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Research on the Development and Application of Electromagnetic Clutch

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Abstract: As a core device, electromagnetic clutch is increasingly used in various fields such as automatic control systems. This paper introduces the basic principles, core components and key role of electromagnetic clutch in mechanical connection and disconnection. By analyzing the historical development of electromagnetic clutch, it points out how technological progress has promoted its application in different fields, including industrial automation, automotive braking system and special application fields. With the development of new materials and new technologies, electromagnetic clutch faces new challenges and opportunities. Future research directions will focus on optimizing design, improving energy efficiency and reducing maintenance costs, while considering the needs of environmental protection and sustainable development to promote the further development and application of electromagnetic clutch technology.

Keywords: Electromagnetic Clutch; Industrial Automation; Mechanical Transmission; Automotive Braking.

1. Introduction

With the development of industrial automation and intelligent manufacturing, the application of electromagnetic clutch in automatic control systems has become more and more extensive [1-3]. Electromagnetic clutch is a key device that uses electromagnetic force to control mechanical connection and disconnection. It realizes the transmission or disconnection of power through electromagnetic action, thereby controlling the start, stop, speed and transmission direction of the mechanical system. The core components of electromagnetic clutch include electromagnetic coil, iron core, friction plate, etc. When the electromagnetic coil is energized, a magnetic field is generated, which makes the iron core generate attraction, thereby pressing the friction plate to achieve connection. When the power is off, the spring force or other mechanical force separates the friction plate, thereby achieving disconnection.

A well-designed electromagnetic clutch not only improves production efficiency and accuracy, but also ensures the safety of operation. At the same time, the research on electromagnetic clutch is of great significance for optimizing product design, improving energy efficiency, and reducing maintenance costs [4-6]. With the emergence of new materials and new technologies, the design and application of electromagnetic clutches are facing new challenges and opportunities. This paper aims to review the basic principles, historical development, and application of electromagnetic clutches in different fields, especially industrial automation, automotive braking systems, and special application fields such as aerospace, medical equipment, etc. Through the analysis of existing technologies and case studies, it aims to identify the limitations of current technologies and future development directions.

2. Historical Development of Electromagnetic Clutches

The concept of electromagnetic clutches can be traced back to the late 19th century, when it was mainly used for signal transmission in telegraph technology [7]. The early design was relatively simple, mainly relying on manual operation to control the generation of electromagnetic fields to achieve the connection and disconnection of the transmission system [8]. With the development of motors and electromagnetism, electromagnetic clutches began to be widely used in industrial machinery in the early 20th century, especially in textile and printing machinery, which significantly improved production efficiency [9-10].

During World War II, the technology of electromagnetic clutches has been significantly developed as military needs have driven the advancement of precision control technology. During this period, people developed a variety of new electromagnetic clutches, including multi-disc and wet clutches, which can work stably at higher speeds and loads. In addition, the introduction of new materials such as high-performance alloys and composite friction materials has further improved the durability and performance of electromagnetic clutches [11].

After entering the 21st century, the development of electromagnetic clutches has focused on intelligence and energy conservation and emission reduction. The use of digital control technology makes the operation of electromagnetic clutches more precise and reliable, and the use of integrated sensors has also improved the self-diagnosis ability of the system. The development and application of environmentally friendly materials has reduced pollution in the production process, which meets the needs of today's society for sustainable development [12].

3. Working Principle of Electromagnetic Clutch

The electromagnetic clutch is mainly composed of an electromagnet, a power input component (usually a drive disc), a power output component (usually a driven disc) and a spring or other release mechanism. The electromagnet is the core of the control device, which can generate magnetic force

under the action of electric current; the drive disc is connected to the input shaft, and the driven disc is connected to the output shaft; a spring or other mechanism is used to separate the drive disc from the driven disc when the power is off [12].

In the pull-in stage, the electromagnet is energized to generate a magnetic field. The magnetic force attracts the moving iron sheet through the magnetic core, so that the driving disc and the driven disc are in close contact. At this time, the power can be transmitted to the output shaft through the input shaft. In the transmission stage, when the driving disc and the driven disc are in close contact, the rotation of the input shaft is transmitted to the driven disc through the driving disc, thereby driving the output shaft to rotate and realizing the power transmission. In the disconnection stage, when it is necessary to disconnect the transmission or change the transmission ratio, the power magnetic field of the electromagnet is cut off and disappears. Under the action of the spring or other release mechanism, the driving disc and the driven disc are separated, interrupting the power transmission, so that there is no mechanical connection between the input shaft and the output shaft.

