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Research on Energy Management Strategy for Novel Dual-motor Series-driven Coupled PHEV

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Abstract: As environmental pollution and energy shortage issues become increasingly severe, the promotion and development of new energy vehicles have become even more crucial. As a type of new energy vehicle, plug-in hybrid electric vehicles (PHEV) not only effectively reduce energy consumption but also address the range anxiety issue brought by pure electric vehicles. However, their multi-power source structure also poses numerous challenges in terms of energy management strategies. Therefore, developing appropriate energy management strategies has become an important research direction for PHEV. This paper proposes a dual-motor PHEV system configuration based on planetary gears. This configuration achieves multiple operating modes, ensuring efficient operation of the proposed vehicle under different operating conditions. For each operating mode, based on the lever analysis method, its dynamic characteristics are analyzed to achieve better overall vehicle economy.

Keywords: Plug-in hybrid electric vehicle; Planetary gear mechanism; Parameter matching; Energy management; Simulation analysis

1. INTRODUCTION

With the continuous development of the economy, environmental pollution and energy shortage have become particularly severe issues. In terms of energy conservation and emission reduction, as well as addressing environmental pollution and energy scarcity, the development of new energy vehicles holds a pivotal significance [1]. Among them, plug-in hybrid electric vehicles (PHEV) possess distinct advantages. Compared to pure electric vehicles, they have the advantage of a longer driving range, meeting passengers' requirements for long-distance travel [2]. In the new energy vehicle industry, PHEV can be categorized into three types based on the connection structure of their powertrain systems: series, parallel, and compound. Various configurations of PHEV can utilize their power coupling mechanisms [3] to enable the engine to operate in a high fuel efficiency region for extended periods and store excess electric energy, thereby reducing energy consumption [4]. Therefore, to advance the development of PHEV, the configuration and innovation of their key structure—the power coupling mechanism—also need to be a focal point of research. Based on this, this paper proposes a novel dual-motor series drive coupled PHEV configuration utilizing a planetary gear as the power coupling mechanism.

2. COMPLETE VEHICLE CONFIGURATION AND DYNAMIC CHARACTERISTICS ANALYSIS

2.1 Vehicle configuration

The plug-in hybrid electric vehicle (PHEV) configuration proposed in this paper is shown in Figure 1. Its configuration mainly consists of motor MG1, motor MG2, engine, and planetary gear mechanism. Among them, motor MG1 is connected to the sun gear of the planetary gear mechanism, and motor MG2 is connected to the ring gear. The principle of priority to electricity consumption is adopted. When the battery is fully charged, three pure electric modes are realized: motor 1 drive, motor 2 drive, and dual-motor speed coupled drive.

Similarly, when the battery is low and the vehicle is operating at a lower speed, clutch C_1 is disengaged while clutch C_2 is engaged. The engine drives motor MG2 to generate electricity while the vehicle is in series drive mode, providing the necessary energy for the vehicle's operation. When the battery is low and the vehicle is operating at a higher speed, both clutches C_1 and C_2 are engaged. The engine transmits power through the ring gear and operates in pure engine drive mode. When the battery is low and the vehicle is operating at high speed, the engine and motor MG1 are used for hybrid drive.

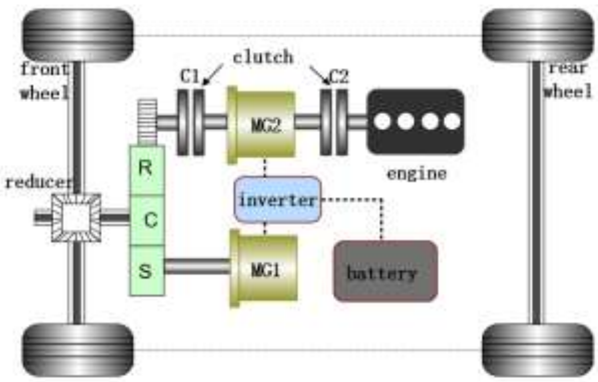

Figure. 1 New dual-motor series drive coupled PHEV configuration

2.2 Dynamic analysis

By controlling the operating states of the power source and clutch, and utilizing the characteristics of the planetary gear mechanism, multiple operating modes can be achieved.

