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Electromagnetic Properties Analysis on Hybrid-driven System of Electromagnetic Motor

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Abstract. The hybrid-driven system made of permanent-and electromagnets applied in the electromagnetic motor was analyzed, equivalent magnetic circuit was used to establish the mathematical models of hybrid-driven system, based on the models of hybrid-driven system, the air gap flux, air-gap magnetic flux density, electromagnetic force was proposed. Taking the air-gap magnetic flux density and electromagnetic force as main research object, the hybrid-driven system was researched. Electromagnetic properties of hybrid-driven system with different working current modes is studied preliminary. The results shown that analysis based on hybrid-driven system can improve the air-gap magnetic flux density and electromagnetic force more effectively and can also guarantee the output stability, the effectiveness and feasibility of the hybrid-driven system are verified, which proved theoretical basis for the design of hybrid-driven system.

Keywords. Electromagnetic Properties; Hybrid-driven System; Electromagnetic Motor; Electric vehicle.

1. Introduction

With the increasing prominent problems of energy and environment, zero pollution, high efficiency electric vehicle has become a hot issue in the field of automotive research. Large capacity battery pack is used as the power source of electric vehicle, the electric motor is used as the engine, and the power of the battery pack is controlled by the controller [1]. Electric car has the advantages of low noise, no pollution and so on, it has become the object of research and development of automobile manufacturers around the world in recent years.

Electromagnetic motor in an electric vehicle is a new driving method. Which makes electric energy is transformed into mechanical energy to drive the permanent magnet piston to do work. Its core is the electromagnetic drive system [2]. Traditional electromagnetic drive system adopts pure electromagnetic drive structure. Although the structure is simple, low cost, simple manufacturing and maintenance. The output of its electromagnetic characteristics cannot meet the requirements of the variable speed of the motor [3]. As speed, the volume, quality, energy consumption is too large, easy to heat and other problems have become a major bottleneck restricting the output of the power piston motor.

With the development and application of permanent magnetic materials, the permanent magnetic materials play an important role in the medium and low speed maglev train to achieve the stability of air gap and low energy consumption, and the high performance rare earth permanent magnet material is introduced into the pure electromagnetic drive system, consisting permanent-magnet drive system, which improve the electromagnetic characteristics of the drive system, reducing the energy consumption, volume and quality in the electromagnetic system and phenomenon of the heat [4].

2. Working Principle Schematic of Electromagnetic Motor

The electromagnetic driving force of electromagnetic motor is produced by the hybrid magnetic drive system. Through the winding coil on the magnetic core (copper or aluminum) with the current, and the permanent magnet piston to form a closed magnetic field. Electromagnetic drive system using electromagnetic and permanent magnet piston repulsion force driven permanent magnet piston work. The current in the coil is controlled by the drive control system to control the electromagnetic. The electromagnetic coil is used to realize the dynamic adjustment so that the electromagnetic force of the piston is changed according to the working requirements [5].

The working flow chart of electromagnetic motor is shown in Figure 1. When the system is working, the corresponding starting system is used to drive the flywheel to rotate the crankshaft through the crankshaft connecting rod mechanism drives the piston movement [6]. Transfer the signal to the control unit when top stop position detection sensor detects the piston to arrive. The electronic control unit controls the hybrid drive system to generate the magnetic field force, and the magnetic force of permanent magnet and piston repulsion.

As shown in Figure 2(a), the piston is driven to work to achieve the transformation of electromagnetic energy to the mechanical energy, the motion of the crank connecting rod device is restrained to ensure the continuous reciprocating motion of the piston, and the linear mechanical energy can be converted to the output of rotating machinery [7]. When the piston is running to bottom dead centre. The electronic control unit interrupt the electromagnetic drive system. The piston depends on the moment of inertia of the flywheel through the reciprocating motion of the crank and connecting rod mechanism. When the piston is stable, start the system to stop working.

