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Characteristics and Simulation Analysis of a Magnetic Planetary Gear Transmission

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Abstract: *Magnetic planetary gears have good application prospects in variable speed devices. Compared with traditional gears, their outstanding advantages are not only the ability to split power when transmitting torque, but also the fact that the input and output shafts are on the same horizontal line; And it has the characteristic of non-contact transmission. In order to improve the application feasibility of magnetic planetary gears, based on the structure and working principle of traditional planetary gears, the finite element model of magnetic planetary gears is established. The coupling form is axial coupling. kinematics analysis and static magnetic field simulation analysis are carried out, and the influence rules of coupling gap, magnetic pole number, gear size and magnetic pole thickness on transmission torque are obtained. Draw a conclusion and obtain the optimal structure and larger transmission torque through finite element simulation analysis. The simulation analysis results provide reference for the external structure and working principle of magnetic planetary gears, thereby greatly shortening their development cycle.*

Keywords: *Magnetic planetary gears, Axial coupling, Static magnetic field, Torque*

1. Introduction

Among various transmission forms, gear transmission is the most widely used in modern machinery. However, traditional gears are usually meshed contact transmission, which has many failure forms and is also affected by processing and installation accuracy, resulting in problems such as high vibration and noise. In response to the problems existing in meshing contact gears, researchers have proposed the concept of non-contact transmission. The invention of magnetic gears has changed the transmission mode of gears. Through its advantages of meshing clearance, magnetic gears have changed power transmission to non-contact transmission torque [1], effectively solving a series of problems caused by traditional contact gear transmission.

Magnetic gears use magnetic force to couple and transmit torque to gears, which has the following advantages [2]: Firstly, magnetic gear transmission has the advantages of no friction, low noise during operation, and low vibration during operation; Second, this structure is suitable for situations where there is no lubrication, high reliability is required, and maintenance is difficult after work; Finally, simple structure for non-contact transmission.

The development of magnetic gears has undergone a long period of sedimentation. In 1987, Japanese scholars S. Kikuchi and K. Tsurumoto put forward the involute structure. The transmission torque of this structure was improved by optimizing the parameters such as pole number, pressure angle, transmission ratio, center distance, air gap, etc., and the structure of the magnetic gear was designed as an involute [3]. In 2004, Professor D. Howe from the University of Sheffield in the United Kingdom proposed a new type of magnetic gear based on the principle of magnetic field modulation. Subsequently, Professor D. Howe proposed a magnetic field modulated magnetic gear structure in the literature, which consists of linear and axial structures, and introduced the structure and working principle [4-6]. K. from the University of Hong Kong T. Chau, envisioning the application of magnetic gears in large-scale wind power systems and electric vehicles, replacing mechanical gearboxes and transmissions with new types of magnetic gears, and adopting a coaxial concentric structure to combine the generator with magnetic gears [7-8].

Nowadays, the development of magnetic gear technology is becoming mature [9], and single pair magnetic gear transmission technology has been widely applied. However, for magnetic planetary gears, theoretical research is still not systematic and in-depth enough. Magnetic planetary gear transmission

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belongs to a type of axial transmission, and its structural advantage is that through secondary gear transmission, not only can the torque generated during power transmission be divided into power, but also the input and output shafts are in the same horizontal line; Moreover, it has the characteristic of non-contact transmission, which reduces space occupation and improves transmission efficiency compared to traditional mechanical gears. In order to improve the feasibility of the application of alternating magnetic planetary gears, Maxwell simulation software is used in this article to analyze and study the characteristics of magnetic planetary gears.

2. Manuscript Preparation

2.1 Structure and working principle of magnetic planetary gears

Design a magnetic planetary gear using neodymium iron boron material as the magnetic block, which has extremely high magnetic energy product and coercive force, making it difficult to demagnetize and ensuring stable torque transmission performance. The support material is stainless steel, which has magnetic properties similar to vacuum and almost no magnetic conductivity. The designed magnetic planetary gear is shown in Figure 1 below.