Pure electric mode: In the standalone drive mode of motor MG1, when the battery is fully charged and the vehicle speed is low, requiring less power, motor MG1 serves as the sole power source to drive the vehicle. The ring gear is locked, clutches C_1 and C_2 are disengaged, and the power from motor MG1 is inputted through the sun gear and outputted from the planet carrier. The dynamic relationship is as shown in equation (1). In the standalone drive mode of motor MG2, when the battery is fully charged and the vehicle speed is medium, requiring less power, motor MG2 serves as the sole power source to drive the vehicle. The sun gear is locked, clutch C_1 is engaged, and clutch C_2 is disengaged. The power from motor MG2 is inputted through the ring gear and outputted from the planet carrier. The dynamic relationship is as shown in equation (2). Dual-motor speed-coupled drive mode: When the battery is fully charged and the vehicle speed is high, to avoid the low efficiency issue of a single motor operating at high speed, the dual-motor speed-coupled drive mode is adopted. At this time, both motors work simultaneously to meet the vehicle speed requirements, with clutch C_1 engaged and clutch C_2 disengaged. The power from motors MG1 and MG2 is inputted through the sun gear and ring gear respectively, and outputted from the planet carrier. The dynamic relationship is as shown in equation (3).

$$\begin{cases} \omega_c = \dfrac{\omega_{MG1}}{1+k} \\ T_c = (1+k)T_{MG1} \end{cases} \tag{1}$$

$$\begin{cases} \omega_c = \dfrac{k \cdot \omega_{MG2}}{i_1 \cdot (1+k)} \\ T_c = \dfrac{i_1 \cdot (1+k)}{k} T_{MG2} \end{cases} \tag{2}$$

$$\begin{cases} (1+k)\omega_c = \omega_{MG1} + \dfrac{k}{i_1} \cdot \omega_{MG2} \\ T_c = (1+k)T_{MG1} = \dfrac{i_1 \cdot (1+k)}{k} T_{MG2} \end{cases} \tag{3}$$

In the formula: ω_c represents the rotational speed of the planet carrier, rad/s; ω_{MG1} represents the rotational speed of motor MG1, rad/s; k is the characteristic parameter of the planetary gear; T_c represents the torque of the planet carrier, Nm; T_{MG1} represents the torque of motor MG1, Nm. ω_{MG2} represents the rotational speed of motor MG2, rad/s; i_1 represents the gear acceleration ratio; T_{MG2} represents the torque of motor MG2, Nm. ω_{eng} represents the engine rotational speed, rad/s; T_{eng} represents the engine torque, Nm.

Hybrid mode (series mode): In the series drive mode, when the battery is low and the vehicle is operating under low-speed conditions with low power demand, the engine drives the motor MG2 to generate electricity, providing energy to the vehicle and driving it. At this time, the ring gear is locked, clutch C_1 is disengaged, and clutch C_2 is engaged. The power of motor MG1 is input through the sun gear and output through the planet carrier. The dynamic relationship is as follows.

$$\begin{cases} \omega_c = \dfrac{\omega_{MG1}}{1+k} \\ T_c = (1+k)T_{MG1} \\ T_{eng} = -T_{MG2} \\ \omega_{eng} = \omega_{MG2} \end{cases} \tag{4}$$

Regenerative braking mode: During braking, the above motors operate in a generating state according to their corresponding working modes, storing the energy generated during deceleration in the battery. When a higher braking force is required, a combined braking method combining mechanical braking and regenerative braking is adopted.

3. CONTROL STRATEGY CONSTRUCTION

3.1 Selection of vehicle parameters

This article focuses on the analysis of dynamic characteristics and control strategies. Given that there have been many detailed studies on parameter matching [5-6], we will not elaborate further here. The vehicle parameters selected based on the vehicle's power performance and economic indicators are shown in Table 1.

Table 1. Vehicle Parameter Table

Parameter	Value
Full load mass m/kg	1800
Rated/peak power/kw	15/30
Motor MG1 rated/peak torque/Nm	70/145
Rated/peak speed/rpm	2000/6200
Rated/peak power/kw	30/60
Motor MG2 rated/peak torque/Nm	95/190
Rated/peak speed/rpm	3000/7500
Rated/peak power/kw	19/38
ISG motor Rated/Peak Torque/Nm	65/130
Rated/peak speed/rpm	2800/5600
Maximum power/kw	75
Engine Maximum torque/Nm	135
Maximum speed/rpm	6500
Characteristic parameters of planetary gearsk(z_r/z_s)	2.5
Final drive ratioi_0	3.5
Reduction ratioi_1	1.6
Battery capacity/Ah	40
Rated voltage of battery/V	360

3.2 Vehicle control strategy

The rules established in this document are based on the premise that in pure electric drive mode, the motor drive can meet the torque requirements of the entire vehicle, and the engine basically does not participate in the work; meanwhile, in hybrid drive mode, the engine operates in the high-efficiency range [7]. Therefore, the specific explanation of the established rules is as follows.

(1) Under driving conditions

When the battery SOC is greater than SOC_{low}, and the vehicle is in the low-speed or starting phase with a speed below 30km/h, the vehicle is driven solely by motor MG1; when the speed is between 30km/h and 75km/h, the vehicle is driven solely by motor MG2; when the speed exceeds 75km/h, the vehicle operates in a dual-motor speed coupling drive mode.

