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Structural Analysis of a New Self - excited Eddy Current Retarder

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Abstract. In view of the eddy current retarder (ECB) power consumption problem, a new type of split self-excited eddy current retarder (S-ECR) is designed in this paper. In order to verify its feasibility and get the best structural parameters, the influence of the structural parameters on the braking torque of the S-ECR is analyzed. To achieve the goal of improving its braking torque, several programs of different structural parameters are proposed and simulation analysis was carried out by using the control variable method. As a result, the optimal structural parameters of the S-ECR are obtained and the feasibility of the new S-ECR are verified.

Introduction

The current domestic heavy-duty vehicles on the use of the largest retarder is the eddy current retarder (ECB) which will consume a lot of power supply system in the brake and cause a huge impact on the other electronic equipment as a result of influencing the car driving stability. The self-excited retarder (S-ECR) has more advantages than the ECB in regards to energy saving and environmental protections[1-4]. In this regard, this paper designs a new type S-ECR which rely on its own generator to provide current to the retarder and will not lose the car power supply, but also play the advantages of separate layout and make full use of chassis space, increases the output of the generator to ensure that the vehicle can provide sufficient braking force at high speed braking that can improve the driving safety of the vehicle.

In this paper, the structure and working principle of the new S-ECR are introduced and the structural parameters of the retarder are optimized and simulated. The optimal structural parameters of the new S-ECR are obtained. It provides a theoretical basis for the following research.

Structure and working principle

The structure of the new type of split S-ECR is shown in Fig. 1, which includes the retarder and the generator and the planetary gear mechanism. The planetary carrier in the planetary gear mechanism is connected with the drive shaft through the spline and is drove to rotate by the drive shaft. The planetary carrier is connected with the sun gear and drives the sun wheel to rotate; the sun wheel rotates together with the permanent magnet in the generator. And the stator in the generator is fixed to the vehicle body without being rotated integrally with the ring gear in the planetary gear mechanism; the outer rotor in the retarder is connected with the drive shaft through the spline and the excitation coil is fixed to the vehicle body. When the vehicle is braking, the relative movement between the permanent magnet of the generator and the coil is generated and the voltage is produced. When the current output from the generator is output to the retarder excitation coil through the controller, the excitation magnetic field generated by the excitation coil forms a circuit between the magnetic pole, the air gap and the drum.The outer rotor to cut the magnetic field during the rotation to form a vortex on the drum and to produce a braking torque that hinders its rotation, thereby hindering the rotation of the drive shaft and slowing down the vehicle. When the brake is not required, the controller disconnects the output voltage of the generator from the energization of the field coil, and there will be not current flows through the excitation coil and the retarder does not act as a brake.

This new type of S-ECR through the planetary gear structure of the speed up the principle of the transmission shaft to the generator to improve the speed of the power plant to increase the output voltage and improve the output to the retarder electromagnetic coil voltage, and then increase the braking torque and improve vehicle safety. The separate arrangement of the generator and the retarder can be arranged in a limited space according to the actual situation of the chassis, The installation flexibility of the self-driven retarder is improved. At the same time, the output power of the generator is improved by the principle of the planetary gear structure, and the braking torque of the S-ECR is increased.