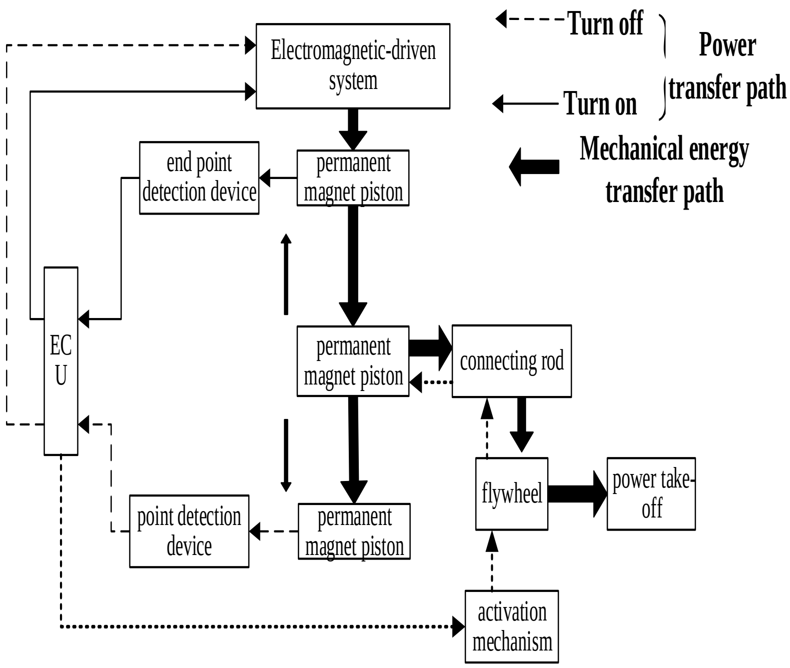

Figure 1. Flow chart of electromagnetic motor.

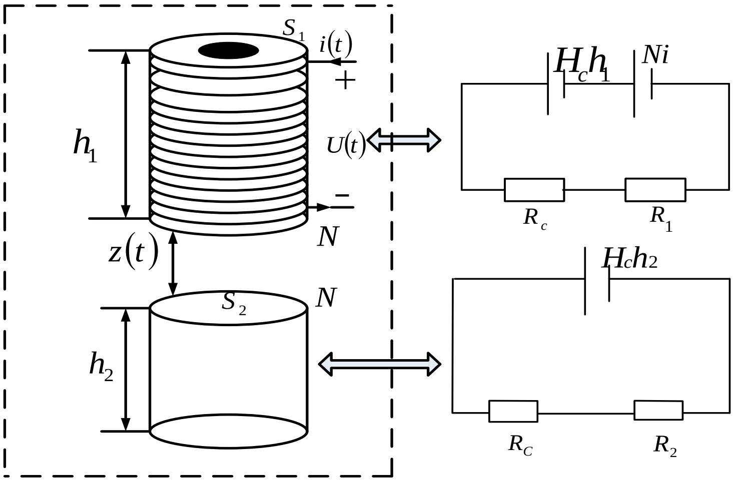

Figure 2. Model of hybrid drive system.

There are many ways to introduce permanent magnet in pure electromagnetic drive system, this paper focuses on the structure described and make the following assumptions, that is the permeability of ferromagnetic materials in magnetic circuit is infinite, magnetic potential landing evenly in the air gap and the permanent magnet piston; and neglect the magnetic leakage and edge effect; and ignore the core and the working stroke of reluctance; and it is assumed that the stiffness coefficient of the piston surface is infinite without considering the elastic vibration or dynamic deformation of the permanent magnet piston itself; and the performance parameter of permanent magnet is constant.

Under the above assumptions, the magnetic circuit model of the hybrid drive system is shown in Figure 2(b). According to Ohm's law of magnetic circuit, the calculation of the magnetic force of the air gap magnetic circuit flux, air gap magnetic flux density and the hybrid electric drive system and the permanent magnet piston [8].

