Acta Technica *62* (2017), No. 5B, 569–578

Design and performance experiment of the self-excitation electromagnetic retarder[1]

Liu Xuejun[2], Wen Zongyin[2], Yang Nianjiong[3], Liu Cunxiang[2,4]

Abstract. According to the structure of the energy-saving self-excitation electromagnetic retarder, combined with the magnetic circuit Ohm's law, the braking torque formula of the electromagnetic retarder is proposed. A transmission shaft of a certain type of vehicle is installed with the designed electromagnetic retarder, to test the performance of the energy-saving self-excitation electromagnetic retarder, three braking states including the vehicle speed from 100Km/h decreased to 40Km/h, the vehicle speed from 80Km/h decreased to 40Km/h and the vehicle speed from 400Km/h decreased until stop are chosen, the curve of the electromagnetic retarder braking torque and the output characteristics of the generator current curve is monitored dynamically. The bench experiment shows that the braking torque which is generated by electromagnetic retarder is at least 756.7 Nm, the average output power of the generator equipped in the electromagnetic retarder is 460W.The generated power which is generated during the vehicle driving 6Km can apply to the vehicle headlight working 1.3h continuously. The experiment result reveals that the energy-saving self-excitation electromagnetic retarder can ensure the vehicle braking effect and has significant role in saving energy and storing energy.

Key words. Vehicle engineering, energy-saving, self-excitation electromagnetic retarder, design, experiment.

[1]Acknowledgement - This work is supported by the national natural science foundation of Guangxi China (2014GXNSFBA118262), Transportation science project of Guangxi China (2013-100); Transportation science project of Guangxi China (2015-261-8), The Opening Project of Guangxi Key Laboratory of Automobile Components and Vehicle Technology, Guangxi University of Science and Technology (No. 2015KFYB01)

[2]Workshop 1 - School of Automotive Engineering, Guangxi Vocational & Technical College of Communications, Nanning 530023

[3]Workshop 2 - Guangxi Key Laboratory of Automobile Components and Vehicle Technology, Guangxi University of Science and Technology; Liuzhou 545006; e-mail: `5041433@qq.com`

[4]Corresponding author:Liu Cunxiang; e-mail: `77664219@qq.com`

1. Introduction

As people are increasing more concerned about energy conservation and driving safety of vehicles, how to better improve the vehicle's energy-saving and emission reduction effects and safety become an unremitting pursuit goal of more manufacturers. With regard to vehicle braking and energy conservation, traditional mechanical friction brakes complete braking by relying on frequent or long-time mechanical friction. In the friction braking process, not only a large amount of toxic dust is produced, but also overheating of brake drum (disk) and friction plate (brake lining) is caused, leading to braking performance decline or even brake failure. Energy saving and safe driving performance of such braking system need further improvement. However, installation of retarder can appropriately solve these problems.

The electromagnetic vehicle retarder is a mechanism for reducing or stabilizing speed of a driving vehicle (especially a vehicle along a long slope) to a certain range without stopping the vehicle. In the automotive industry in Europe, the United States, Japan and other developed countries, retarder has been installed and used in a variety of passenger cars and medium and heavy vehicles as a standard parts of necessary supplementary to the existing vehicle brake system. At present, technical mature retarders suitable for loading include hydraulic retarder, eddy current retarder, permanent magnet retarder, etc. However, they also have shortcomings. For instance, hydraulic retarder has large volume and weight, slow brake response [1−3], with braking force greatly affected by vehicle speed; eddy current retarder is slightly poor in energy-saving aspect[4−6]; permanent magnet retarder has a small braking torque which cannot be adjusted[7]. Although the media reported that France Telma produced self-excitation eddy current retarder, the product has not been seen yet.

The existing retarders only achieve the braking effect, but fail to consider how to further turn the vehicle kinetic energy into stored electric energy for the purpose of energy conservation.

