International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 85

Energy Consumption Analysis of Parallel PHEV with Different Configurations Based on Rule Control Strategy

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ABSTRACT

There are certain differences in the layout of the energy systems of plug-in hybrid vehicles (PHEVs), which will result in the effects of energy management strategies. Based on the analysis of the technical characteristics of the single-motor mainstream technology routes P2, P3 and P4, this paper establishes a parallel PHEV model with different configurations based on the rule control strategy, and analyzes the impact of different configurations on the fuel economy of automobiles under the China Automotive Test Cycle (CATC).The results show that in the CD and CS stages, the P3 configuration has lower fuel consumption, and its pure electric driving range is relatively high. The P3 configuration pure electric cruising range is 0.2km and 3.1km higher than P2 and P4 respectively. This result is instructive for researchers to study the development of hybrid vehicles.

Keywords: PHEV, Hybrid vehicle Configuration, CATC, Energy consumption analysis

NONMENCLATURE

Abbreviations	
CD	Charge Depletion
CS	Charge Sustaining
Symbols	
T_{req}	Torque required
SOC_{min}	Minimum state of charge
$T_{e\text{-}max}$	Motor maximum torque

1. Introduction

The plug-in hybrid electric vehicle (PHEV) combines the advantages of traditional internal combustion engines and pure electric vehicles to both use external grid charging and efficient use of fuel energy for longer pure electric continuation. Driving mileage, reducing vehicle emissions, has become a hot spot for research and development of new energy vehicles at home and abroad in recent years [1-2].

The more scientific and popular classification in the industry is based on the position of the drive motor in the hybrid drive system and is distinguished by different digital codes, namely P0, P1, P2, P3, P4 configuration hybrid system [3],As shown in Figure 1 .

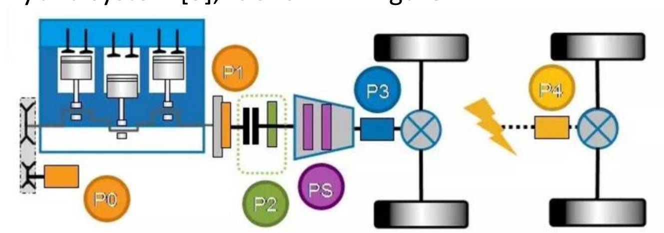

Fig 1. Hybrid electric vehicle motor distribution

The vehicle control strategy is one of the cores of hybrid vehicle technology. In order to improve the fuel economy of the P2 configuration hybrid system, Qixun Zhou [4] and others based on the model analysis, comprehensively consider the external characteristics of the engine, the characteristics of the power battery and the efficiency of the electric drive system, and divide the steady-state working range of the power components and the battery pack. , establish new control rules in each mode, and dynamically switch the working mode according to the change of working conditions. The hardware-in-the-loop simulation test of the parallel hybrid vehicle under ECE driving cycle shows that the overall fuel consumption under the rule control strategy is 20% lower than the original vehicle fuel consumption. Jiande Wang [5] based on CVT parallel hybrid vehicle, comparatively analyzed the characteristics of P2 and P3 configuration, calculated and off-line optimized system efficiency of two configurations in typical working mode, simulation results show that in NEDC (New European Driving Cycle) Under the working conditions, the fuel consumption of P2 and P3 configurations is basically the same under low speed conditions, and the cumulative fuel consumption P2 is slightly lower than the P3 configuration. Yang Yalian et al. [6] based on the DP algorithm, respectively carried out fuel economy simulation analysis of P1 and P2 single-motor hybrid configuration schemes. The comparison results show that P2 saves about 6.68% of fuel consumption compared to P1 , and more improvements can be observed from the proposed speed-coupled , which reduces fuel consumption by 13.82% compared to P1 .

This paper establishes a rule-based control strategy and different configurations of PHEV models, and performs software simulation under CATC driving cycle to analyze the impact of configuration on the fuel economy of the vehicle.

2. Model and simulation

2.1 Control Strategy Design

The rule-based control strategy has the characteristics of logic clarity, real-time and robustness, and is often used as the main method for the development of commercial-level vehicle controller control strategies [7].

The rules laid out in this paper are as follows: as shown in Figure 2.