Where, the air gap magnetic flux is

$$\varphi_1(x,i)=\frac{\mu_0 S_1(Ni+H_c h_1)}{x(t)+h_1/\mu_r} \tag{1}$$

The gap flux density is

$$B_1=\frac{\phi(x,i)}{S_1}=\frac{\mu_0(Ni+H_C h_1)}{x(t)+h_1/\mu_r} \tag{2}$$

The electromagnetic force is

$$F_M=\frac{1}{2}\mu_0 S_1\left[\frac{Ni+H_C h_1}{x(t)+h_1/\mu_r}\right]^2+\frac{1}{2}\mu_0 S_2\left[\frac{H_C h_2}{x(t)+h_2/\mu_r}\right]^2 \tag{3}$$

$x(t)$ is the displacement curve of piston for periodic reciprocating motion, and it is

$$x(t)=R(1-\cos\alpha)+L(1-\sqrt{1-\lambda^2\sin^2\alpha})+c \tag{4}$$

And through the permanent magnet piston force analysis, while analyzing the piston force, it is approximate that the crankshaft rotates at a constant speed, the piston as isolated and analysis of its force situation [9].

The permanent magnet piston mechanical equation written along the cylinder center line direction, that is

$$m\frac{\mathrm{d}^2 x(t)}{\mathrm{d}t^2} = F_M + mg + P_\mathrm{j} - F_\mu \tag{5}$$

Reciprocating inertia force of piston P_j is

$$P_\mathrm{j} = -m_\mathrm{j} a = -m_\mathrm{j} R w^2 \cos\alpha - m_\mathrm{j} R w^2 \lambda \cos 2\alpha \tag{6}$$

To sum up, the equations of the electromagnetic drive system dynamic model are obtained,

$$\begin{cases} F_\mathrm{M} = \dfrac{1}{2}\mu_0 S_1 \left[\dfrac{Ni + H_\mathrm{c}\mathrm{h}_1}{x(t) + h_1/\mu_\mathrm{r}}\right]^2 + \dfrac{1}{2}\mu_0 S_2 \left[\dfrac{H_\mathrm{c}\mathrm{h}_2}{x(t) + h_2/\mu_\mathrm{r}}\right]^2 \\ P_\mathrm{j} = -m_\mathrm{j} a = -m_\mathrm{j} R w^2 \cos\alpha - m_\mathrm{j} R w^2 \lambda \cos 2\alpha \\ m\dfrac{\mathrm{d}^2 x(t)}{\mathrm{d}t^2} = F_\mathrm{M} + mg + P_\mathrm{j} - F_\mu \\ B_1 = \dfrac{\phi(x,i)}{S_1} = \dfrac{\mu_0 (Ni + H_\mathrm{C} h_1)}{x(t) + h_1/\mu_\mathrm{r}} \end{cases} \tag{7}$$

3. Simulation analysis of hybrid drive system

Setting the simulation parameters of hybrid drive system and piston group, the Simulink diagram of hybrid-drive system is established shown in Figure 3. And the data of the piston group is derived from the partial data of a certain type of engine.

The design parameters of control object model are put into the simulation. Setting the current period T=0.02s, as shown in Figure 4, as previously stated, assume that the crankshaft rotates at a constant speed.

Under the condition that the winding current of the hybrid drive system is stable, we get the simulation of air gap magnetic flux density, electromagnetic force and acceleration is obtained [10]. The magnetic flux density and electromagnetic force curves were compared with those of pure electromagnetic drive, as shown in Figure 5, Figure 6 and Figure 7.

The output torque and the induced potential depend to a great extent on the flux density distribution in the air gap, the magnetic flux density (hereinafter referred to as "air gap flux density") has a direct effect on the performance of the motor. As can be seen from Figure 5, the variation of the air gap magnetic flux density with the time and the displacement of the piston changes periodically [11].