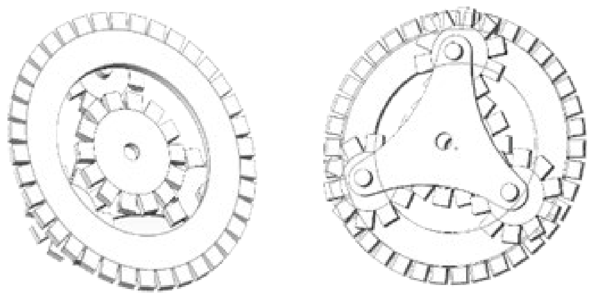

Figure 1: Structural model of magnetic planetary gears

The main application of magnetic planetary gear transmission is the principle of magnetic field theory, which states that the same type repels each other and the opposite type attracts each other. When the driving wheel and the driven wheel are matched, the magnetic poles of the magnetic teeth are opposite, and the adjacent magnetic poles of the same gear are different. The magnetic field generated during operation generates gravity, which changes in a sine function. During operation, the transmission torque is provided by the tangential component force in the direction of the coupling force. The torque generated in the coupling area increases, decreases, and disappears with the rotation of the magnetic driving wheel, and the corresponding magnetic coupling transmission cycle disappears, decreases, increases, and generates, Two pairs of magnetic teeth form a complementary relationship, so that the active wheel drives the driven wheel to transmit stable torque.

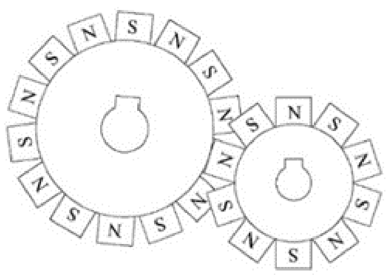

Figure 2: Schematic diagram of magnetic gear transmission principle

The transmission principle of the designed magnetic planetary gear is that the sun gear is magnetized by the excitation of the motor, and according to the magnetic theory of same-sex repulsion and opposite-sex attraction, the torque is transmitted to the planet gear for revolution[10]. The planet rotates while cooperating with the gear ring for revolution, and the output torque is transmitted to the planet carrier to complete the torque output of the device. The feasibility of designing a new type of transmission device based on ferromagnetic theory has also been demonstrated in the process of a series of planetary gear train transmissions.

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The solver used in this article is a static field, which generates a constant magnetic field excited by a constant excitation source of a permanent magnet [11]. In the static excitation formula, linear and nonlinear materials can be solved, and the magnetic potential A satisfies the following equation:

$$J_z(x,y) = \nabla \times \left\{\frac{1}{\mu_r \mu_0}[\nabla \times A_z(x,y)]\right\} \tag{1}$$

In the formula, A_z (x, y) is the component of the vector magnetic potential on the Z-axis, and J_z (x, y) is the current density of the current flow cross-section, μ_r is the relative magnetic permeability of the material in the solution domain, μ_0 is the magnetic permeability of the material in vacuum.

According to Ampere's loop law in a static magnetic field:

$$\nabla \times \mathrm{H} = \mathrm{J} \tag{2}$$

According to Maxwell's equation:

$$\begin{cases} \nabla\times\mathrm{B}=0 \\ \mathrm{H}=\dfrac{\mathrm{B}}{\mu_r\mu_0} \end{cases} \tag{3}$$

Obtain:

$$\nabla\times\left(\frac{\mathrm{B}}{\mu_r\mu_0}\right) = J \tag{4}$$

By B=Δ × A can obtain:

$$\nabla\times\left(\frac{1}{\mu_r\mu_0}\nabla\times\mathrm{A}\right) = J \tag{5}$$

Calculate the vector magnetic potential A based on the above calculation formula. Substitute the following formula:

$$\begin{cases} \mathrm{B}=\nabla\times\mathrm{A} \\ \mathrm{H}=\dfrac{\mathrm{B}}{\mu_r\mu_0} \end{cases} \tag{6}$$

The final result is that the magnetic induction intensity of the static magnetic field is equal to the magnetic field intensity.

The theory used in Maxwell to calculate static torque is the virtual work theory, and the expression for torque is:

$$T = \left.\frac{dW(\theta,i)}{d\theta}\right|_{i=const} = \frac{\partial}{\partial\theta}\left[\int_V \left(\int_0^H B\cdot dH\right) dV\right] \tag{7}$$

In the equation, W（θ, i) is the magnetic field energy storage of the system, and i is a constant current.