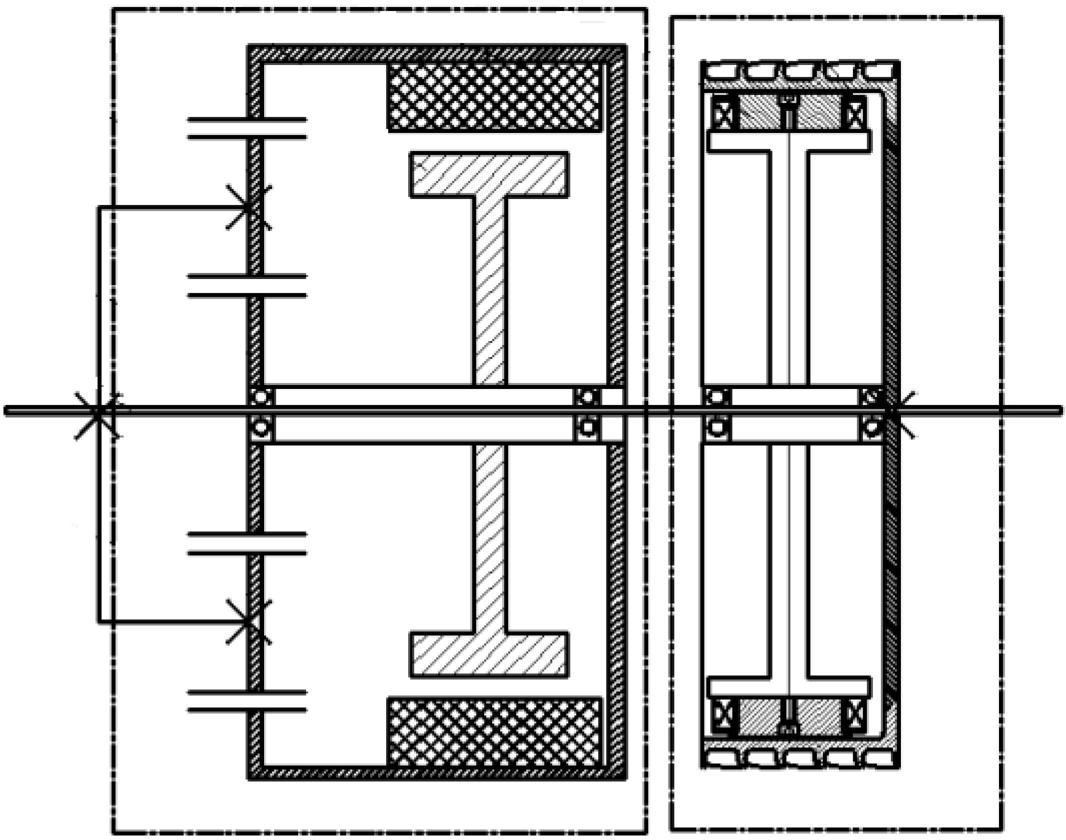

Fig.1 Schematic diagram of the structure of split type self-resetting retarder

Parameter design

The new type S-ECR braking power is [5]:

$$P = \frac{2N_p B^2 w^2 S a^2}{p r} \Delta h \tag{1}$$

Where N_p is the number of magnetic pole, generally take $N_p = 6$; ω is the air gap magnetic field angular velocity, rad / s; S is the yoke area of the air gap, m^2; a is the magnetic pole along the rotor circumferential length, mm; ρ is the rotor resistivity, Ω·m; Δh is the equivalent penetration depth of the eddy current, the formula is[6]:

$$\Delta h = \sqrt{\frac{2}{w m s}} = \sqrt{\frac{2 r}{w m}} \tag{2}$$

Where σ is the conductivity of the rotor, s/m; ω is the magnetic field change angular velocity, rad/s, the formula is:

$$w = \frac{2p\mathrm{N}_{\mathrm{p}}\mathrm{n}}{60} \quad (3)$$

μ is the permeability of the drum, H / m, the formula is:

$$m = m_{\mathrm{r}} \cdot m_0 \quad (4)$$

μ_r is the relative permeability of the drum, μ_0 is the vacuum permeability, $\mu_0 = 4\pi\times10^{-7}$. B is the magnetic flux density of the air gap magnetic field, T, the formula is[7]:

$$\mathrm{B} = \frac{m_0 \mathrm{SNI}}{2\mathrm{L}} \quad (5)$$

Where I is the current flowing into the field coil, L is the air gap width, and N is the number of turns of the coil.

So the braking power of the slow device is:

$$\mathrm{P} = \frac{N_p^{\frac{5}{2}} n^{\frac{3}{2}} Sa^2 \mathrm{N}^2 \mathrm{I}^2 m_0^{\frac{3}{2}}}{225\ \mathrm{L}^2}\sqrt{\frac{15p}{rm_r}} \quad (6)$$

According to P = T · ω, the braking force of the retarder is:

$$\mathrm{T} = \frac{2\mathrm{N}_{\mathrm{p}}^{\frac{3}{2}} \mathrm{N}^2 \mathrm{I}^2 \mathrm{Sa}^2 m_0^{\frac{3}{2}}}{\mathrm{L}^2}\sqrt{\frac{\mathrm{n}}{15prm_{\mathrm{r}}}} \quad (7)$$

Determination of material parameters of outer rotor

In the outer rotor, the soft magnetic material with high magnetic permeability, low magnetic reluctance and low remanence is selected. The magnetic field disappears automatically after the disappearance of the external magnetic field, which accords with the design idea of the retarder. In this paper, the S-ECR outer rotor material selection of low carbon steel, the saturation of the magnetic induction B is 2.2T, the magnetic induction strength of the operating point of the strength range of 1.1 ~ 1.7T[6].