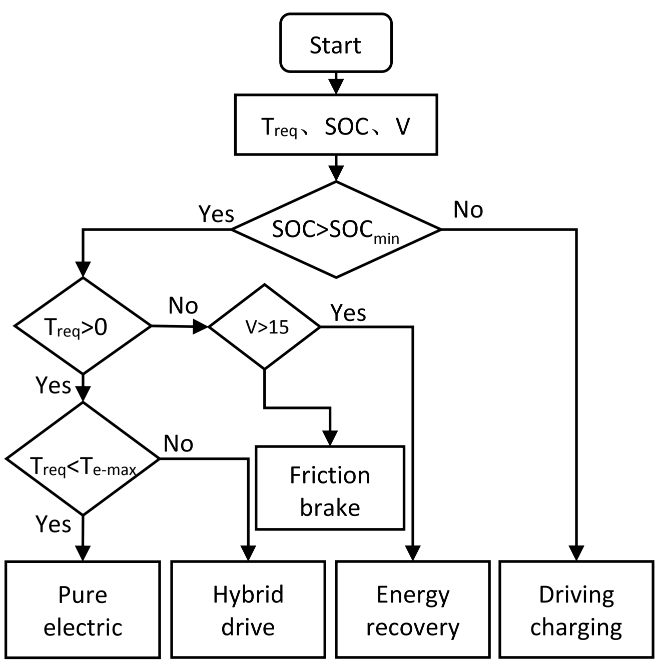

Fig 2. Working mode switching diagram

Mode switching conditions and engine and motor status are shown in Table 1.

Table 1. Mode switching rules

Mode	Engine	Motor	Switching condition
Pure electric	off	electric	$SOC>SOC_{low}$ &$T_{req}<T_{e-max}$
Driving charging	on	generator	$SOC<SOC_{low}$
Hybrid drive	on	electric	$SOC>SOC_{low}$ &$T_{req}>T_{e-max}$
Energy recovery	off	generator	$T_{req}<0$&V>15km/h

2.2 Hybrid system modeling

Figure 3 shows the overall architecture of the model. The driver sends control commands to the hybrid control system by controlling the accelerator pedal and brake pedal opening according to the target speed of the driving conditions. The hybrid control system is based on the hybrid control system. The developed control strategy sends commands to the sub-controllers of the power system, performs output vehicle speeds, and feeds back real-time vehicle information to the hybrid control system.

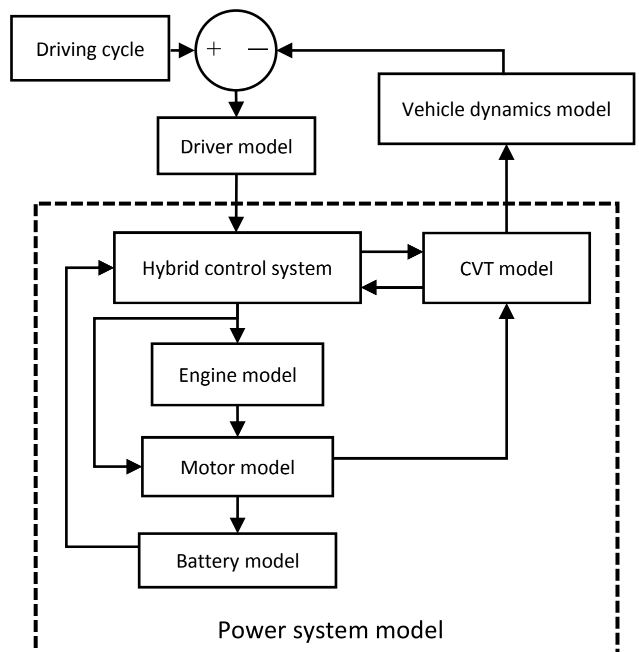

Fig3. Overall architecture of a hybrid vehicle model

2.3 Simulation

According to the control idea established in the previous section and using MATLAB to establish the simulink control model, compile the model created by Simulink into a dll file acceptable to the simulation software, and load this file into the Control Strategy module in the simulation software for simulation. The P2, P3, and P4 car models are respectively built in the simulation software, as shown in Figure 4.

