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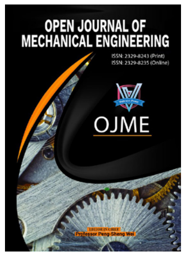

ARTICLE

ANALYSIS AND COMPARISON OF DCT NEW ENERGY HYBRID CONFIGURATION

Sienna Byrne*

Faculty of Engineering and Informatics, University of Bradford, Bradford BD7 1DP, United Kingdom
****Corresponding Author E-mail: Sienna@hotmail.com***

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ABSTRACT

The advantages of applying DCT technology in hybrid electric vehicles are introduced. Several hybrid configurations equipped with DCT are proposed in combination with theory and practice. The advantages and disadvantages of the four configurations are analyzed from the aspects of structural characteristics and functional applications. The feasibility of various configurations is qualitatively analyzed from the perspectives of engineering realization, R&D cost and R&D cycle. The paper focuses on two configurations with feasibility and research value: the scheme that the P2 motor is arranged in front of the gearbox has good feasibility in the short term. The integration scheme of P2.5 motor and gearbox electromechanical coupling will be the main development trend of DCT hybrid vehicles.

KEYWORDS

DCT hybrid configuration, P2, P2.5, PI+P4, scheme comparison.

INTRODUCTION

With the depletion of petroleum resources and the increasingly serious environmental problems, the country has increasingly stringent requirements for fuel consumption and emissions. The development of electric vehicles is getting more and more attention. Electric vehicles can be divided into three categories: hybrid vehicles, fuel cell vehicles and pure electric vehicles. Among them, pure electric vehicles have the disadvantages of short driving range and high cost of existing power batteries. Its marketization promotion process is very slow and still needs a long process. Fuel cell vehicles have not yet broken through due to fuel cell technology and the resulting cost problems. It will also take a long time to enter the market in large quantities. Under the above background, an automobile-Hybrid Electric Vehicle (HEV), which uses a traditional automobile internal combustion engine and an electric motor as dual power sources, emerges as the times require. It has become one of the most industrialized and market-oriented models of electric vehicles.

Dual Clutch Transmissions (DCT) is a new type of automatic transmission in the field of automotive automatic transmissions. DCT not only inherits the advantages of manual transmission (MT) and automatic mechanical transmission (AMT), such as high transmission efficiency, compact structure and light weight. It also integrates the characteristics of AT shifting without power interruption. In terms of structure and performance, DCT is more suitable for the use of hybrid vehicles, and has become the development direction of hybrid vehicle transmission technology.

Based on the research results at home and abroad and the comparison results of various new energy transmissions in the market, based on a certain DCT existing in our factory, this paper analyzes the advantages of using DCT transmission technology in hybrid electric vehicles. Several configurations of DCT-equipped hybrid powertrains are proposed. The advantages and disadvantages of each are analyzed from the aspects of structure and function. The feasibility of each configuration was qualitatively analyzed from the perspectives of engineering realization, R&D cost and cycle.

2.TECHNICAL ADVANTAGES OF DCT FOR HYBRID POWER

Compared with the traditional gearbox, DCT has obvious performance advantages, as shown in Table 1.

Table 1: Comparison and analysis of the advantages of hybrid power using DCT

performance	AMT	DCT	CVT	AT
comfort	-	++	++	++
dynamic	++	++	+	0
fuel economy	++	++	0	0
cost price	+	0	-	0
Transmission efficiency	+	++	+	-

Note: -, 0, +, ++ indicate that the performance is improved in order from bad to good

The advantages are embodied in:

(1) Reducing the complexity of the powertrain and the cost of the drive train is one of the difficulties in the industrialization of hybrid cars. The DCT eliminates the torque converter. The compact structure of the dual clutch makes the transmission much smaller than other types of transmissions. The mass is also lighter. The mass of a hybrid vehicle

equipped with DCT is much smaller than that of other vehicles.

(2) Cancelling the idling speed of the internal combustion engine is one of the main energy-saving ways for HEVs. DCT can completely cancel the idling of the internal combustion engine because it can completely separate the internal combustion engine from the transmission when stopping. This further improves the fuel economy of the vehicle.

(3) With the help of the structural characteristics of the DCT, it is possible to realize the shift without power interruption without the aid of the rear motor of the transmission. It can improve the working efficiency of the motor, and also make the arrangement of the drive motor in the vehicle more flexible. It is of great significance for exploring new configurations of hybrid vehicles.