2.2 Finite element modeling of magnetic planetary gears

Save the assembly model in Solid Works in an. step file format that Maxwell can open, open the 3D model simulation solver in Maxwell software, set the corresponding solution type, import the required 3D model of Solid Works into Maxwell simulation software, and generative model. Set the material of the material, the magnetic block is made of neodymium iron boron material, and the N and S poles are staggered; The supporting device is made of stainless steel material, and its properties do not affect magnetism, keeping the magnetic field strength H and magnetic induction strength B continuous. The boundary condition is set to the balloon boundary, and the boundary is set to infinity. Divide the mesh, select a triangular mesh to divide the model, and set the triangle edge length to 8mm. Finally, the vector magnetic potential A is used for solving. The obtained modeling parameters are shown in Table 1, finite element modeling is shown in Figure 3.

Table 1: Modeling parameters.

Parameter	Parameter value
Number of solar wheel magnetic poles/pair	7
Outer diameter of solar wheel D/mm	70
Inner diameter of solar wheel d/mm	50
Number of magnetic pole pairs of planetary gears/pair	5
Outer diameter of planetary gear D/mm	35
Inner diameter of planetary gear d/mm	28
Number of magnetic pole pairs on the gear ring/pair	19
Outer diameter of gear ring D/mm	160
Inner diameter of gear ring d/mm	140
Pole thickness/mm	5/10/15/20
Magnetic pole material	NdFeB
backlash	4/6/8/10
support material	stainless steel

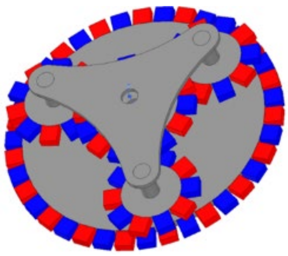

Figure 3 Finite Element Model of Magnetic Planetary Gears.

2.3 Analysis of the Influence of Gear Parameters on Torque

The magnitude of transmission torque is influenced by factors such as gear mesh clearance, number of magnetic poles, thickness of magnetic rings, and gear size. In this article, a gear model is established in a static magnetic field, the mesh is divided and solved, and simulation analysis is completed for four influencing variables. Among them, the maximum number of magnetic poles is selected based on the size of the gear; In the supporting material, due to the magnetic properties of stainless steel similar to vacuum, the size of the gear does not affect the result of transmitting torque. In addition, it has been learned from references to other literature that the size of the gear has little effect on the maximum output torque and can be ignored.

The size of gear clearance is an important factor affecting torque transmission. If two gears are too close together, energy consumption will occur, which increases friction loss and interferes with the correct flow direction of the magnetic induction line; Excessive distance weakens the magnetic force, and the magnetic torque generated by the driving wheel is too small to drive the driven wheel, resulting in abnormal operation. The thickness of magnetic teeth is an important factor affecting torque. For the same pair of gears, the thicker the magnetic teeth, the greater the output torque during operation. Therefore, it is necessary to select appropriate magnetic tooth thickness parameters to achieve normal, smooth and effective rotation.

For magnetic planetary gears, the thickness of the gear magnetic poles and the gear meshing clearance have a significant impact on the transmission torque. However, in the selection of gap and magnetic pole thickness, both too small a gap and too thick a magnetic pole can cause magnetic leakage. Therefore, appropriate clearances and magnetic tooth thickness should be selected. This way, the transmission effect is the best, and the torque generated by magnetic field coupling is the most ideal, which can achieve the maximum output torque.

2.4 Optimization of Magnetic Planetary Gear Structure

According to the simulation experiment analysis, the model diagram of the magnetic planetary gear with the best parameters is obtained, and the distribution nephogram of magnetic field intensity and magnetic induction intensity is obtained, as shown in Figure 4 and Figure 5 respectively.