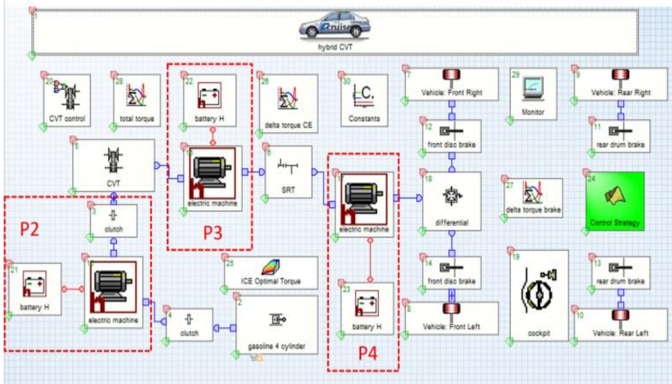

Fig 4. Simulation model

In order to make the simulation more reliable, try to make the main parameters of different configurations consistent, and refer to the actual model to select the parameters of the motor. The main parameters of different configurations are shown in Table 2.

Table 2. Main parameters of the simulation

		P2	P3	P4
Vehicle	Curb weight(kg)		1538	
	Frontal area(m^3)		2.47	
Engine	Displacement(ml)		1498	
	Max power(kw)		76	
	Max speed(1/min)		5800	
Electric machine	Max power(kw)	110	114	96
	Max torque(nm)	200	339	250
Battery	Capacity(kwh)		11.3	
Gear box	Gear ratio		0.5-2.8	

According to China's PHEV energy evaluation national recommended standard GB / T 19753 light hybrid electric vehicle energy consumption test method [8] will be divided into condition A, condition B, 50km / h constant speed endurance three sets of tests, conditions A and conditions B corresponds to the CD(Charge Depletion) stage and the CS(Charge Sustaining) stage of the PHEV, respectively. Condition A is defined as the highest state of charge of the energy storage device at the end of charge; Condition B is defined as the lowest state of charge of the energy storage device at the end of the operational discharge.

Driving cycle is the most basic basis for vehicle development and evaluation. In recent years, China has carried out in-depth research and formulated a test condition cycle that is in line with China's actual road driving conditions, namely the China automobile test cycle(CATC). The main parameters of CATC are shown in Figure 5 and Table 3.

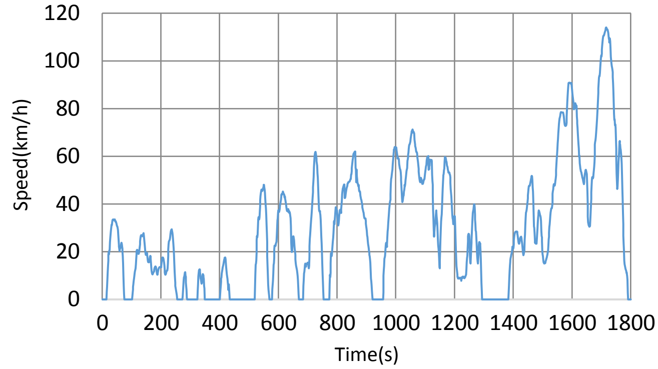

Fig 5. Driving cycle curve

Table 3. Main parameters of CATC

Parameter name	Values
Driving time(s)	1800
Maximum vehicle speed (km/h)	114
Average vehicle speed(km/h)	29.13
Maximum vehicle acceleration (m/s^2)	1.93
Average vehicle acceleration(m/s^2)	0.36
Idling percentage(%)	23.3

3. **Results and discussion**

The three sets of simulation results are shown in Figure 6.

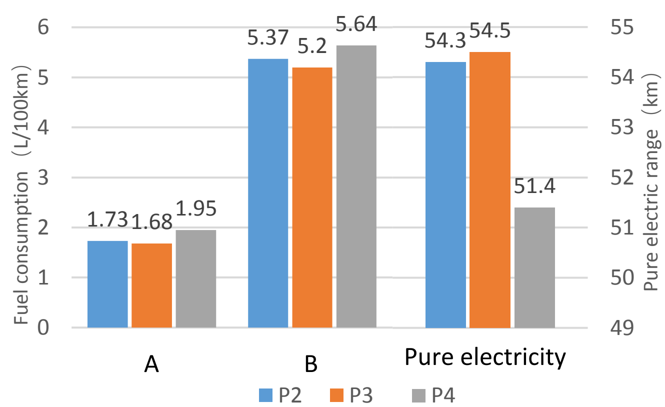

Fig 6. Simulation results

It can be seen from the above figure that in the case of condition A, the fuel consumption per 100 km of P3 configuration is 0.05L and 0.27L lower than that of P2 and P4 respectively. In the case of condition B, the fuel consumption per 100 km of P3 configuration is 0.44L and 0.17L lower than that of P2 and P4 respectively. The P3 configuration pure electric cruising range is 0.2km and 3.1km higher than P2 and P4 respectively. Different configurations based on the same energy management strategy have great differences in fuel consumption and cruising range of PHEV. Therefore, it is necessary to re-optimize the energy management strategies for PHEV with different configurations.