The inside and outside diameter and thickness of the outer rotor should take into account the actual space size of the chassis and the braking torque output performance and the rotor cooling and other factors. The inner and outer diameter of the outer rotor should not be too large to occupy the chassis space, nor too small to affect the output of the braking torque, the thickness should be in the premise of ensuring the strength of rotation, as small as possible to promote the heat dissipation of the outer rotor.

According to the geometric relationship, the radius of the rotor is [8]:

$$\mathrm{D}_1 = \frac{\mathrm{a}}{2\sin(q/2)} \quad (8)$$

Where a is the pole width, mm;θ is the center angle of the fan yoke, rad;

According to experience, the outer radius of the rotor is:

$$\mathrm{D}_2 = \mathrm{D}_1 + 0.03\mathrm{m} \quad (9)$$

Determination of air gap width L and coil turns

The air gap width L between the retarder rotor and the stator coil is an important parameter that affects cost and braking performance. The relative permeability of the air is 1, so even a small air gap will produce a very large magnetic resistance. If the L selection is too large, the B will be weakened; if the L selection is too small, it is easy to scratch when the rotor and stator are affected by thermal expansion at work, and affecting driving safety. Therefore, from the reduction of the magnetic resistance, increase the magnetic induction strength, L should be as small as possible; but from the processing and reduce the possibility of scratch, L should be slightly better.

The magnetomotive force of the retarder is[8]:

$$\Phi = \mathrm{NI} = \frac{4r\mathrm{L} + \sqrt{2}ea^{2}wm_{0}\Delta h}{4rm_{0}} \tag{10}$$

After determining the material and parameters of the retarder parts, the magnetomotive force Φ can be obtained. Field winding turns N= Φ/I. The excitation current I is provided by the generator, whereby the number of turns of the field winding can be obtained. According to the rated parameters of the generator design, set the input excitation current I is 20A, through the calculation, the coil turns selected range of 90 to 100 turns is more appropriate.

It can be seen from equation (5) that there is a certain quantitative relationship between the magnetic flux density B and the air gap width L when the current I is input after the retarder material and the number of turns of the coil are determined. As mentioned earlier, The intensity range of B working point is 1.1~1.7T, if the input 20A current, in the constraint range, the magnetic induction intensity B can reach the working point range when the air gap length is 1.2mm ~ 1.4mm. From the point of view of increasing the braking torque, the air gap length L is selected as 1.2 mm.

Determination of transmission ratio of planetary gear mechanism

The current input to the retarder is generated by the mutual movement between the generator permanent magnet and the stator coil. The rotation speed of the transmission shaft is transmitted to the rotor permanent magnet through the planetary gear mechanism, and the rotation of the permanent magnet is driven. Therefore, the size of the planetary gear mechanism transmission ratio determines the size of the permanent magnet rotation, affecting the performance of the power generation device is to determine the output torque of the retarder key. Therefore, when determining the transmission ratio of the planetary gear mechanism, it should meet the design requirements of the rated speed of the generator, taking into account the transmission efficiency and other aspects of the impact, select the appropriate transmission ratio.

In this paper, the rated speed of the generator is 1500r/min, and the speed of the drive shaft is 800r/min.Considering the influence of the transmission efficiency, the transmission ratio of the planetary gear mechanism should be between 0.4 and 0.6. The ultimate goal of this paper is to retard the brake torque output maximum, so the choice of transmission ratio should be as small as possible.

Determination of power plant parameters

The rated parameters of the generator are set according to the brake torque of the retarder of 700N·m, and the rotor permanent magnet is selected as the high performance NdFeB permanent magnet. The generator of the new retarder described in this paper is installed separately from the retarder, so that the actual size of the generator can be adjusted according to the actual remaining situation of the chassis space to maximize the utilization of the chassis space. The main rated data of the generator are shown in Table 1.

Table 1 The generator rated parameter table

Parameters	Value
Rated power/kw	2
Rectified voltage/V	100
Rated frequency/Hz	100
Rated speed/(r/min)	1500
power factor	0.8

The generator in the work will also be due to the tangential force on the rotor to produce a certain size of the electromagnetic torque. The total braking torque of the S-ECR is actually the sum of the electromagnetic moment produced by the retarder and the electromagnetic moment generated by the generator. However, it can be seen from the finite element calculation that the electromagnetic torque produced by the generator is much smaller than the electromagnetic torque generated by the retarder. Therefore, the braking torque of the new S-ECR is mainly the electromagnetic moment produced by the retarder [9].