2. Structure of energy-saving self-excitation electromagnetic retarding device

Figure1 shows the structural schematic diagram of energy-saving self-excitation electromagnetic retarder. The energy-saving self-excitation electromagnetic retarding device consists of self-excitation electromagnetic retarder, vehicle transmission shaft and generator shaft. The self-excitation electromagnetic retarder is mainly composed of retarder rotor disk, electromagnetic iron core and electromagnetic coil. The retarder rotor disk, rolling bearing I and rolling bearing II in the self-excitation electromagnetic retarding device support the vehicle transmission shaft. the vehicle transmission shaft is in a stepped shaft shape, the retarder iron core is in clearance fit with the retarder coil, the retarder iron core is fastened to the rotor of the electromagnetic clutch coil, the stator disk of electromagnetic clutch coil is fastened to the support frame and connected with the vehicle transmission shaft through the flat key II. the end of the retarder rotor disk 3 is connected with rotor disk electromagnetic clutch coil, flange plate via fastening bolts. the sucking disk of the rotor disk electromagnetic clutch is supported by the support frame of the generator shaft connector by means of ball spring on the both sides, the ball spring is fastened to the support frame of the generator shaft connector, and the support frame of the generator shaft connector is connected to the connection block and generator shaft by fastening screws.

Targeting at problems of the existing retarders, the designed energy-saving self-excitation electromagnetic retarder can effectively improve space utilization of the vehicle chassis. When the vehicle brakes, the kinetic energy in vehicle driving drives the rotation of the retarder iron core, thereby generating eddy current braking torque on the retarder rotor disk, so that the vehicle slows down; In addition, the electromagnetic clutch can be controlled via the controller, so that the retarder rotor disk is connected with the generator shaft. In this way, the kinetic energy in vehicle driving can be further utilized to drive rotation of the generator shaft, so that the kinetic energy is turned into electric energy through the generator and stored in the battery to further enhance the vehicle braking effect. The joint action of the two forms of retarding mechanisms can effectively and reliably ensure the vehicle braking effect and achieve energy storage, energy saving purposes. The structure of the rotor disk electromagnetic clutch in the energy-saving self-excitation retarding device is shown in Figure 2, while Figure 3 shows the physical diagram of the energy-saving self-excitation electromagnetic retarding device.

3. Operating principle of energy-saving self-excitation electromagnetic retarding device

The electromagnetic-hydraulic composite brake's working theory is illustrated as follows:

When the driver stamps the brake pedal at brake, the control unit will control electrification of electromagnetic clutch coil rotor disk. As the retarder iron core is in clearance fit with the retarder coil, the electromagnetic clutch coil rotor disk will move in the direction of electromagnetic clutch coil stator disk, until combination of the two. After the combination, the retarder iron core will rotate around the vehicle transmission 1, which will generate alternating magnetic fields within the retarder coil, resulting in numerous eddy currents on the retarder rotor disc, thereby hindering the rotation of the vehicle transmission shaft and playing the role of retardation. At the same time, the control unit controls electrification of the rotor disk electromagnetic clutch coil. Then, under the action of electromagnetic force, the rotor disk electromagnetic clutch sucking disk overcomes the ball spring elastic force and moves in the direction of rotor disk electromagnetic clutch coil, until combination of the two. After the combination, the generator shaft connector support frame will rotate around the vehicle transmission shaft together with the retarder rotor disk. Through the connection block and fastening screw, the generator shaft connector support frame drives the generator shaft rotation. Generator shaft rotation will make the generator generate power and supply power to the battery. In addition to retardation, this process also achieves the purpose of energy recovery.

1-vehicle transmission shaft, 2-thrust washer, 3-retarder rotor disk, 4-retarder

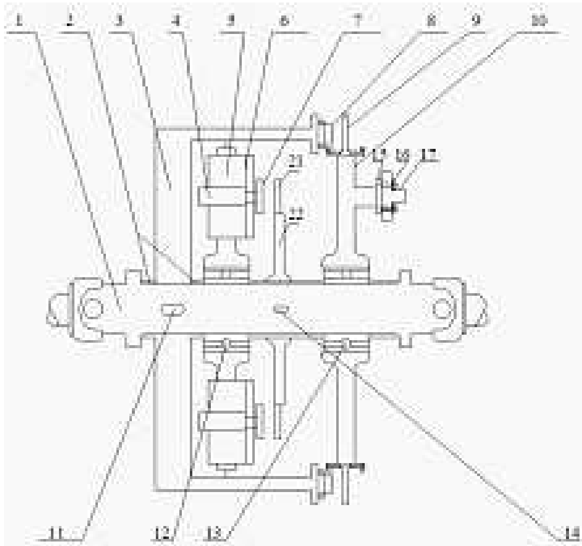

Fig. 1. structural schematic diagram of energy-saving self-excitation electromagnetic retarding device

