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Analysing Powertrain Control Strategies on NVH Optimization of PHEV

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ABSTRACT

The paper reviews the parallel hybrid electric vehicles, a more environmentally conscience alternative to the internal combustion engine. Automobile manufacturers are combining internal combustion engine with electric motor which makes hybrid electric vehicle (HEV). More specifically, the parallel powertrain is one of the effective and efficient configurations for HEV. The structure of parallel powertrain and main parts in it are shown by a graph. Then the issue with vibration is addressed and reasons of why they occur is explained. Two control strategies are introduced to improve the problem of vibration in parallel hybrid vehicle (PHEV). First being the Nonlinear feedforward-feedback control strategy (NFFCS), the specific law of control is mentioned, and all five phases of drive mode changing are listed. Its advantages and some drawbacks are reviewed. The Second being, a novel dual-loop control strategy (DLCS) which is also based on the five phase of mode change. The characteristics of both control strategies are assessed, and the conclusion was reached that there are both pros and cons for the two control strategies under different circumstances.

Keywords: *PHEV, NVH, NFFCS, DLCS*

1. INTRODUCTION

Ever since the discovery of the idea, scientists have made great efforts to control and minimize the effect of global warming, which was caused by the ignition of minerals such as fossil fuels and coal in the 18th century [1] [2]. One of the substantial components that contributed to global warming is the automotive industry. Although automotive manufacturers have made great efforts to minimize emissions of their vehicles, introducing technologies such as fuel injectors, catalytic converters, the general public was still not satisfied. Along with the problem of global warming, there's also problems such as insufficient gas mileage, minimized performance.

This is why the automotive industry came up with a new hybrid powertrain, which utilizes power output from the internal combustion engine and the electric motor. The brand-new powertrain solved problems like insufficient gas mileage, and reduced performance. And most importantly due to the utilization of different power output methods that led to the more efficient application of fossil fuel, the all-new powertrain massively reduced carbon emission relative to the internal combustion engine [3]. Hybrid electric vehicles are significantly different from traditional automobile in the way that they are powered. While traditional automobile has a single power source of internal combustion engine (ICE), HEV however, has another power source of electric motor apart from ICE. This difference determines that powertrain configuration is vital to the design of HEV.

However, the problems of noise vibration and harshness (NVH) are challenging the performance of HEV [4]. When HEV runs at different speed, it automatically changes the driving model: drove by motor only, hybrid (motor and engine), and engine drive only [5]. The drive model transition would create NVH because of the mismatch of the torque in the powertrain system [6] [7], and the start-stop process of engine [8]. The drive comfort is valued by both passengers and drivers [6]. In these years, considering the global emphasis on the carbon emission, the demand of hybrid vehicle is expanding [9], Many researchers and automobile industries have paid much effort to boost the performance of NVH to increase the drive comfort.

Yechen and Xiaolin investigate the NVH conditions of different components of powertrain and provides specific optimal strategy for each component [4]. Mallick states a solution that investigate proper light materials and minimize the mechanical conponents to reduce the NVH [10].

Currently there are three popular kinds of system configuration: series, parallel and power-split [4]. A parallel configuration allows the ICE and the electric motor drive the vehicle simultaneously since they are connected to the same output shaft.The mechanical structure determines that the vehicle is capable to have a higher efficiency that traditional vehicle. In 1997 TOYOTA launched Prius which used the parallel configuration of power spiting, soon it is proved by the market that this is a successful solution to the problem of HEV powertrain design. Parallel configuration has been a mature and popular powertrain layout for HEV [5], thus, parallel configuration will be the focus of this article. In terms of NVH, the control system optimization is proposed as an efficient NVH solution. The feedforward or feedback control could track the operation condition of different component and fine-turned the The energy convention controlling on the powertrain is the most significant point on HEV design [11]. Besides, the components (clutch, planetary gear, shift) in powertrain would be coordinated perfectly by control strategy [12]. Sungwha and Woulsun develop a mode shift mode algorithem for power split HEV to reduce the torque [13].

This article provides a comprehensive review of control strategy solution for parallel HEV. The main analysis filed is related to the powertrain vibration optimization. Layout of PHEV and reasons of NVH are published. In addition, two specific control designs are introduced and explained. The results will be compared and discussed to find the appropriate method. Finally, the direction for further improvement of parallel structure Powertrain in the future will be listed.

2. DISCUSSION

2.1. Parallel hybrid electric vehicle (PHEV)

The transmission system in PHEV is driven by both engine power output and electric power output in parallel as shown in Figure 1. In different situations different control strategy is used seeking for higher efficiency and less emission. In table 1: Speed and torque vehicle needed also the state of charge is considered, based on these, different power resource is chosen of Electric Vehicle Mode (EV), Conventional Vehicle Mode (CV), Hybrid Vehicle Mode (HY) and Engine Recharged Mode (ER).