(4) When the configuration and parameters of the hybrid vehicle are matched, sometimes it is necessary to sacrifice the shifting power in exchange for the fuel economy of the whole vehicle. DCT has the advantage of dynamic shifting, which makes up for this deficiency.

3. DCT HYBRID CONFIGURATION ANALYSIS

According to the definition and analysis of the current general new energy configuration, P represents the position of the motor. Put different numbers in different positions. The DCT new energy hybrid structure can be defined as the following (as shown in Figure 1).

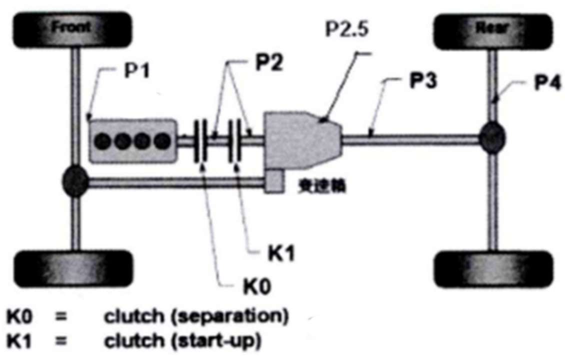

Figure 1: Schematic analysis diagram of hybrid configuration

In theory, DCT is used in two-wheel drive vehicles, and can adopt P2 configuration and P2.5 configuration. DCT is used in four-drive models, and can adopt PI+P4 configuration. These three configurations are described in detail below.

3.1 DCT+P2 two-drive configuration

3.1.1 P2 configuration features and new core components

The P2 configuration is a typical hybrid configuration with a single motor in parallel. As shown in Figure 1, the permanent magnet synchronous motor for driving is arranged before the clutch of the gearbox startup K1. The separation K0 clutch separates the P2 internal drive motor from the internal combustion engine. The P2 system including motor, clutch, clutch actuator, and dual mass flywheel (as shown in Figure 2) can be made into a separate P2 module. It is integrated in the front end of the DCT as a separate component.

After integrating the P2 module, P2+DCT can realize: all parallel hybrid functions (pure electric driving, hybrid driving, internal combustion engine driving, energy recovery, parking charging, driving charging); restarting the internal combustion engine during driving/static; By adjusting the power and torque of the motor in the P2 module, it can cover medium hybrids to plug-in hybrids; It can support acceleration times of less than 5S from 0 to 50km, and can achieve a pure electric cruising range of more than 50km.

The main new core components of the P2+DCT system.

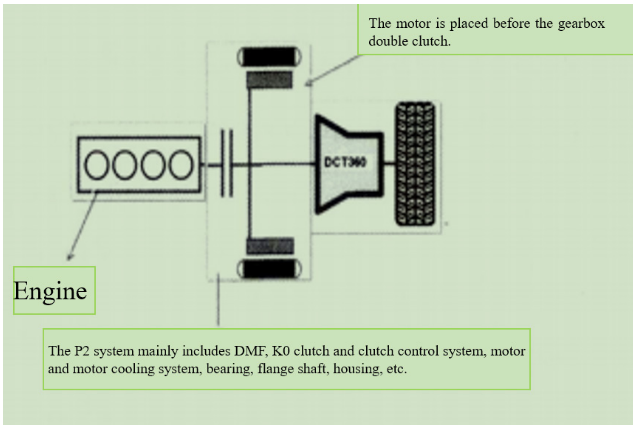

Figure 2: Schematic diagram of P2 module

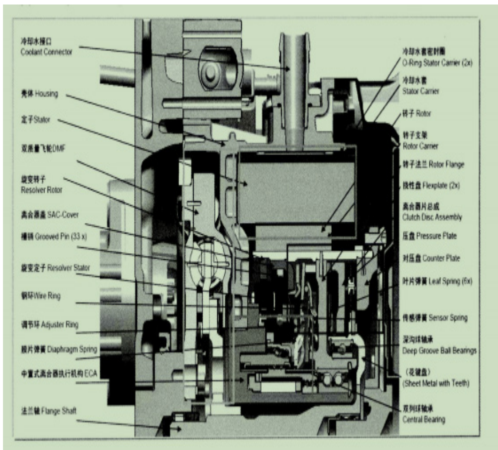

Figure 3: P2 module of SFL

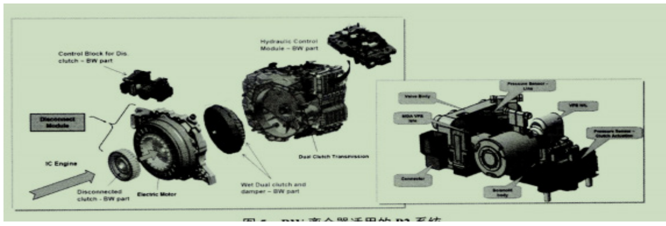

Figure 4: P2 system for BW clutch

(1) K0 clutch. The newly added K0 clutch is arranged between the internal combustion engine and the electric motor for switching the power source in different modes. The clutch can be a wet or dry clutch, depending on the value of the transmitted torque. If the internal combustion engine value is larger, it is recommended to use the wet type. If the internal combustion engine torque is not large, a dry clutch can be used. This avoids drag torque and complex cooling system and oil pump designs;