When the battery SOC is less than SOC_{low} and the vehicle speed is below 30km/h, the car operates in a series drive mode, driven solely by motor MG1. Simultaneously, the engine starts to drive motor MG2 to generate electricity, recharging the battery. When the vehicle speed ranges from 30km/h to 75km/h, the required rotational speed increases, allowing the engine to operate within its high-efficiency range, driving motor MG2 to generate electricity and regulating the engine's high-efficiency range. When the vehicle speed exceeds 75km/h, both the engine and motor MG1 jointly drive the vehicle, with motor MG2 functioning as a generator to replenish energy for the battery.

When there is a high power demand, such as during rapid acceleration or hill climbing, the vehicle operates in hybrid drive mode regardless of the battery's State of Charge (SOC), to ensure optimal driving performance.

(2) Under braking conditions

When the battery SOC is greater than SOC_{high}, that is, when the battery SOC is greater than 0.9, indicating sufficient power, no brake energy recovery is performed to prevent damage to the battery due to overshoot. Instead, mechanical braking is used exclusively.

When the battery SOC is less than SOC_{low} and the braking demand torque is relatively small, the braking energy recovery is performed by the motors under various vehicle speed operating modes. When the vehicle speed is less than 30km/h, the motor MG1 performs the braking energy recovery to charge the battery; when the vehicle speed is between 30km/h and 75km/h, the motor MG2 performs the braking energy recovery; when the vehicle speed is higher than 75km/h, both motors MG1 and MG2 jointly perform the braking energy recovery to improve efficiency. When the battery SOC is less than SOC_{low} and in emergency braking conditions, the braking demand torque is relatively large. At this time, the torque of the electric braking alone cannot meet the requirements, so the additional required braking force needs to be supplemented by mechanical braking.

4. SIMULATION RESULTS AND ANALYSIS

To verify the effectiveness of the established model and rule-based strategy, the parameter matching results from the previous section and the Simulink vehicle simulation model [8] were combined. The matching parameters were inputted into the simulation model, and the UDDS driving cycle was used as the test condition for simulation analysis and verification. To evaluate the operational effects under different modes in pure electric and hybrid modes, different battery SOC parameters were inputted, and the vehicle speed following curve is shown in the figure below.

From the simulation curve of vehicle speed following, it can be seen that the simulated vehicle speed can effectively follow the actual required vehicle speed, achieving the expected effect of the simulation model.

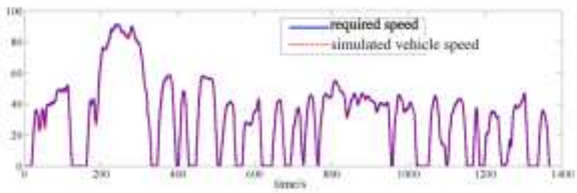

Figure. 2 Vehicle speed following curve

To verify the effectiveness of the simulation model and control strategy in pure electric mode, the initial battery SOC was set to 0.9. The simulation analysis results are shown in the battery SOC change curve and motor torque change curve below: In pure electric mode, the engine does not operate, and the output torque is zero. The motor MG1 and motor MG2 cooperate to output torque to provide power for the vehicle's travel. According to the logic threshold control strategy and the overall vehicle structural design, during vehicle travel, the working modes of single motor MG1 drive, single motor MG2 drive, and dual-motor speed coupling drive are implemented respectively. In the initial time period, the vehicle has just started and the speed is low, requiring less power. At this time, the single motor MG1 drive working mode is satisfied, so the motor MG1 alone provides torque to drive the vehicle. In the subsequent time period, the vehicle speed reaches a medium speed, and the required power increases, satisfying the single motor MG2 drive working mode. Therefore, the motor MG2 alone provides torque to drive the vehicle. In the time period around 200-300s, the vehicle speed is high and the required power is large, satisfying the dual-motor joint drive working mode. At this time, both motors MG2 and MG3 simultaneously provide driving torque. During vehicle operation, the power battery SOC changes continuously. During braking, energy is recovered, which meets the conditions in pure electric mode.

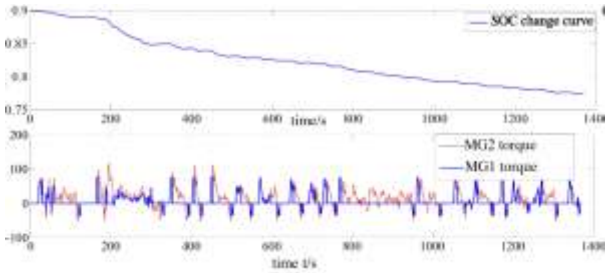

Figure. 3 Component operating state diagram in pure electric mode

Meanwhile, to verify the superiority of this configuration of PHEV over conventional hybrid electric vehicles with a single motor configuration, the operating point state diagram of the two motors in pure electric mode is shown below.

