The Research and Development Prospects of Recycling and Utilizing Technology for Automotive Braking Energy

Jianwei Li*
Automotive Engineering Department, Zibo Vocational Institute, Zibo, Shandong, 255314, China
*Corresponding author’s e-mail: 10874@zbvc.edu.cn

Abstract. Recycling the automotive braking energy and regenerating the recovered energy back to the automobile as a driving force when the car accelerates or starts is an effective way to improve the automotive rate of fuel utilization, ameliorate vehicle emissions performance. The key to automotive braking energy recycling technology is how to store the energy generated during the braking process of the automobile. The current situation of recycling and utilizing the automotive braking energy was analysed. On the basis of the energy storage solutions of the battery, an equipment was put forward, which utilized the energy of braking to drive the SR motor, the kinetic energy would transform into electrical energy during the process of braking so as to charge the electrical equipment and the battery. While starting or accelerating, the SR motor not only provided power to the transmission, but also provided compressed air for improving the combustion by driving the compressor.

1. Introduction
With the rapid development of the social economy and the sharp increase in energy consumption, the issue of energy supply and demand has become the focus of more and more countries, and also has produced more serious environmental problems.

With the development of the automobile industry, the energy consumed by automobiles is also increasing in the total energy consumption. How to achieve energy conservation in automobiles has become the theme of the development of the automobile industry in the world. The braking frequency is increasing because of the frequent acceleration and deceleration due to traffic density and traffic congestion. The kinetic energy of the traditional braking system is converted into heat and consumed by the friction of the brake and the friction between the wheel and the ground. At the same time, continuous long-term braking will reduce the braking performance of the brakes, which will reduce the driving safety of the vehicle. Frequent braking will increase the wear of the friction materials of the tires and brakes, which will increase the maintenance cost of the vehicle. Therefore, recycling automobile braking energy and regenerating the recovered energy back to the automobile as a driving force when the car accelerates or starts is an effective way to improve the automotive rate of fuel utilization, ameliorate vehicle emissions performance, extend the service life of automobile brakes and achieve energy conservation in automobiles, which has important research significance and practical value.

2. The model analysis of vehicle energy
The automotive engine is a machine that converts the chemical energy of a fuel into heat by burning it, then transforms it into mechanical energy and drags some machinery to work. In a working cycle, the useful work of the working fluid on the piston cannot be completely outputted. The energy is inevitably
lost in the internal transmission process of the engine. The useful work of the engine and the distribution of various losses are usually tested by the following methods.

2.1. The energy of the fuel consumed by the engine
In the engine, the heat is generated by mixing fuel and air and then combusting. Assuming that the fuel is completely burned, the amount of heat generated per hour is presented by:

\[ Q_T = Bh_h \]  

where \( Q_T \) is the fuel energy generating by the engine per hour; \( h_h \) is the low calorific value of fuel.

2.2. The energy converted into useful work
The relationship between the effective power and the effective torque output from the power output shaft when the engine is operating is expressed by:

\[ P_e = \frac{2\pi n T_{e\theta}}{60 \times 10^3} = \frac{T_{e\theta} h}{9550} = 0.1047 T_{e\theta} n \times 10^{-3} \]  

where \( P_e \) is the effective power; \( T_{e\theta} \) is the effective torque \( (N \cdot m) \); \( n \) is the engine speed \( (r/min) \).

Because of the principle of \( 1kW \cdot h = 3.6 \times 10^3kJ \), the energy converted into useful work \( Q_E \) can be expressed by:

\[ Q_E = 3.6 \times 10^3 P_e \]  

2.3. The energy delivered to the cooling medium
The energy transferred to the cooling medium can be calculated by:

\[ Q_S = G_a c_s (t_2 - t_1) \]  

where \( G_a \) is the flow per hour \( (kg/h) \) of engine cooling medium; \( c_s \) is the specific heat capacity; \( t_1 \) is the inlet temperature of the cooling medium \( (^{\circ}C) \); \( t_2 \) is the outlet temperature of the cooling medium \( (^{\circ}C) \).

2.4. The energy taken away by exhaust
The energy taken away by exhaust can be expressed by:

\[ Q_R = (B + G_k) (c_{pr} t'_2 - c_{pk} t'_1) \]  

where \( Q_R \) is the energy taken away by exhaust; \( G_k \) is the amount of air consumed per hour \( (kg/h) \); \( c_{pr}, c_{pk} \) are the constant pressure specific heat capacity of exhaust gas and air \( [kJ/(kg^{\circ}C)] \); \( t'_2 \) is the working fluid temperature at the inlet of the intake pipe \( (^{\circ}C) \); \( t'_1 \) is the temperature of the exhaust gas \( (^{\circ}C) \) near the exhaust valve.

2.5. The energy of incomplete combustion of fuel
In the actual working cycle, the non-instantaneous combustion loss and afterburning loss will be formed. At the same time, incomplete combustion can occur. The energy loss in this process is approximately calculated as:

\[ Q_B = Q_T (1 - \eta_r) \]  

where \( Q_B \) is the energy of incomplete combustion of fuel; \( \eta_r \) is the combustion efficiency.

2.6. The other energy loss
Since this part of the energy cannot be accurately calculated separately, the total energy value is generally determined only according to the following formula.

\[ Q_L = Q_T - Q_E - Q_S - Q_R - Q_B \]  

where \( Q_L \) is the other energy loss.