(2) The motor and its cooling system. Current hybrid systems usually use permanent magnet synchronous motors, depending on the vehicle requirements. The motor can be selected according to parameters such as acceleration per 100 kilometers, gradeability, and vehicle weight. With motors of different lengths, the motor power can be increased or decreased. The cooling system of the motor is integrated in the P2 system, which is usually water-cooled or oil-cooled.

(3) K0 clutch release mechanism: The K0 clutch actuator requires high execution accuracy. This clutch needs to accurately transmit the motor starting torque. In a very short period of time, the internal combustion engine is dragged from a standstill to the same speed of the motor, and the internal combustion engine during the traveling process is started. Extreme comfort requirements are required. The actuator is usually electric or electro-hydraulic.

(4) K0 clutch control system: K0 clutch control needs to develop new control software. It mainly includes K0 clutch separation and

combination control, clutch lubrication control (if wet clutch is used), clutch self-adjustment strategy, etc. This part of the control strategy can be integrated into the current TCU or add a small controller to communicate the control signal with the HCU through CAN or Flexray.

3.1.2 Specific scheme design of P2 configuration

The K0 clutch in P2 can be a wet clutch or a dry clutch. Solutions are divided into two categories because of the different types of disconnect clutches:

Option 1: Dry clutch + electric actuator

Figure 3 takes a typical Schaeffler SFL company's P2 module as an example. Its characteristics are:

(1) The dry clutch (in the red frame) can reduce the drag torque when the clutch is opened without the problem of pump body packaging. The hardware is self-adjusting. Software adaptation is relatively easy.

(2) The electric actuator (in the blue box) has a fast control response. The control accuracy can reach 1N-m. The clutch release and engagement time can be controlled within 100ms.

(3) An optimized dual-mass flywheel design (in the yellow box) is adopted and integrated into the system.

(4) The motor (in the green frame) is modular, and the 33mm, 55mm, and 77mnm E-motors of United Electronics can be selected.

Scheme 2: Wet clutch + electro-hydraulic actuator

Figure 4 is an example of a P2 system suitable for a typical BW wet clutch. Its characteristics are:

(1) The P2 system coupling (including scheme design and assembly) is the responsibility of the gearbox OEM.

(2) Wet clutch is adopted, which is common with the original CCF. The cost has certain advantages.

(3) Adopt electro-hydraulic actuator. Through the cooperation of the two electromagnetic valves of VFS&MDA and the two sensors of clutch pressure and system oil pressure, the control of clutch separation and combination and lubrication control is completed.

(4) Need to increase the electronic pump and electronic pump control. Provide clutch oil pressure when the internal combustion engine is not operating.

(5) The control of the clutch and the control of the electronic pump can be integrated into the TCU body. But the existing TCU hardware needs to be changed.

3. 2 DCT+P2.5 two-drive configuration

3.2.1 P2.5 Configuration and structural features and new core components

Compared with the P2 configuration mode, which can form modules independently, the P2.5 mode integrates the motor into the gearbox. It can be described as a real "electrical and mechanical coupling integrated new energy gearbox". In the P2 configuration the electric machine is located between the combustion engine and the gearbox. In this configuration, the motor speed must be the same as the crankshaft. Therefore, this arrangement cannot use efficient high-speed electric motors, so that the ability of hybrid power expansion is limited. Therefore, we independently developed a DCT-based P2.5 configuration.

