Design of a Single Motor Special Hybrid Transmission

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Abstract: The development of electric vehicle power system has become an important technical route of energy conservation and emission reduction. Hybrid system based on engine optimization is becoming a feasible technology at present. The motor and transmission system was integrated for the dedicated hybrid gearbox at the beginning of the design, with obvious advantages in performance and cost. Therefore, this design method has been favored by many automobile companies. In this paper, a single-motor multi-gear hybrid scheme is introduced, which can realize the pure electric mode with two gears and hybrid mode with four gears. At the same time, this scheme also has the advantages of compact mechanism and low product cost.

1. Introduction

Electric vehicle has become the development trend of power system. Pure electric and hybrid systems have achieved considerable sales in China and are playing a positive role in improving the urban environment. With the development of technology and the intensification of industry competition, all kinds of electric drive technologies have been survival of the fittest, and some special hybrid gearboxes have gradually shown advantages in performance and product cost. In China, hybrid products are more likely to adopt extended technical solutions. That is, on the basis of the existing gearbox on the integration of motor hybrid gearbox. This scheme can extend the life of existing products and share the upfront product investment, but it is only recommended as a short-term product technology.

At present, the special hybrid gearbox is mainly represented by the products of Toyota, general motors and Honda motor company. Toyota THS hybrid system and GM Voltec hybrid system both adopt dual-motor hybrid technology, and achieve the integration of fixed speed ratio, taking into account both fuel economy and power performance. This kind of technology is difficult in solution development and function realization and needs long-term technical investment. The i-MMD hybrid system of Honda adopts series-parallel technology, and the fuel consumption performance of the vehicle relies too much on the special engine, the voltage platform of the hybrid system and the vehicle hybrid upgrade.

At present, the multi-gear mixing system based on the single motor, the motor to achieve the optimization of the engine working interval, reduce the fuel consumption of the whole vehicle, and at the same time can reduce the number of gearbox gear, reduce the cost of gearbox, these have gradually become the research focus. In this paper, a special hybrid gearbox is designed with a set of compound planetary arrangement mechanism and shift elements, which can realize the pure electric mode with two gears and the hybrid mode with four gears and be applied to the strong hybrid plug-in hybrid system.
2. Design of special hybrid transmission

Automatic transmission shift technology is adopted in the design of the scheme to realize the shift without power interruption. With the planetary arrangement as the core part, two wet brakes and clutch are integrated. The mixing system scheme is shown in figure 1. The compound planetary arrangement can be divided into two planetary arrangements. The planetary row of the single planetary wheel consists of the solar wheel (S), the first planetary wheel (P1), and the first inner gear ring (R1). The double planetary wheel planetary row consists of the solar wheel (S), the first planetary wheel (P1), the second planetary wheel (P2), and the second inner gear ring (R2). Among them, the planet shelf and the sun wheel share, which can simplify the mechanical mechanism, make the structure more compact and easy to arrange.

![Figure 1. Special hybrid transmission scheme](image)

The motor (EM) is connected to the sun wheel (S), and the first brake B1 is arranged between the planet frame and the gearbox housing. A second brake B2 is arranged between the first inner gear ring (R1) and the gearbox shell. The transmission input shaft is connected to the planet frame through the first clutch C1 and the sun wheel through the second clutch C2. The engine is connected to the gearbox input shaft through a flywheel shock absorber. The second inner gear ring (R2) serves as the power output shaft of the planetary platoon mechanism, on which a reduction gear is installed. The power is transferred to the differential through the two-stage reduction gear, and then the semi-axle drives the vehicle.

The brake and clutch adopt wet multi-plate friction shift element and design hydraulic control system to realize shift operation. Therefore, it is suggested that the motor should adopt oil cooling method and design a multi-functional hydraulic system to realize gear shift control and motor cooling.

3. Working principle of hybrid system
3.1. Build a planetary row model

Planetary arrangement mechanism has the advantages of compact structure, strong bearing capacity and large speed ratio range, so it is widely used in automatic transmission. Lever analysis method is often used in the analysis of planetary displacement mechanism, which converts the torque relationship of each axis of planetary displacement into the balance analysis of "force". Lever analysis method is often used in the analysis of planetary displacement mechanism, which converts the torque relationship of each axis of planetary displacement into the balance analysis of "force". The equivalent lever models of common single-planet wheel and double-planet wheel and planetary row are shown in figure 2 and figure 3. In the lever model, the dotted line represents the zero speed line, above which is the positive speed, below which is the negative speed. According to the rotation speed relation of the planetary arrangement mechanism, the planetary arrangement state in the lever model is a straight line, and the rotation speed of the third axis can be calculated from the rotation speed of any two axes. When the planetary frame is fixed, the rotation speed of the sun wheel and the inner gear ring in the single planetary wheel planetary row is opposite. The rotation speed is the same in the double planetary wheel planetary row.
The compound planetary exhaust mechanism adopted in the mixing scheme in this paper can be divided into single planetary exhaust and double planetary exhaust. In the lever model, the levers of common components can be combined, and the clutch and brake can be arranged on the corresponding levers according to the mixing scheme, to obtain the equivalent lever model as shown in figure 4.