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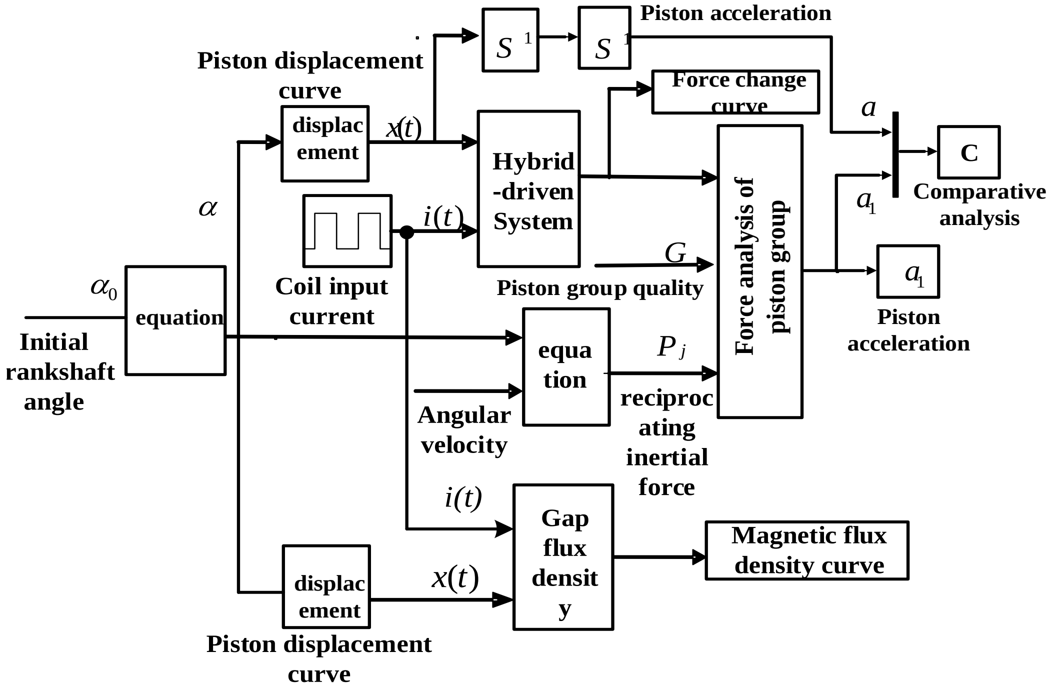


Figure 3. Diagram of hybrid-drive system.

