

A Brief Analysis of Electromagnetic Principles in Mechanical Design

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Abstract: Mechanical design is a crucial branch of engineering technology that focuses on the conception, development, and optimization of mechanical systems. This field encompasses a wide range of activities, from the initial design ideas to the final implementation of complex machinery. One of the innovative aspects of mechanical design is the application of electromagnetic phenomena, which offers valuable insights and references for improving various mechanical systems. This paper utilizes a literature review approach to delve into the application of electromagnetic principles within mechanical design. It explains the fundamental concepts of these principles and assesses their significant roles, particularly in areas such as electromagnetic drive, electromagnetic braking, and electromagnetic induction. By presenting practical examples, the paper highlights the importance and vast potential of integrating electromagnetic principles into modern mechanical design. Ultimately, this study aims to foster technological advancements in mechanical design, streamline the design process, and effectively solve real-world engineering challenges.

Keywords: mechanical design, electromagnetic drive, electromagnetic braking, electromagnetic induction.

1. Introduction

With the continuous advancement of technology, the application of electromagnetic principles in mechanical design is becoming increasingly widespread. The introduction of electromagnetic technology brings new ideas and methods to mechanical design, enhancing the performance and efficiency of mechanical systems. Researching the electromagnetic principles in mechanical design requires a clear understanding of the principles themselves, as well as their critical role in guiding practical applications, such as electromagnetic drive and electromagnetic braking.

A paper regarding electromagnetic induction research offers further insights and understanding of electromagnetic principles, including theoretical analyses, experimental studies, and data acquisition systems [1]. Another work about the application of mechanical design explores the applications of mechanical design and automation within the field of intelligent manufacturing, addressing topics such as optimizing automated production lines, the use of intelligent robots, constructing digital factories, and integrating smart manufacturing technologies [2]. This research effectively combines electromagnetic principles.

Mechanical Design and Analysis of Modular Active Magnetic Bearing Test Rig examines the mechanical design and analysis of a modular active magnetic bearing testing apparatus [3]. It presents the design and analysis results and compares different modeling approaches, documenting the complexities and requirements of connecting electromagnetic components to rotors and actuators to optimize mechanical and electromagnetic performance.

This paper employs a literature review method to analyze the specific applications of electromagnetism in mechanical design. The research aims to deepen the understanding of how electromagnetic principles can be applied in mechanical design, contributing to the development of more advanced and reliable mechanical products.

2. Overview of electromagnetic principles

2.1. Electromagnetic induction

When a conductor moves in a magnetic field or when the magnetic field changes, an induced electromotive force is generated within the conductor. This phenomenon is the foundation of electromagnetic induction, which underpins the working principles of electrical devices such as generators and transformers. In a study, it is noted that the phenomenon of electromagnetic induction occurs when a conductor cuts through magnetic field lines, resulting in the generation of electrical energy [4]. Many devices around us rely on electricity, such as various equipment in factories and large buildings. As one of the key principles for the generation and transmission of electrical power, the importance of electromagnetic induction is undeniable.

2.2. Ampère's Law

In the article regarding Ampère's Law and Coulomb's Law in electromagnetism, a comparison is made between Ampère's Law and Coulomb's Law. By examining various aspects such as physical significance, ideal models, formula representations, properties of forces, transmission media, and theoretical status, the study effectively enhances the understanding of Ampère's Law [5]. A current-carrying conductor experiences a force when placed in a magnetic field, and the magnitude of this force is directly proportional to the current intensity, the strength of the magnetic field, and the length of the conductor within the field. This relationship is known as Ampère's Law, which serves as the theoretical foundation for electromagnetic drive and electromagnetic braking.

2.3. Lenz's Law

The magnetic field of the induced current always opposes changes in the magnetic flux that produce the induced current. Lenz's Law establishes the relationship between the direction of the current in electromagnetic induction and the changes in the magnetic field. The study *Understanding and Application of Key Difficulties in Lenz's Law* analyzes and interprets Lenz's Law from different perspectives. First, it examines how the change in original magnetic flux induces a change in the induced magnetic flux, determining the direction of the induced magnetic flux and then inferring the direction of the induced current [6]. Second, it approaches the topic from the perspective of energy conservation, directly determining the polarity of the induced magnetic flux based on the polarity of the original magnetic flux, which then allows for the determination of the induced current.

3. Application of Electromagnetism in Mechanical Design

3.1. Electromagnetic drive

Electromagnetic drive is a technology that converts mechanical energy based on the principles of electromagnetic induction. Its core involves the movement of a magnetic field relative to a conductor, which generates an induced current, causing the conductor to move through the action of Ampère's force. This phenomenon is widely applied in various devices, such as electric meters, electromagnetic speedometers, induction motors, induction cookers, transformers, and mine detectors.

Electromagnetic drive devices are categorized into two types: linear motors and rotary motors.

Linear motors are devices that directly convert electrical energy into linear mechanical energy. They generate electromagnetic forces between the stator and the mover to achieve linear motion of the mover. Linear motors offer advantages such as high speed, high precision, and high acceleration, making them widely used in automation production lines and CNC machine tools.

Rotary motors are the most common electromagnetic drive devices, including electric motors and generators. Electric motors convert electrical energy into rotational mechanical energy, powering various mechanical devices. Generators, on the other hand, convert mechanical energy into electrical energy, supplying power to electrical systems.