The electromagnetic clutch can achieve rapid and accurate connection and disconnection, which is particularly suitable for systems that require frequent start-stop or speed regulation. It has simple control and fast response speed, and can achieve high-precision power transmission control. In addition, since its operation does not rely on direct mechanical contact, compared with traditional mechanical clutches, the electromagnetic clutch has higher reliability and longer service life.

4. Application Fields and Case Analysis of Electromagnetic Clutch

4.1. Industrial Automation and Mechanical Transmission

In the field of industrial automation, electromagnetic clutches are widely used in conveyor belt systems, automatic assembly lines and machine tools, etc. They can achieve fast and precise mechanical motion control, especially in application scenarios that require frequent start and stop or forward and reverse rotation. For example, in automated assembly lines, electromagnetic clutches are used to control the start and stop of conveyor belts. When it is necessary to pause the movement of items on the assembly line for assembly, inspection or packaging, the electromagnetic clutch can quickly cut off the power transmission of the conveyor belt drive system, thereby stopping the movement of the conveyor belt. After the operation is completed, the electromagnetic clutch is activated again to restore the power transmission of the conveyor belt, achieving efficient and precise production process control.

In metal processing machinery, such as punching machines, shearing machines, etc., electromagnetic clutches are used to control the working cycle of the machinery, including starting and stopping stamping or cutting actions. The electromagnetic clutch not only achieves high-precision control, but also provides a safety mechanism that can quickly cut off power in an emergency to protect the safety of operators and equipment. In heavy machinery and equipment such as construction and mining, electromagnetic clutches are used to control the movement or rotation of mechanical arms and the operation of other actuators. By precisely controlling the electromagnetic clutch, complex actions can be accurately executed, improving work efficiency and safety.

4.2. Automobile Braking System

Electromagnetic clutches also play an important role in the automotive industry, especially in braking systems and gearboxes. In some high-performance vehicles, electromagnetic clutches are used to dynamically adjust the braking force to provide better handling and safety. At the same time, electromagnetic clutches are also used in automatic transmissions to achieve smooth and rapid gear shifting [13-14].

In order to reduce the mechanical and electromagnetic shocks caused by the rigid connection between the wheel hub and the motor, Yang et al. proposed a permanent magnet bistable electromagnetic clutch that flexibly connects the motor and the wheel hub [15]. Based on a dynamic simulation model, the static and dynamic performance of the clutch unit was studied. The proposed current pulse width analytical solution was used to optimize the design, determine the capacitance, charging voltage, number of coil turns and coil wire diameter, and optimize the electromagnetic clutch.

4.3. Special Application Fields

The application of electromagnetic clutches in the aerospace field is another example of its technological innovation. In satellite communication systems, electromagnetic clutches are used to precisely control the direction of antennas to ensure accurate signal transmission [16-17]. In the field of medical devices, electromagnetic clutches are used in devices such as surgical robots to provide precise motion control to ensure the accuracy and safety of surgery [18].

Yin et al. proposed an ankle exosuit based on electromagnetic clutch, which is suitable for stroke survivors of different body types [19]. The exosuit includes a single motor drive unit, two new electromagnetic ratchet clutches and functional textiles. Compared with other ankle rehabilitation robots, this exosuit can adapt to different users in terms of adaptive preload after wearing, keeping the device transparent when power is off, and providing timely assistance.

Ma et al. proposed a new SMA wire clutch designed to reduce weight and shorten response time [20]. The proposed SMA clutch can track a given sinusoidal trajectory with a high accuracy of 3.4% in the clamping area. Through the study of the proposed SMA clutch, it is expected to be used in weight-restricted environments such as satellites.

5. Summary and Outlook

As a mature and continuously improving technology, electromagnetic clutch plays a vital role in many fields. From the early simple mechanical control to today's highly automated and intelligent applications, the development of electromagnetic clutches reflects the continuous evolution of scientific and technological progress and social needs. In the future, with the continuous emergence of new materials and new technologies, the performance of electromagnetic clutches will be further improved and the application field will be further broadened. At the same time, facing the dual challenges of energy consumption and environmental protection, the research on electromagnetic clutches will pay more attention to high efficiency and environmentally friendly design.

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