Generally, the ratio of the energy of each part to the total energy of fuel combustion is called heat balance. The range of heat balance values for each part of the energy is shown in Table 1.

| ENGINE TYPE | \( Q_S \) % | \( Q_S \) % | \( Q_R \) % | \( Q_B \) % | \( Q_L \) % |
|-------------|-----------|-----------|-----------|-----------|-----------|

It can be seen that only 25% to 40% of the heat is converted into useful work, and the remaining 60% to 75% of the energy is lost through various forms such as cooling medium and exhaust gas.

3. The current situation analysis of recycling the automotive braking energy

The key to automotive braking energy recycling technology is how to store the energy generated during the braking process of the automobile. Nowadays, the research on the recovery and utilization of the automotive braking energy at home and abroad mainly focuses on the following four aspects: mechanical energy storage, hydraulic energy storage, pneumatic energy storage and electrochemical energy storage.

3.1. The mechanical energy storage

One of the common methods of mechanical energy storage is the flywheel energy storage, which uses the high-speed rotating kinetic energy of the flywheel to recover and store the braking energy. The working principle diagram is shown in Figure 1. When the car needs to brake or decelerate during driving, the inertia kinetic energy accelerates the rotation of the flywheel, and the braking energy will be converted into the rotating kinetic energy. When the car starts or accelerates, the kinetic energy will be transmitted to the vehicle body. The traditional metal flywheel is mainly made of steel. The structure of the flywheel energy storage is simple and easy to implement. However, the kinetic energy stored by the flywheel is somewhat related to the moment of inertia for the flywheel, while the larger mass and diameter are contradictory to the cost and installation space, which limits the application range.

3.2 The hydraulic energy storage

The hydraulic energy storage system includes two processes of braking energy recovery storage and release. The working principle of the hydraulic energy storage is shown in Figure 2. When the state of vehicle is converted from driving to braking or deceleration, the electro-hydraulic servo device controls the secondary component to work as the hydraulic pump, and the transmission shaft is accelerated and drives the secondary component through a pair of transmission gears. The Inertia energy will be stored in the accumulator in the form of hydraulic energy. When the vehicle accelerates, the high-pressure hydraulic energy stored in the accumulator impels the secondary component to rotate, which directly gives to the transmission shaft by the transmission gear so as to ensure that the vehicle starts or accelerates quickly. Although this recycling method has been realized on the bus, it has a certain limitation in the use with limited installation space on the mechanical transmission chassis.
3.3 The pneumatic energy storage

The working principle of the pneumatic energy storage system is similar to the hydraulic energy storage system. The flow chart of the scheme is shown in Figure 3. During the braking or deceleration of the vehicle, the air compressor will be driven by the transmission mechanism and convert the inertial energy into air pressure energy which will be stored inside the gas storage tank. When the vehicle accelerates, the high-pressure gas will enter the air motor circuit under the control of the electromagnetic valve. The air motor converts the air pressure energy into mechanical energy and supplies to the transmission shaft, which will assist the automobile to start or accelerate quickly. However, the pneumatic energy storage system requires a high degree of sealing performance and has a limited application range due to the installation of the high-pressure gas storage tank.

3.4 The electrochemical energy storage

The electrochemical energy storage makes use of the unique structure of the motor to realize the mutual conversion of the driving mechanical energy and electric energy according to the motor’s reversibility of the working process. During the braking process, the motor operates in the state of the generator, and the mechanical energy drives the rotation of the motor. While the electric energy will be generated and stored in the battery. When the vehicle begins to start, the motor acts as a motor to convert the stored electrochemical energy into mechanical energy that drives the vehicle's motion. The working principle is shown in Figure 4. This kind of electrochemical energy storage system has the advantages of simple structure, high reliability and convenient operation. However, the battery has a certain restrictive effect on the popularization and application of the electrochemical energy storage system.

Figure 2. The working principle diagram of the hydraulic energy storage system

Figure 3. The flow chart of the pneumatic energy storage system

Figure 4. The working principle diagram of the electrochemical energy storage system
4. The development prospects of recycling and utilizing technology for automotive braking energy

According to the analysis above, it can be known that the braking energy stored by the electrochemical energy storage system and converted into mechanical energy to external output if necessary is a considerable and effective utilization mode. It not only avoids the problem of low reliability of the hydraulic and pneumatic recycling system, but also solves the problem that the quality of the mechanical recycling system is contradictory to the larger diameter, the cost and installation space. Based on the electrochemical energy storage system and the structure of the turbocharger, this paper proposes a new type of recycling and utilizing scheme for automotive braking energy. The working principle diagram of the new type of recycling and utilizing scheme for automotive braking energy is shown in Figure 5.

![Working principle diagram of recycling and utilizing automotive braking energy](image)

The design ideas are as follows. When the vehicle brakes, the control unit receives the brake signal and sends a control command to the electromagnetic clutch I. Then the electromagnetic clutch I is controlled to work so that the secondary element and the rotor shaft of the SR motor are connected as an integral part. The secondary component is coupled to the drive shaft and rotated together with the rotor shaft of the SR motor. The SR motor will be operated in generating mode.

When the vehicle starts up again or accelerates, the electromagnetic clutch I and the electromagnetic clutch II will be controlled to work simultaneously. On the one hand, the SR motor works in the electric mode. On the other hand, the SR motor drives the compressor to pressurize the outside air and send it to the engine. The SR motor used in this scheme is simple in structure and the rotor has no permanent magnets and windings so that it has less power loss, higher working efficiency and reliability, wider speed regulation range and flexible control. Therefore, this design scheme is more suitable for working in the regenerative braking situation and rotating situation in the forward and reverse directions, which has better application value and popularizing prospects.

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