
- Secondary Coil (Receiving Coil): Identical or similar to the primary coil, placed near it to receive the induced EMF.
- AC Voltage Source: A function generator or simple AC power supply to create a time-varying current in the primary coil.
- Resistors: To limit the current and protect circuit components.
- Multimeter/Oscilloscope: To measure the induced voltage in the secondary coil.
- Non-magnetic Support Structure: To hold the coils in place and allow adjustment of the distance between them.
- Iron Core (optional): To demonstrate the effect of magnetic coupling enhancement.

3.2 Working Principle

The primary coil is connected to an AC voltage source, generating an alternating current that produces a time-varying magnetic field around it. This changing magnetic field links with the nearby secondary coil, inducing an electromotive force (EMF) in it according to Faraday's Law of Electromagnetic Induction. The magnitude of the induced voltage can be observed and measured using a voltmeter or oscilloscope connected across the secondary coil.



Fig -1: Figure Model of Mutual Induction Effect

By varying the following parameters, students can experimentally verify the principles of mutual induction:

- The number of turns in each coil.
- The distance between the primary and secondary coils.
- The frequency and amplitude of the AC current.
- The use of an iron core to enhance magnetic coupling.

3.3 Educational Benefits

This model provides a visual and measurable representation of mutual induction, enabling students to connect theoretical concepts with real-world observations. The simplicity of the setup encourages active participation, hands-on learning, and better retention of fundamental electromagnetic principles. Additionally, it serves as a foundation for understanding complex applications such as transformers, wireless chargers, and inductive sensors

4. CONCLUSIONS

In this paper, a simplified and practical model of mutual induction has been presented, aimed at enhancing student understanding through hands-on experimentation. By utilizing basic electrical components such as coils, resistors, and an AC power source, the model effectively demonstrates the fundamental principles of mutual induction in an accessible and interactive manner. This approach addresses the common challenges students face in visualizing and comprehending electromagnetic concepts, particularly the phenomenon of magnetic coupling and induced voltage. The proposed model serves as a valuable educational tool by bridging the gap between theoretical knowledge and practical application. Through experimental manipulation of key parameters—such as coil turns, distance between coils, and the introduction of a magnetic core—students can directly observe the effects of mutual induction, thereby reinforcing their conceptual understanding. The model not only simplifies complex electromagnetic interactions but also fosters critical thinking, problem-solving skills, and active learning among students. Furthermore, the model lays a foundation for understanding real-world engineering applications where mutual induction plays a crucial role, such as in transformers, wireless power transfer systems, and inductive sensors. By connecting classroom learning to practical engineering scenarios, the proposed model enhances the relevance and applicability of the subject matter. Overall, the simplified mutual induction model is a cost-effective, easy-to-implement, and pedagogically effective solution for improving the quality of engineering education. Its adoption in academic settings can significantly aid in developing a deeper and more intuitive understanding of electromagnetic principles among students.

6. REFERENCES

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