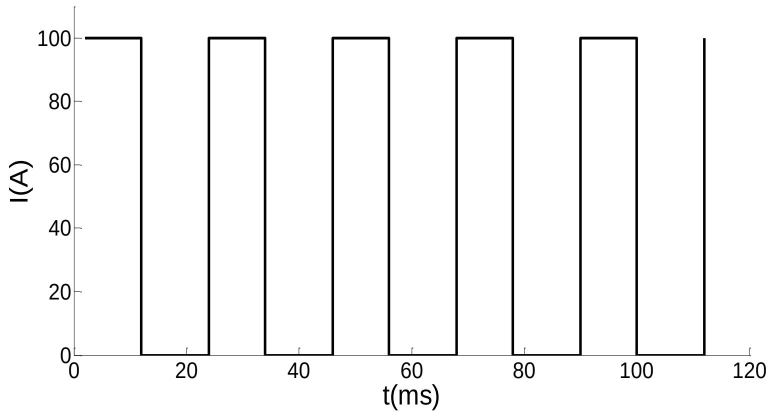
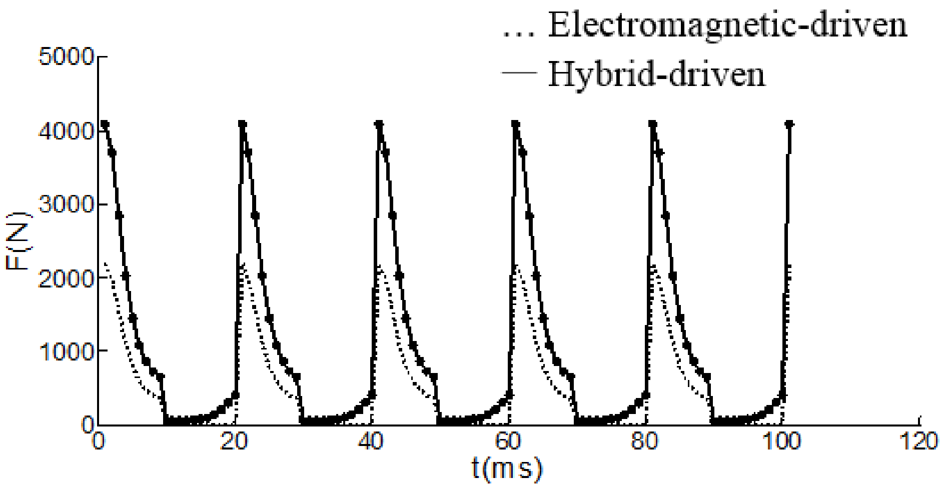
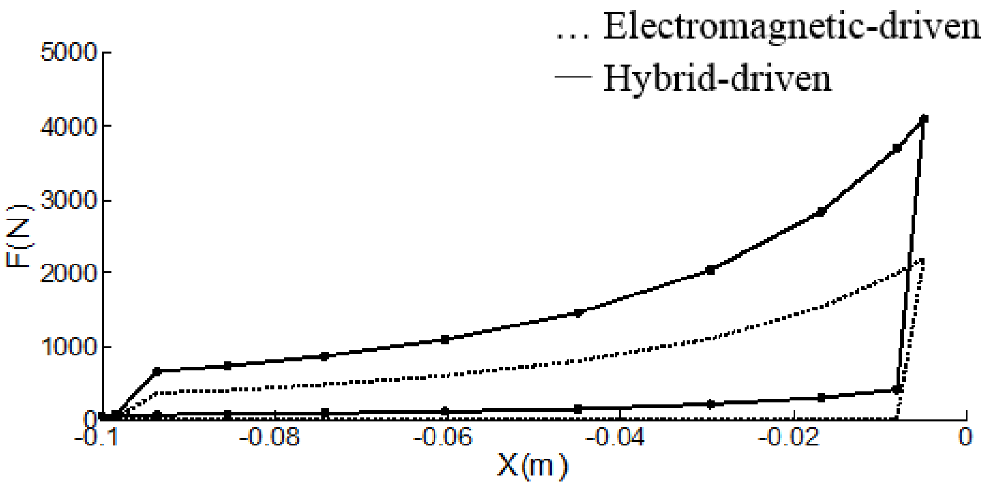


Figure 4. Cycle curve of current.



(a) Air-gap flux density changes with time.

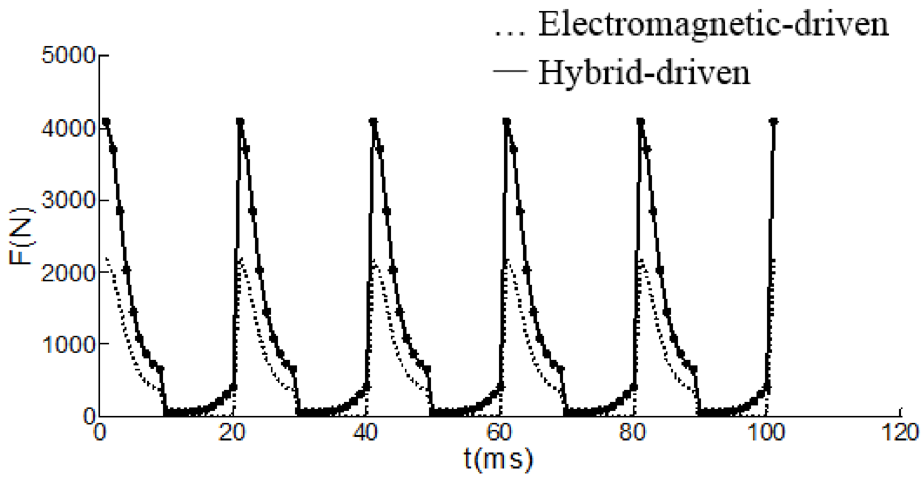


(b) Air-gap flux density with displacement.