iron core, 5-eletromagnetic retarder coil, 6- retarder coil bracket, 7- electromagnetic clutch coil rotor disk, 8-rotor disc electromagnetic clutch coil, 9-rotor disc electromagnetic clutch sucking disk, 10-generator shaft connector support frame, 11-flat key I, 12-rolling bearing I, 13-rolling bearing II, 14- flat key II, 15-connection block, 16-fastening screw, 17-generator shaft, 18-fastening bolt, 19-flange plate, 20-ball spring, 21-electromagnetic clutch coil stator disk, 22-electromagnetic clutch coil stator disk support frame.

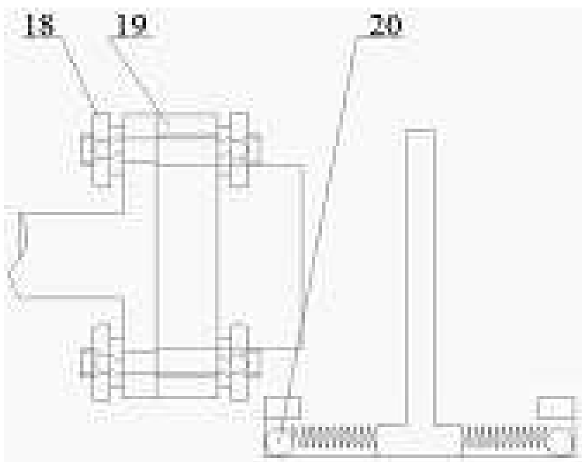

Fig. 2. structural schematic diagram of rotor disk electromagnetic clutch

Fig. 3. energy-saving self-excitation electromagnetic retarding device

4. Calculation of braking torque of energy-saving self-excitation electromagnetic retarding device

According to the magnetic circuit Ohm's law, the magnetic fluxΦ is:

$$\Phi = \frac{\Psi}{R_m} \tag{1}$$

Where:

$$\Psi = Ni_e \tag{2}$$

In the formula, Ψ—magneto motive force; $R_m = R_{m0} + R_{m1} + R_{m2} + R_{m3}$; N—turn number of coil around the iron core; i_e—instantaneous current of the coil; R_m—reluctance; R_{m0}—gap reluctance; R_{m1}—partial reluctance of the brake disk; R_{m2}—yoke reluctance; R_{m3}—core reluctance.

Thus, formula (1) can be written as:

$$\Phi = \frac{Ni_e}{R_{m0} + R_{m1} + R_{m2} + R_{m3}} \tag{3}$$

Because of high magnetic permeability of the soft magnetic materials used in the electromagnetic retarder rotor disk, yoke and retarder iron core, the reluctance of these materials is very small relative to the gap reluctance, which can be ignored in calculation. Therefore, the total reluctance of the magnetic circuit is:

$$R_m = R_{m0} = \frac{l_g}{\mu_0 S} \tag{4}$$

In the formula, l_g—air gap spacing; $\mu_0 = 4\pi \times 10^{-7} H/m$; S—cross-sectional area of retarder iron core.

Therefore, the magnetic induction intensity$B$ in the magnetic circuit is:

$$B = \frac{\Phi}{S} = \frac{\mu_0 N i_e}{l_g} \tag{5}$$

The braking torque $T_L$generated by the electromagnetic brake on the electromagnetic retarder rotor disk is[6]:

$$T_L = \sigma R^2 S d B^2 \omega = \sigma R^2 \tag{6}$$

In the formula: σ—conductivity of electromagnetic retarder rotor disk; R—The distance from the center of the retarder rotor disk to the center of the projection of retarder iron core on the disk; d—thickness of electromagnetic retarder rotor disk; ω—rotation angular velocity of electromagnetic retarder rotor disk.

It is difficult to obtain the instantaneous current of coil in formula (5). For ease of calculation, the magnetic induction Bin formula (6) can be calculated according to literature [8]:

$$B = \frac{8\pi\rho\mu_0 N I}{16\pi\rho l_g + \sqrt{2} S \Delta_h \mu_0 k_e \omega} \tag{7}$$

In the formula: ρ—electrical resistivity of electromagnetic retarder rotor disk; Δ_h—skin depth of the eddy on the rotor disk; k_e—conversion coefficient, normallyk_e=1.5??