Simulation experiment

As the selection of structural parameters, the selected value is only the theoretical level of the best program, Therefore, in order to evaluate the rationality of the structural parameters of the new S-ECR, the control variable method is used to simulate the braking torque of the retarder structural parameters in Table 2. Select the optimal program parameters in the selection range are comparable to several sets of data for variable control, where program 1 is the optimal structural parameter program selected above, and the other program has a difference in the structural parameter value as compared with program 1. By controlling the method of a single variable, to verify the rationality of parameter selection.

Table 2 The self-excited retarder structural parameters

Structural parameters	N_p	N	D_1	D_2	L	i
Program1	6	100	310	340	1.2	0.4
Program2	6	100	310	340	1.3	0.4
Program3	6	100	310	340	1.2	0.5
Program4	6	100	320	350	1.2	0.4
Program5	6	90	310	340	1.2	0.4

Fig.2 shows the comparison of braking torque under the different programs. As can be seen from the diagram, the brake torque reaches the maximum when the retarder in the five structural parameters is about 5s, and the braking torque of the program 1 can reach 670N·m. The maximum value of the retarder braking torque starts to fall after 5s, because the drive shaft is reduced by the maximum braking torque before, the output speed begins to decrease, the output voltage of the generator decreases, and the excitation of the input retarder Current weakened, resulting in reduced electromagnetic torque. The difference between the braking torque of program 4 and program 1 is very small, Even in the first 2 seconds of the braking situation is better than the program 1, which means that the inner and outer diameter dimensions of the rotor have a weak influence on the braking torque in a reasonable range, In the actual manufacturing retarder, according to the actual situation of the chassis to design the size of the rotor. While the braking torque of the other three schemes has a significant difference compared with the program 1, and the maximum braking torque achievable by the program 2 is only 610 N·m, which indicates that the air gap width has a great influence on the output of the braking torque. From the simulation results, even within the reasonable range of the parameters, the selection of the coil turns, air gap width and transmission ratio still has a greater influence on the braking torque. The simulation results verify the feasibility of the previous structure parameter selection.

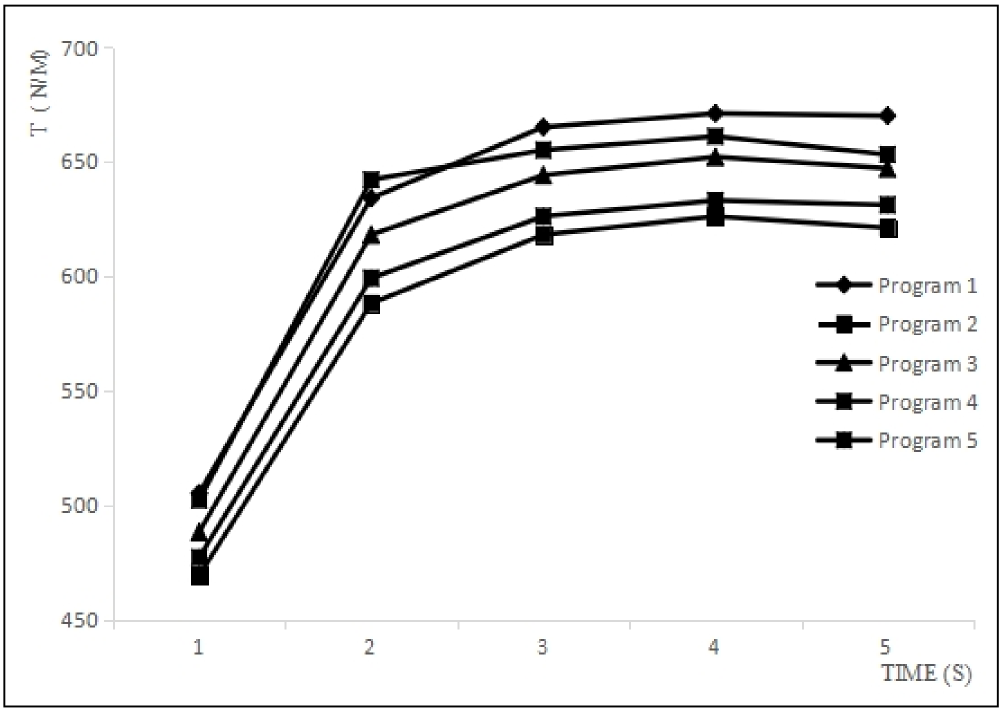

Fig.2 Comparison of braking torque under the different programs.