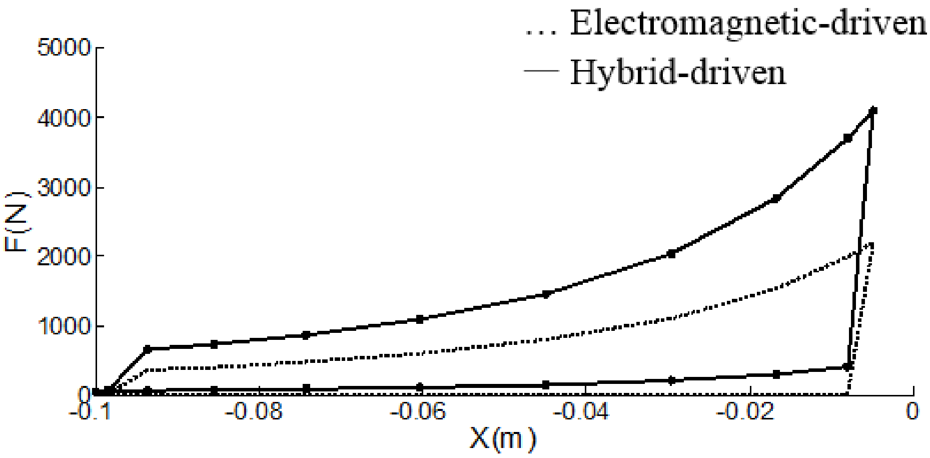
Figure 5. Air-gap magnetic flux density curve of hybrid-driven system.

When the piston reaches TDC flux density in the air gap reached the maximum, maximum output electromagnetic repulsion force of hybrid drive system. When the piston reaches the bottom dead point and the current drops to zero. Due to the existence of permanent magnetic core, the air gap magnetic density is not zero, there is a certain amount of residual air gap magnetic flux density.

Figure 6 shows that with the change of time and piston displacement the magnitude of the electromagnetic force generated by the hybrid drive system exhibits a periodic change. It is the same as conventional engine compression and work. Finally, it completes a cycle of power piston motor. The piston moves two strokes between TDC and BDC. The crankshaft rotates a cycle. After the permanent magnet piston reaches the TDC. The electromagnetic repulsive force reaches the maximum and drive the permanent magnet piston to move BDC.



(a) Electromagnetic force with time.



(b) Electromagnetic force with displacement.

Figure 6. Electromagnetic force curve of hybrid-driven system.