To this end, formula (6) can be adjusted as:

$$T_L = \frac{64\sigma R^2 S d (\pi\rho\mu_0 N I)^2 \omega}{(16\pi\rho l_g + \sqrt{2} S \Delta_h \mu_0 k_e \omega)^2} \tag{8}$$

5. Performance test analysis of energy-saving self-excitation electromagnetic retarding device

According to the optimization design theory, Ansoft Maxwell 2D / 3D software was adopted for magnetic field analysis, and bench test was carried out by referring to literature [9]. The final structure parameters of energy-saving self-excited electromagnetic retarder are as follows:

Transmission shaft diameter 0.16m, retarder rotor disk diameter 0.88m, copper material was selected for rotor disk, electrical pure iron (with maximum magnetic permeability up to 0.024 H / m) was selected for retarder iron core, the retarder is winded by 4 sets of coil (2000 turns per set of coil, coil material is copper), the gap between the retarder iron core and rotor disk is 0.001m, the electromagnetic retarding device limits the maximum input current within 25A through the current limiter.

The test conditions are:

Indoor temperature: 24??; relative humidity 40% -45%; atmospheric pressure: 756mmHg;

Test reference standard: GB12676-1999 "Automotive brake system structure, performance and test methods"; GB7258 "technical conditions for motor vehicle operation safety".

In the test, three braking states including the vehicle speed decreased from 100Km/h to 40Km/h, the vehicle speed decreased from 80Km/h to 40Km/h and the vehicle speed decreased from 400Km/h until stop are chosen, the curve of the electromagnetic retarder braking torque and the output characteristics of the generator current curve are monitored dynamically. The variation curve of electromagnetic retarder torque with the braking time is shown in Figure 4, and the variation curve of generator output current with the vehicle speed is shown in Figure 5.

40km/h braking to stop

80km/h braking to 40km/h

100km/h braking to 40km/h

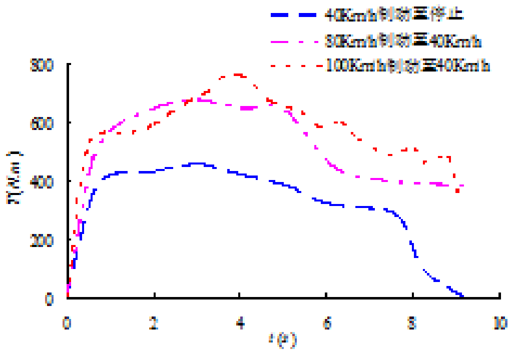

Fig. 4. variation curve of electromagnetic retarder torque with the braking time

Current output from vehicle speed 40km/h to stop

Current output from vehicle speed 80km/h to 40km/h

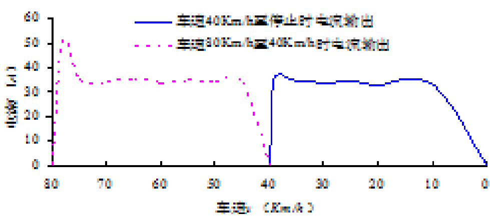

Fig. 5. variation curve of generator output current with the vehicle speed

Figure 4 shows that energy-saving self-excitation electromagnetic retarding device works at brake. The higher the vehicle speed at brake is, the greater the braking torque is. When the vehicle speed is decreased from $100Km/h$ to $40Km/h$, the maximum torque generated is $757.6N \cdot m$. In the two braking modes of "vehicle speed decreased from 100Km/h to 40Km/h", and "vehicle speed decreased from 80Km/h to 40Km/h", the vehicle speed is $40Km/h$ at the end of the brake. At this time, the braking torque generated by the energy-saving self-excitation electromagnetic retarding device is the same as the initial braking speed in the braking mode of "vehicle speed decreased from 400Km/h until stop". As can be seen from Figure 4, braking torque generated by the retarding device is substantially equal despite different braking modes when the speed reaches $40Km/h$, and there is only a slight difference due to factors such as heating of the retarder coil.

As can be seen from Fig.5, the generator connected to the energy-saving self-excitation electromagnetic retarder starts operation at the time of braking. The higher the initial braking speed is, the greater the initial current is. But as the vehicle speed slows down, because the alternator itself has the ability to limit the output current to prevent overload, the generator maintains about 35A output current at different vehicle speeds.