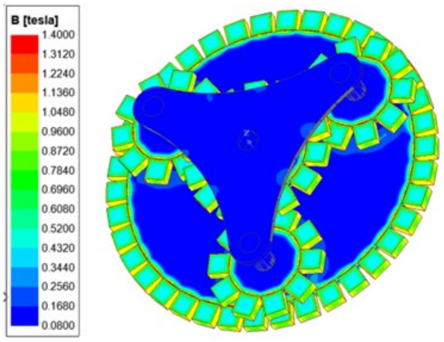

Figure 4: Cloud Chart of Magnetic Field Intensity

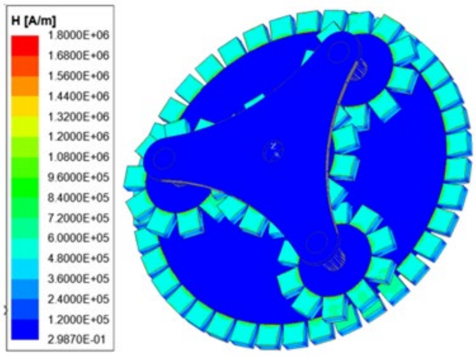

Figure 5: Cloud Chart of Magnetic Induction Intensity

Magnetize the driving wheel and obtain the torque analysis diagram of the driven wheel. The torque varies in a function, with the minimum value being when the N pole is relative to the S pole. At this time, the N pole generates a downward magnetic field line, while the S pole generates an upward magnetic field line. At this time, the magnetic force is not circulating; When the maximum value is two N poles facing each other, the magnetic field lines of the two magnetic blocks are all downward, and when passing through the magnetic block, the magnetic force direction is upward.

2.5 Analysis of kinematics

First, use 3D software such as SolidWorks to complete the modeling of permanent magnet planetary gear design. After the modeling is completed, carry out kinematics analysis on it. Finally, get the data of solar cycle angular velocity and planetary carrier angular velocity as shown in Figure 6 and Figure 7 below.

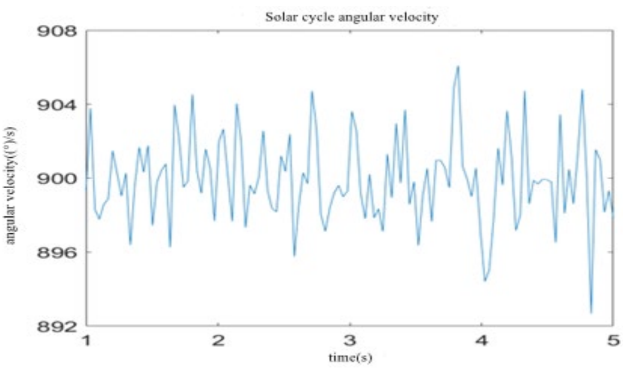

Figure 6: Rotation Angle Speed of the Sun Cycle

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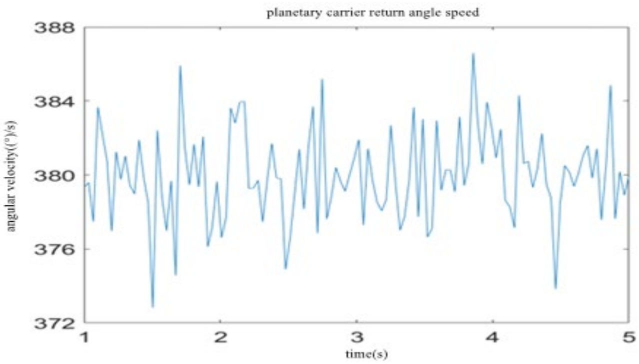

Figure 7: Planetary carrier return angle speed

Through kinematics analysis, it can be concluded that the new magnetic planetary gear based on the ferromagnetic theory can completely achieve the given movement, and it also proves the feasibility of the new transmission device design based on the ferromagnetic theory.

3. Conclusions

The Maxwell finite element analysis software was applied to complete the construction of the gear train model, and the effects of coupling clearance, magnetic pole number, gear size, and magnetic ring thickness on the maximum output torque of the magnetic planetary gear were obtained. Finally, the design parameters that generate the maximum torque were obtained, providing a theoretical basis for the future design of this type of magnetic planetary gear structure.

Magnetic planetary gears can replace traditional planetary gears for torque transmission, non-contact transmission, no friction, no failure forms, simple structure, no dust generation, and have good application prospects in variable speed devices. The current material used is neodymium iron boron material, which is not easy to demagnetize and ensures stable torque transmission performance.

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