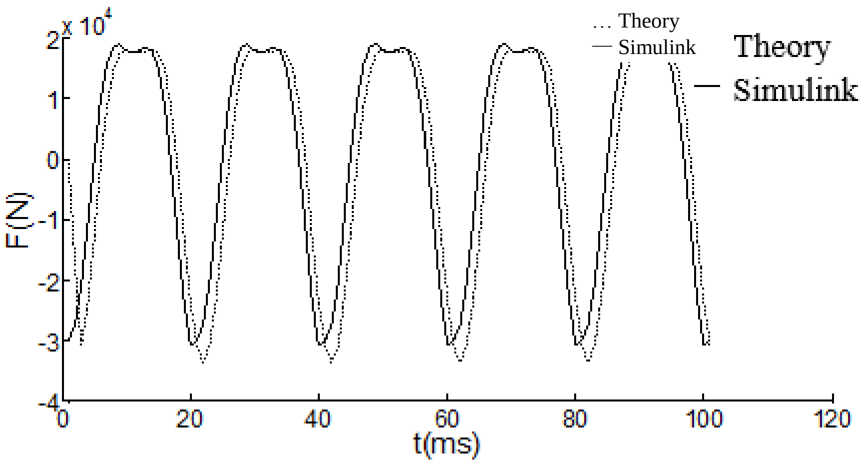
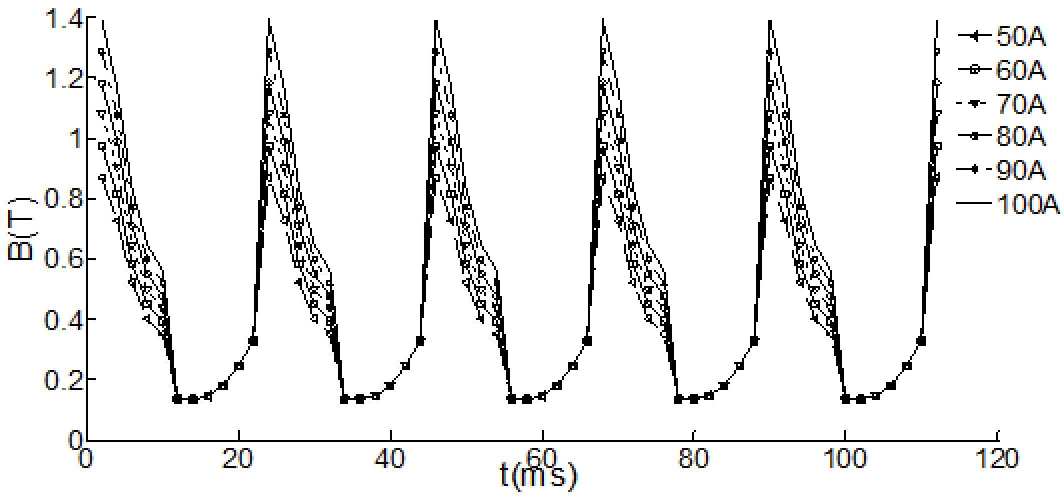
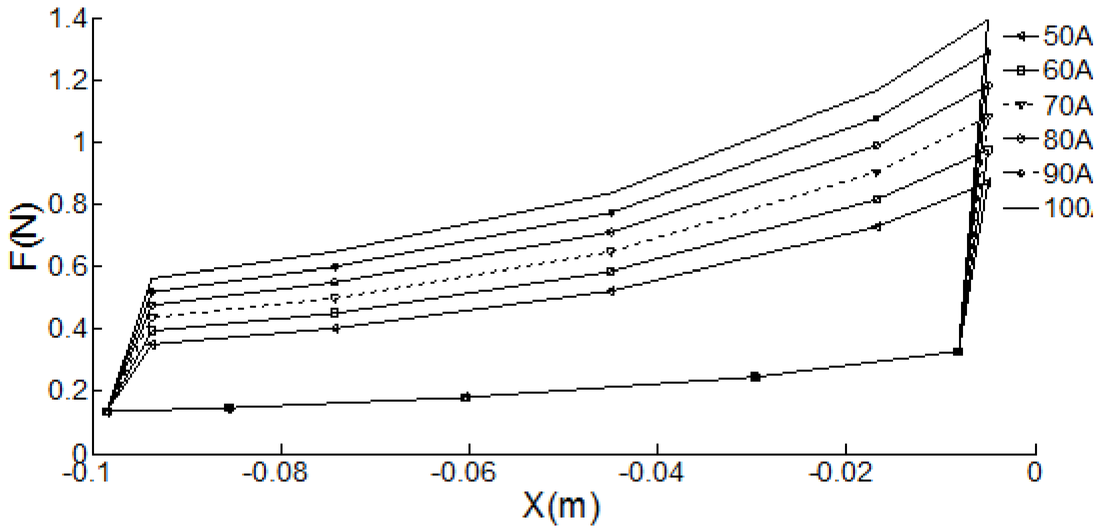


Figure 7. Comparison of engine piston theoretical acceleration and simulation acceleration

The electromagnetic force increases progressively with displacement and is not in a state of rapid decline in the process of piston downward movement. The rate of decline shows a slow block variation (as shown in Figure 6 (a)). When the piston reaches the BDC, electromagnetic repulsion is almost zero because of the existence of residual air gap magnetic density, the electromagnetic repulsion force is small but not zero when the piston reaches the BDC. From Figure 5 and Figure 6, it is shown that adding permanent magnet core increases the output value of air gap magnetic flux density and electromagnetic force and improves the air gap magnetic flux density and the electromagnetic force output sensitivity of the hybrid drive system with the piston position.