Fig. 3 is the output curve of braking torque under the Continuous braking of program 1. The figure shows that the retarder braking torque quickly reaches its maximum value, but then begins to drop significantly. At 30s, the braking torque is reduced to about 300 N·m and less than 200 N·m at 60s. This is due to prolonged braking leading to a rapid increase in the temperature of the retarder, the anti-thermal decay performance of the retarder is reduced, the relative permeability of the iron material becomes smaller, resulting in larger magnetic flux leakage, the magnetic induction between the air gap quickly becomes smaller and the braking torque drops rapidly. In addition, the decrease in braking torque is also related to the reduction of the speed of the drive shaft.

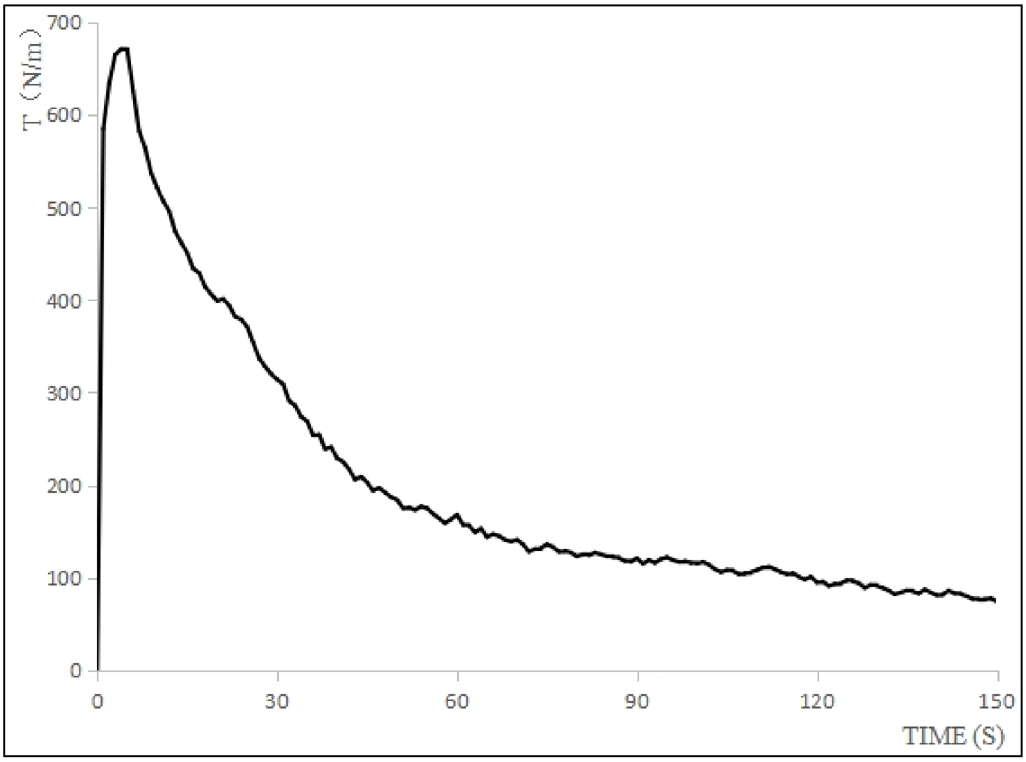

Fig.3 The continuous braking characteristics of programs 1.

Conclusions

By comparing the simulation results of the five schemes, the optimal value of structural parameters such as transmission ratio, air gap length and coil turns of planetary gear mechanism is obtained, the influence of structural parameters on the performance of retarder is summarized, at the same time verified the feasibility of this new type of split self-excited retarder. This new type of split self-excited retarder, not only can reduce the load of the original power system and improve the economy of the car, but also can make full use of chassis space, according to the actual chassis space design retarder size. Catering to the idea of energy saving and emission reduction advocated by today's society, there will be broad market prospects in the development of the future.

In the next phase of the study, continue to optimize the structural parameters to ensure that the retarder low-speed high-performance braking conditions will be the focus of research. In addition, focuses on study the effect of temperature increase on the performance of the S-ECR, improve the heat dissipation capacity and thermal degradation properties, solve the influence of temperature on the brake torque decline, is also the focus of future research.

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