![Figure 4. Equivalent lever model of hybrid scheme](image)

3.2. Working mode of hybrid system

By controlling different clutches and brakes, multiple drive gears can be realized to ensure that only two shift elements are involved in each shift. The design of two gears in pure electric drive mode can optimize the working point of the motor and meet the needs of plug-in hybrid system and extender electric system. In the mixing mode, the drive mode of four gears is designed. The control logic of each gear is shown in table 1.

In pure electric drive, gear shifting is realized by switching the brakes. In the first gear, large torque output can be used for low-speed starting process; in the second gear, high speed can be achieved to improve the vehicle speed; in the second gear, pure electric design can reduce the motor torque and speed requirements. Pure electric mode is also used for reversing, avoiding complicated transmission mechanism design.
Table 1. Mixing system shift control logic

| Working mode       | B1 | B2 | C1 | C2 |
|--------------------|----|----|----|----|
| EV-1               | x  |    |    |    |
| EV-2               |    | x  |    |    |
| HEV-1(+EM)         | x  |    |    | x  |
| HEV-2(+EM)         |    | x  |    | x  |
| HEV-3(+EM)         |    | x  |    | x  |
| HEV-4(+EM)         | x  |    |    | x  |
| Idle charge        |    | x  |    | x  |

Note: x- means the shift element is closed

Figure 5. Pure electric working mode

The engine will be the main power source when the hybrid power is driven. Two low-speed transmission ratios, one direct gear and one overspeed gear are designed, and the auxiliary optimization of the motor can meet the use requirements of the vehicle in various working conditions. The working mode of each hybrid power is in motion to achieve a large torque output. The overspeed gear working mode is used for high speed, and the engine itself works in a high efficiency range, as shown in figure6. In the low-speed gear position, the coaxial drive of the engine and motor is in the state of idling, and when necessary, the power and braking energy recovery is more conducive to improving the efficiency of the power system.
When parking power is generated, the output shaft is locked by the parking mechanism and is the torque fulcrum of the planetary platoon mechanism. The motor will work in the power generation state of negative and positive speed, as shown in figure 7.

3.3 Mixing system transmission ratio design

The gear ratio of each gear is determined by the gear ratio setting of the planetary mechanism. The planetary speed ratio $i_1$ (ZR1/ZS) and $i_2$ (ZR2/ZS) were taken as variables to calculate the speed ratio of each gear as follows:

$$i_{EV-1} = \frac{i_2}{1}$$ \hspace{1cm} (1)

$$i_{EV-2} = \frac{(\frac{2}{1})+i_2}{(\frac{2}{1})+1}$$ \hspace{1cm} (2)

$$i_{HEV-1} = \frac{i_2}{i_1}$$ \hspace{1cm} (3)

$$i_{HEV-2} = \frac{(\frac{2}{1})+i_2}{(\frac{2}{1})+1}$$ \hspace{1cm} (4)

$$i_{HEV-3} = 1$$ \hspace{1cm} (5)

$$i_{HEV-4} = \frac{(\frac{2}{1})}{(\frac{2}{1})+1}$$

The planetary speed ratio $i_1=1.9$ and $i_2=3.6$ were preliminarily selected to obtain the speed of each gear, as shown in table 2. In the future, the whole system performance is simulated and analyzed by combining engine and motor data, and then the speed ratio is optimized.
Table 2. Hybrid gearbox gear ratio

| Gear ratio | Speed ratio |
|------------|-------------|
| EV-1       | 3.6         |
| EV-2       | 1.9         |
| HEV-1      | 3.6         |
| HEV-2      | 1.9         |
| HEV-3      | 1           |
| HEV-4      | 0.65        |

4. Conclusions
In this paper, a single-motor multi-gear hybrid special gearbox is designed, and the product cost, performance requirements and application platform are comprehensively considered. The scheme is summarized as follows:

(1) Adopt compound planetary arrangement mechanism, which has the advantages of compact structure and easy arrangement; The gear shifting components are multi-plate friction components commonly used in automatic transmission.

(2) Design two pure electric gears and four hybrid gears. The two gears can optimize the operating range of the motor, meet the demand of long-term pure electric use, and achieve higher speed performance, reducing the torque and speed requirements of the motor.

(3) The hybrid solution can be used in HEV and PHEV systems for a-class vehicles and compact SUV platforms. For heavier vehicles, it is recommended to use it together with the P4 electric drive system.

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