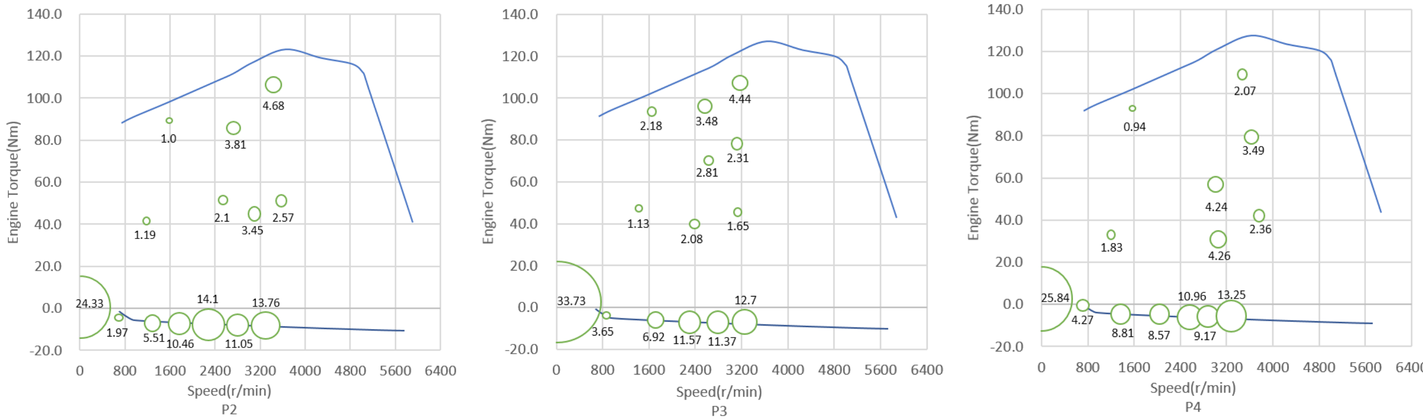

Fig 7. Engine operating point distribution (%)

In order to further analyze the impact of the three configurations of the CS stage on the fuel economy of the vehicle, Figure 7 shows the distribution of engine operating points for the three configurations under B conditions.

It can be seen from the above figure that when the power battery is at the lowest state of charge at the end of discharge, the operating point of the P2 configuration engine is mainly distributed in the high-efficiency zone, the range is concentrated, and the working speed range is between 1000-3300r/min. In a total of 1800 seconds of driving cycle, the engine has 20.08% of working time. The operating point of the P3 configuration engine is concentrated compared to P2, and there is 14.99% working time. P4 configuration is between P2 and P3.

The P2 configuration motor is located between the engine and the transmission. At low speeds, the torque of the motor passes through the transmission, causing the torque output to the wheel side to increase significantly. The P3 configuration motor is located on the transmission output shaft and has higher drive efficiency and higher braking energy recovery than the P2 configuration. The P4 configuration is to place the motor on the drive axle, but because the motor directly drives the half shaft, the speed is limited, and the actual driving efficiency is is lower than P2 and P3.

4. **Conclusions**

This paper establishes a parallel PHEV model with different configurations based on the rule control strategy, and analyzes the effects of different configurations on fuel consumption and pure electric mileage in 100 km under Chinese working conditions. Three conclusions could be drown as follows:

1. Under the case of condition A, the fuel consumption per 100 km of P3 configuration is 3.0% and 16.1% lower than that of P2 and P4 respectively. In the case of condition B, the fuel consumption per 100 km of P3 configuration is 3.3% and 8.5% lower than that of P2 and P4, respectively.
2. The pure electric cruising range of P3 configuration are 0.2km and 3.1km higher than P2 and P4 respectively.
3. Compared with other configurations, the operating point of engine under the P3 configuration is relatively concentrated in high effective area. This result is instructive for the configuration selection of hybrid electric vehicle development.

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