Based on dual-clutch technology, some of the advantages of hybrid and parallel hybrids can be combined, thereby increasing the degree of freedom of motor expansion. Based on the characteristics of a certain DCT, we have designed a flexible modular hybrid drive kit such as P2.5 in the hybrid concept. The function of the original dual-clutch gearbox has been further expanded through lower investment. The "torque-split" hybrid drive system uses a compact high-speed electric motor. The motor is incorporated into the housing in a series-parallel manner and is connected to a driven tooth of the 1234 intermediate shaft. With this arrangement, we can achieve the transmission of the input torque of the internal combustion engine and the electric machine by using different gear sets. Therefore, unlike pure parallel hybrids, this layout allows both the combustion engine and the electric machine to work within the optimal efficiency range. In general, even with high-speed motors, the optimal efficiency ranges for electric motors and internal combustion engines are completely different. With the dual-clutch two wide range of multiple ratio options, we can achieve any combination of internal combustion engine and electric motor power while maintaining the highest efficiency of fuel consumption and available torque.

Torque distribution schemes can only be implemented in dual-clutch transmissions. Neither a continuously variable transmission nor a planetary automatic transmission can implement two independent torque distribution paths that can each select multiple gear ratios. They also can't make charge changes like torque-splitting dual-clutch transmissions. The torque-splitting hybrid can be adjusted arbitrarily, except for voltage and battery. In this way, it can meet the different needs of mild, umbrella hybrid or plug-in hybrid power without affecting the whole. The output power of the motor can exceed 100 kW without changing the gearbox. The motor can even be adjusted "in the field" by modifying two parameters, the number of windings and the length of the assembly. By reducing the number of stator and rotor blades and changing the actual length of the motor, the length of the assembly can be adjusted.

The connection method and vehicle attitude of this scheme are shown in Figure 5. The new core components of the e-DCT under the P2.5 configuration include: ① motor and its cooling system; ② motor shaft and its support; ③ idler system and its support; ④ electronic pump. It is used to provide oil pressure to meet the action execution and cooling lubrication under pure electric conditions.

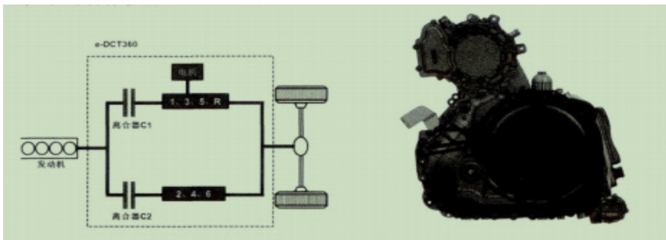

Figure 5: P2.5 Connection Mode and Vehicle Attitude

3.2.2 DCT+P1+P4 four-drive configuration

New energy four-wheel drive vehicles usually adopt the method of P4+P1/P2/P2.5 structure plow. P4 is driven by the rear axle motor, and the power output by the motor is decelerated and torqued through a gear box or a two-speed gearbox. The front axle retains the original traditional car power system. The easiest way is to add a BSG motor to the pulley at the front end of the engine. For quick and smooth engine restarts both stationary and while driving. In this way, the front axle engine torque output, the rear axle motor output, and the power are coupled through the four-gallop transmission mode of the ground hissing. If it is necessary to further increase the power of the whole vehicle and improve the economy of the whole vehicle, the front axle can also adopt the electromechanical coupling gearbox of P2 or P2.5 configuration, such as BYD's "Tang".

Figure 6 takes the conventional P1+P4 as an example. The requirements for DCT in each mode are.

(1) Pure electric mode: The gearbox is in reverse state for a long time.

(2) Hybrid mode: The gearbox works in a similar way to the traditional one. The shift command comes from the vehicle energy control system HCU. The power is coupled through the road surface.

(3) Driving charging: In rear-wheel-drive two-drive mode, the engine starts. The clutch in the transmission is disengaged. The engine button

meter charges the battery through the BSG motor. In four-wheel drive mode, the engine provides both driving force and additional torque to the battery. The transmission is in target gear.

(4) Parking charge: The gearbox is in P gear. The clutch is disengaged. The engine torque meter charges the battery via the BSG motor.

(5) Braking energy recovery: only a certain braking force and braking energy recovery are provided by the rear axle motor. If the engine stalls when braking, the clutch needs to be disengaged at the same time. Engine torque can charge the battery via the BSG motor.

(6) Engine mode: the same as the traditional car.