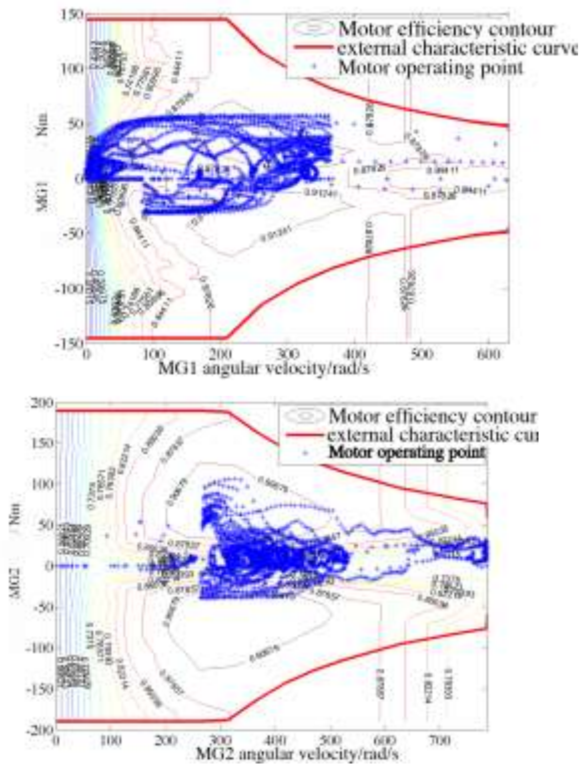

Figure. 4 Motor operating point state diagram

From the state diagram of the motor operating points in Figure 4 above, it can be seen that the operating points of Motor MG1 are mostly in the low-speed region, while those of Motor MG2 are mostly in the medium-speed region. This confirms the effectiveness of the collaborative operation of the two motors. When facing different types of operating conditions, the two motors can effectively avoid power redundancy in single large motor configurations. At low speeds and low power demand, Motor MG1 operates in a single drive mode. As the vehicle speed increases and the power demand rises, it gradually transitions to being driven by Motor MG2. At the same time, when facing high-speed driving requirements, the two motors are jointly driven, effectively avoiding the low efficiency of single motor high-speed driving. Therefore, in this configuration, the operating points of the motors mostly operate in the higher efficiency region, effectively improving fuel economy and verifying the superiority of the proposed configuration.

5. CONCLUSION

Based on the aforementioned simulation analysis, it can be observed that under UDDS driving conditions, the power components are capable of switching between the working modes formulated by the control strategy at any time. Therefore, the dual-axis coupled PHEV power system designed in this study meets the design requirements. This configuration avoids the issues of single mode and low efficiency present in traditional single-motor hybrid vehicles. The proposed dual-motor configuration, utilizing two motors of different sizes, enables the vehicle to operate as efficiently as possible under various driving conditions, reducing power redundancy. A rule-based energy management strategy was established using MATLAB\Simulink, achieving reasonable mode transitions and effectively enhancing the overall vehicle economy, which holds significant research value.

6. REFERENCES

[1] HE H W, MENG X F, WANG Y, et al. Deep reinforcement learning based energy management strategies for electrified vehicles: Recent advances and perspectives[J]. Renewable and Sustainable Energy Reviews, 2024, 192: 114248.

[2] HUANG Y, WANG H, KHAJEPOUR A, et al. Model predictive control power management strategies for hevs: A review[J]. Journal of Power Sources, 2017, 341: 91-106.

[3] ZHANG F Q, HU X S, LANGARI R, et al. Energy management strategies of connected HEVs and PHEVs: Recent progress and outlook[J]. Progress in Energy and Combustion Science, 2019, 73: 235-256.

[4] LI J W, LIU J, YANG Q Q, et al. Reinforcement learning based energy management for fuel cell hybrid electric vehicles: a comprehensive review on decision process reformulation and strategy implementation[J]. Renewable and Sustainable Energy Reviews, 2025, 213: 115450.

[5] ZHAO Y, CAI Y, SONG Q. Energy control of plug-in hybrid electric vehicles using model predictive control with route preview [J]. IEEE/CAA Journal of Automatica Sinica, 2021, 8(12): 1948–1955.

[6] TRAN D D, VAFAEIPOUR M, EL BAGHDADI M, et al. Thorough state-of-the-art analysis of electric and hybrid vehicle powertrains: topologies and integrated energy management strategies [J]. Renewable and Sustainable Energy Reviews, 2020, 119: 109596.

[7] SHEN P, ZHAO Z, GUO Q, et al. Development of economic velocity planning algorithm for plug-in hybrid electric vehicle [J]. IEEE Transactions on Intelligent Transportation Systems, 2022, 23(6): 5501-5513.

[8] LUO D, JI W, HU X. Parameter optimization and control strategy of hybrid electric vehicle transmission system based on improved GA algorithm [J]. Processes, 2023, 11(5): 1554.