To measure the output power of the generator on the energy-saving self-excitation electromagnetic retarding device, the average current intensity$\bar{I}$ of its output should be calculated, as in formula (9)

$$\bar{I} = \frac{\int_0^t I(t)dt}{t} \tag{9}$$

Therefore, the output current-time curve is fitted for the two braking modes of vehicle speed decreased from 80Km / h to 40Km/h, vehicle speed decreased from 40Km/h until stop. And the fitting equation is obtained as in formula (10), formula (11):

$$I40 - 0 = -2.9427t_4 + 23.721t_3 - 66.629t_2 + 79.096t - 1.6716 \tag{10}$$

$$I80 - 40 = -5.3819t_4 + 129.58t_3 - 1154.5t_2 + 4510t - 6484.6 \tag{11}$$

It can be obtained via calcuation that:

$$I40 - 0 = 30.0355A; I80 - 40 = 31.236A \tag{12}$$

As the electromagnetic retarder limits the maximum input current within 25A through the current limiter, the current intensity genereated by the generator in different braking modes is greater than the maximum operating current of the electromagnetic retarder, which ensures reliable operation of the electromagnetic retarder.

Assume that a vehicle installed with energy-saving self-excitation electromagnetic retarder drives 6Km from the suburbs to the urban area, with a total braking time of 10min. If the regulating voltage of the generator voltage regulator is 15V, then the output power of the generator to the electrial equipment in the vehicle is:

$$P_{80-40} = UI_{80-40} = 469W \tag{13}$$

$$P_{40-0} = UI_{40-0} = 451W \tag{14}$$

The average power output$\bar{P}$ of the generator to the electrical equipment in the vehicle is:

$$\bar{P} = 460W \tag{15}$$

Generating capacity E of the electromagnetic retarder is:

$$E = \bar{P} \cdot t \tag{16}$$

According to calculation, $0.077 KW \cdot h$ electricity is generated, which can supply 1.3 continuous hours' power for headlamp of 60W vehicle.

6. Conclusions

(1) The developed energy-saving self-excitation electromagnetic retarder can effectively and reliably ensure vehicle braking effect while achieving energy storage, energy saving purposes.

(2) The braking torque formula obtained by magnetic circuit Ohm's law can provide the theoretical basis for further analysis of the braking effect of the energy-saving self-excitation electromagnetic retarder.

(3) The torque test and generator current output characteristic test were carried out by using the test bench. Test results show that energy-saving self-excitation electromagnetic retarder not only has adequate braking torque, but also can generate power sufficient for automotive lighting system operation.

References

[1] R. Q. Huang, G. Y. Li, H. Hu: *Hydraulic retarder and eddy current retarder.* Mechanical & electrical engineering technology *10* (2005), Nos. 82–85, 106.

[2] J. C. Timothy, J. E. Mowatt: *Development of a hydraulic retarder for the allison AT545R transmission.* SAE paper *9* (1995), Nos. 13–15.

[3] J. Shi, X. X. Guo: *Current status and development trend of hydraulic checking-brake for vehicles.* Vehicle & power technology *4* (2001), Nos. 52–57.

[4] R. He, H. J. Shen, X. J. Yang: *Overview of auxiliary braking technology for commercial vehicles.* Journal of traffic and transportation engineering *02* (2009), Nos. 54–63.

[5] R. He, F. Y. Yi, J. Q. He: *Calculation method of braking torque of eddy current retarder.* Automotive Engineering *2* (2004), Nos. 197–200.

[6] R. He, F. S. Ding: *Calculation method of braking torque of wheel retarder.* Automobile technology *10* (2008), Nos. 10–12.

[7] R. He, W. Z. Zhao, R. X. Niu: *Calculation method of braking torque of permanent magnet retarder for vehicles.* Calculation method of braking torque of permanent magnet retarder for vehicles *04* (2006), Nos. 66–69.

[8] C. X. Liu, R. He: *Analysis of structure of friction brake and non-contact wheel retarder system.* Transactions of the chinese society of agricultural machinery, *6* (2010), Nos. 25–30.

[9] C. X. Liu, R. He: *Design and experimental study of test bench for electromagnetic brake and friction brake integrated system.* Automobile technology *1* (2012), Nos. 51–55.

Received November 16, 2017