(a) Air-gap flux density with time.



(b) Air gap flux density with displacement.

Figure 8. Air-gap magnetic flux density curve of hybrid-driven system with different currents

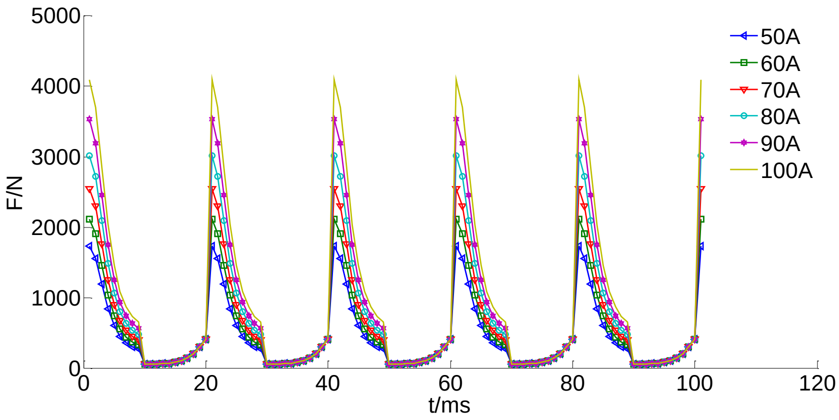


Figure 9. Electromagnetic force curve of hybrid-driven system with different currents

Under the action of hybrid drive system, the theoretical acceleration of piston is compared with the simulated acceleration. As shown in Figure 7, when the piston is subjected to force analysis, the influence of the piston lateral force is neglected, and the axial force of the piston is mainly considered. On the one hand, the addition of permanent magnetic core increases the electromagnetic repulsion force of the piston at TDC, on the other hand, the piston reaches BDC, due to the analysis of residual electromagnetic force is not zero, to a certain extent, weakened the piston stop down the stop acceleration trough point movement in the process of value, which makes the theoretical curve and actuall curve slightly deviation. On the whole, the theoretical curve of the piston is consistent with the actual curve.

As shown in Figure 8 and Figure 9, a preliminary study on the analysis of the hybrid drive system in different working mode under the current operation of the piston air gap magnet and electromagnetic force with time and displacement change curve. In the setting of the 50A-100A current mode, the magnetic flux density and electromagnetic force of the air gap are periodic changes with the increase of current. When the piston reaches TDC, the magnetic flux density and electromagnetic force increase with the increase of current, during the movement of the piston down point, the air gap magnetic flux density and electromagnetic force decrease regularly with the increase of the displacement. When the piston reaches BDC, values both are the minimum. During the operation of the piston from TDC to TDC, the electromagnetic force increases very little. When the piston stops TDC in reaching the moment, electromagnetic force suddenly increases, the process not only ensures the output of driving piston movement, but also reduces the limitation of the residual electromagnetic force on the piston during the operation of the piston up and down point.

4. Summary

In this paper, a new method of working on the hybrid permanent magnet piston driven by electric motor was presented. The electromagnetic conversion characteristics of the hybrid drive system were studied, and the feasibility of the scheme of driving the piston was proved by simulation.

The electromagnetic characteristics of the hybrid drive system under different operating modes were discussed. Through the analysis of air gap magnetic flux density and electromagnetic force, with the increasing of the current, the magnetic flux density and electromagnetic force increase regularly, which indirectly influence output characteristics of power piston motor. The addition of the permanent magnetic core improves the electromagnetic characteristics of the hybrid drive system, however, the drive system composed of electromagnetic permanent magnet was unstable in nature.

It was a next research direction that how to stabilize the output of the system under certain conditions by designing a stable controller and reduce the value of residual electromagnetic force when the piston stops at the bottom and realize the maximum utilization of the hybrid drive system.

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