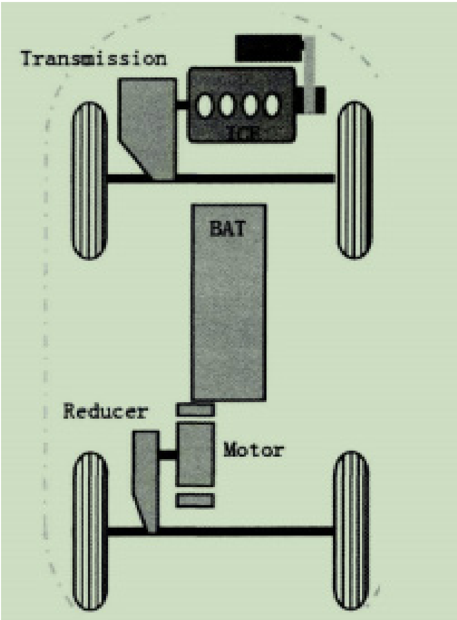

Figure 6: PI+P4 vehicle configuration

During the driving process of the whole vehicle, the hybrid mode HEV and the pure IU mode EV structure are reasonably combined (as shown in Table 2). The best balance of economy and power can be achieved.

The requirement of the P1+P4 configuration for the DCT is only to increase the electron pump. The electronic pump needs to meet the needs of two working conditions: In the reverse drag mode of the pure electric gearbox, it must meet the lubrication of clutch, auxiliary, bearing, etc.; In the process of switching from pure electric to hybrid mode and restarting the engine, it needs to activate the synchronizer to the target gear and engage the clutch to the half-engagement point. After the engine is restarted and the speed regulation is completed, the engine power is immediately involved to quickly realize the switch from pure electric to hybrid mode.

4. COMPARISON OF DCT WITH P2 AND P2.5 HYBRID CONFIGURATION

Based on the above analysis, the comparison of P2 and P2.5 of DCT hybrid is as follows.

Program	Motor Selection Range	Key Components Added	Pure Electric Mode	Hybrid Gear	Reverse Mode	Braking Energy Recovery Path
P2	Nmoter =Nengine Tmoter +Tengine ≤360N·m	C0 Clutch + Control	6	6	Reverse Gear	Whole Gearbox Double Clutch
P2.5	Wide Range of Options Tmoter +Tengine Meets Differential Torque Limit After Torque Increase	Gear Idler Drive Bearing Electronic Pump	3	6 or 8	The Motor Is Driven Forward Separately Motor Reverse Independent Drive Engine Alone Drive Hybrid Drive	Differential Intermediate Shaft

Both schemes have their own advantages and disadvantages, as follows.

Configu-ration	advantages	disadvantages
P2	Less changes to the gear shaft of the transmission body; Mature technology and low risk; Simpler tcu control; Short development cycle;	Increased axial dimension; All power must go through the gearbox, and the power is most affected by the gearbox; Torque limit; The torsional dampers integrated in the dual clutch need to be eliminated; The core technology is mastered by the p2 module supplier; Vehicle level control is more complex;
P2.5	The axial size of the transmission is small, which is consistent with the original transmission, which is convenient for vehicle layout; In the hybrid mode, the motor does not have to be the same as the crankshaft speed, so the motor selection range is wide, and the engine and the motor can work in the high-efficiency range;	The radial dimension of the gearbox is increased; There is a power interruption when shifting in pure electric mode;

5. CONCLUSIONS

This paper mainly discusses the feasibility and advantages of hybrid application of DCT. Several hybrid configurations of DCT are proposed and analyzed in detail. The structural characteristics, new core

Table 2: P1+P4 vehicle working condition distribution

Working Condition	Start Up		Low Acceleration		Slow Speed		Cruise		Rapid Acceleration		High Speed		Slow Down	Parking Power Generation
Model	EV		EV	Driving Power generation	EV	HEV	EV	Fuel	HEV		EV	HEV	Energy Recovery	Power Generation
SOC status	Normal	Low	Normal	Low	Normal	Low	Normal	Low	Normal	Low	Normal	Low	Normal	Low
Drive Parts	Motor	BSG	Motor	ICE+BSG	Motor	ICE+ Motor	Motor	ICE+ BSG	ICE+Motor		Motor	ICE+ Motor	Motor+ BSG	ICE+BSG

components and specific application design of each configuration are described in detail. The advantages and disadvantages of each configuration are analyzed. The results are as follows.

DCT has the advantages of small size, light weight, high transmission efficiency and power shifting. The structural characteristics of the dual clutch make it have obvious advantages in the application of hybrid vehicles.

DCT is used in strong hybrid vehicles. Its main configuration is: P2 scheme, P2.5 scheme and PI+P4 scheme of four-wheel drive. These three types of configurations have their own advantages and disadvantages, which should be comprehensively considered according to the needs in practical application.

In the short term, the P2 scheme in which the motor is arranged in front of the gearbox has good feasibility. But in the long run, the P2.5 scheme of the electromechanical coupling of the motor and the gearbox will be the main development trend of DCT hybrid vehicles.

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