3.2. Electromagnetic braking

Electromagnetic braking is a technology that utilizes electromagnetic force to achieve mechanical braking, widely applied in various industrial equipment and vehicles. Its working principle involves generating a magnetic field by energizing an electromagnetic coil, which attracts or repels a core to control the movement of the brake disc or brake pads, thereby achieving the braking effect.

Electromagnetic braking includes two methods: electromagnetic clutch brakes and regenerative braking.

Electromagnetic clutch brakes are devices that use electromagnetic force to accomplish mechanical braking. When energized, the electromagnetic clutch brake releases, allowing the mechanical device to move; when de-energized, the clutch tightens, causing the mechanical device to stop rapidly. Electromagnetic clutch brakes are commonly used in cranes, elevators, and other equipment.

Regenerative braking is a braking method that converts the kinetic energy of a mechanical device into electrical energy and feeds it back to the grid. It generates a reverse electromotive force in the motor, turning the motor into a generator and converting kinetic energy into electrical energy. Regenerative braking is energy-efficient and environmentally friendly, making it widely used in electric vehicles and rail transit systems.

3.3. Application of electromagnetic induction in mechanical design

3.3.1. Sensor

Electromagnetic induction sensors utilize the principles of electromagnetic induction to convert measured physical quantities into electrical signals. For example, inductive sensors can measure physical quantities such as displacement and pressure, while Hall sensors can measure magnetic field strength and current. Electromagnetic induction sensors offer advantages such as high precision and good reliability, making them widely used in fields like industrial automation and automotive electronics.

In the realm of smart homes, sensors are applied extensively. For instance, infrared sensors detect human activity to automatically turn lights on and off, thereby enhancing energy efficiency. This

integration of electromagnetic induction sensors in various applications showcases their versatility and importance in modern technology, contributing to more efficient and intelligent systems.

3.3.2. Wireless charging

Wireless charging technology utilizes the principles of electromagnetic induction to enable wireless charging of devices. It generates electromagnetic induction between the transmitter and receiver to transfer electrical energy from the transmitter to the receiver, providing charging services for mobile devices, electric vehicles, and more. Wireless charging technology offers advantages such as convenience, speed, and safety, making it a promising direction for the future of charging technology.

Wireless charging has been applied in the field of intelligent transportation. For example, wireless charging smart vehicles are equipped with a wireless charging module embedded between a receiver and a charger on the underside of the vehicle, allowing for autonomous charging while the vehicle is in motion. This innovation showcases the potential of wireless charging in enhancing the functionality and efficiency of modern transportation systems.

4. Applications of electromagnetic principles in mechanical design

4.1. Electric vehicles

Electric vehicles use electric motors as their driving mechanism, employing the principles of electromagnetic induction to convert electrical energy into mechanical energy, thus propelling the vehicle. Additionally, electric vehicles incorporate regenerative braking technology to convert kinetic energy during braking back into electrical energy, recovering energy and improving energy efficiency.

The electromagnetic compatibility (EMC) of electric vehicles is a crucial factor in ensuring their reliability and safety. Electromagnetic interference (EMI) in electric vehicles primarily arises from low-voltage systems, such as the rapid switching of power sources in motor drive systems and charging systems, the operation of motor windings, and signal coupling between high-voltage cables and low-voltage cables. Addressing these EMI issues is essential for the optimal performance of electric vehicles.

4.2. Automated production lines

The principles of electromagnetism in automated production lines primarily involve the application of solenoid valves. A solenoid valve is a device that uses electromagnetic force to control the flow of fluids (liquids or gases). Solenoid valves play a crucial role in automation control systems, enabling precise control of fluid media through electromagnetic force, thereby regulating, switching, and controlling fluid media during the automated production process. For example, in industrial automation production lines, solenoid valves can be used to control the pressure and flow of hydraulic systems, ensuring the stability of the production process and the quality of the products.

4.3. CNC machine

The electromagnetic principles in Computer numerical control (CNC) machine tools encompass various applications, such as electromagnetic suspension and electromagnetic chucks, which collectively enhance the performance and processing precision of CNC machines. For instance, in CNC machining centers, the electromagnetic suspension system uses electromagnetic forces induced by windings to attract the guide rails, allowing the crossbeam to float in the air. This reduces friction and improves processing accuracy and efficiency.

Linear guide rails utilize the principles of electromagnetic action to directly convert electrical energy into linear motion. This design means that the machining accuracy and lifespan of CNC machine tools largely depend on the quality of the guide rails.

5. Conclusion

The principles of electromagnetism hold significant application value in mechanical design. By appropriately applying technologies such as electromagnetic drive, electromagnetic braking, and electromagnetic induction, the performance and efficiency of mechanical systems can be enhanced, enabling intelligent and automated control. With the continuous advancement of technology, the application of electromagnetic technology in mechanical design will become increasingly widespread, presenting new opportunities and challenges for the development of the machinery industry.

This paper integrates the knowledge of electromagnetic principles with mechanical design for preliminary research, aiming to effectively apply these principles in practical mechanical design. However, the application in specific areas lacks sufficient detail, and in-depth research has not yet been conducted, indicating a need for future focus and exploration.

Building on this research, future efforts will involve applying specific theoretical aspects of electromagnetic principles to particular industries or fields, and even effectively utilizing them in the design practices of specific types of equipment or individual components.

The close integration of electromagnetic principles and mechanical design is a complex process involving multiple dimensions and interdisciplinary intersections, with vast application potential in structural design, simulation technology, system optimization, as well as materials and processing technologies in the future.

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