Table 1: Four main driving models of PHEV and its different

	Power Resources		Situation		
	Electrical Motor	Internal Combustion Engine	Speed	Torque	State Of Charge
EV	√		Low	Low	Good
CV		√	High	High	Bad
HV	√	√	High	High	Good
ER		√	Low	Low	Bad

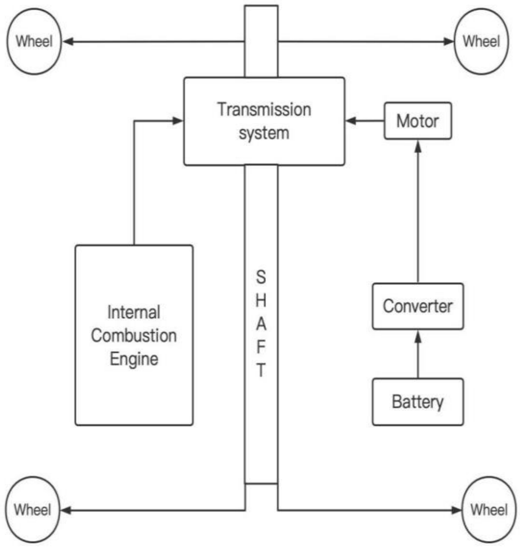


Figure 1: General structure of PHEV

2.2. The problem of vibration and reasons

Due to the nature and the main selling points of the hybrid vehicle (HV), what once was the main driving force now plays a less dominant role in producing power. And with that being said, the modification of the traditional ICE powertrain brings about new complications, a significant of the bunch would be the problem regarding vibration. Which is attributable to the electric motor in a HV powertrain, the engine does not necessarily have to be running for the vehicle to move. This concept might seem flawless on paper, but in reality, what was never taken into consideration in an ICE powertrain was the vibration occurring during the start and stop of the ICE, since traditionally, vibration was just a unavoidable phenomenon that is directly linked with starting/stopping or operating a motor vehicle, and was seen as a necessary evil that never bothered the population. But, with the new HV powertrain, the electric motor operates with significantly less vibration than an ICE, and with the constant starting and stopping of the ICE, the two operations that produce the most vibration repeat indefinitely during the operation of a HV, the significant contrast magnified the problem of vibration and posed as a notable difficulty [14].

2.3. Control strategies

2.3.1. Nonlinear feedforward-feedback control strategy (NFFCS)

In order to achieve smooth and efficient mode transition, one of the popular control principles is the powertrain torque coordination, and speed synchronization is the extension advanced ideal of torque-based strategy [15]. Xiangyang, and Yinghua have analysis the model transmission of the parallel configuration during acceleration [16]. It proves a multi-phase control strategy to deal with the engine start. A nonlinear feedforward-feedback controller based on differential flatness and PID algorithm is developed to track the engine status and the adjust the position of clutch. Figure 2 displays the Matlab-Simulink multi-domain modeling of nonlinear controller. When the clutch torque capacity is bigger than the transmission torque and the different speed between the two sides of clutch is lower than a reference value, the clutch would be lockup to keep the speed and torque transmission. On the contrary, the clutch would slip and release. This strategy controls the clutch pressure by providing a reference trajectory of engine speed so that the time consumption would be less.

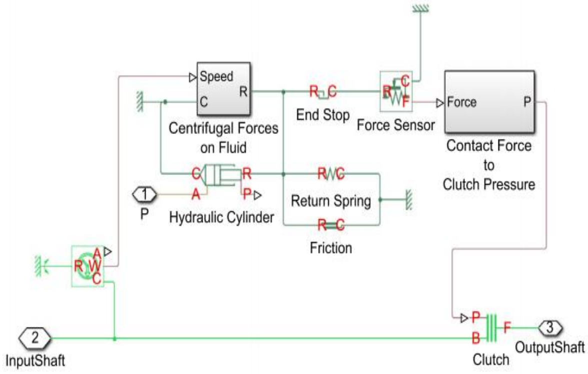


Figure 2: General layout of control units [16]

In the analysis, the transmission occurs in the acceleration status, which in the motor drive model to engine drive model There are five phases involved in the control strategy in Figure 3. In the phase 1, the clutch pressure would be first fast filling when the vehicle hybrid control unit (HCU) decides to start the engine which could help the clutch response rapidly. In the phase 2, the clutch engaged, and the ICE is driven by the motor through the connection of clutch. In the phase 3, when the ICE speed is about the reach the motor speed. The ICE would be ignited. The clutch would be disconnected to avoid the vibration transfer through the powertrain. In the phase 4, the ICE is ignited and the coordinate the speed with the motor. In the phase 5, the clutch is engaged, ICE start to drive the vehicle, the motor torque decreases to compensate the additional torque from ICE. The ICE gradually takes the lead. The vehicle acceleration process has stable vibration condition which the engine is starting. As a result, the simulation proves that the control strategy could meet the requirement of driving comfort at the engine start.

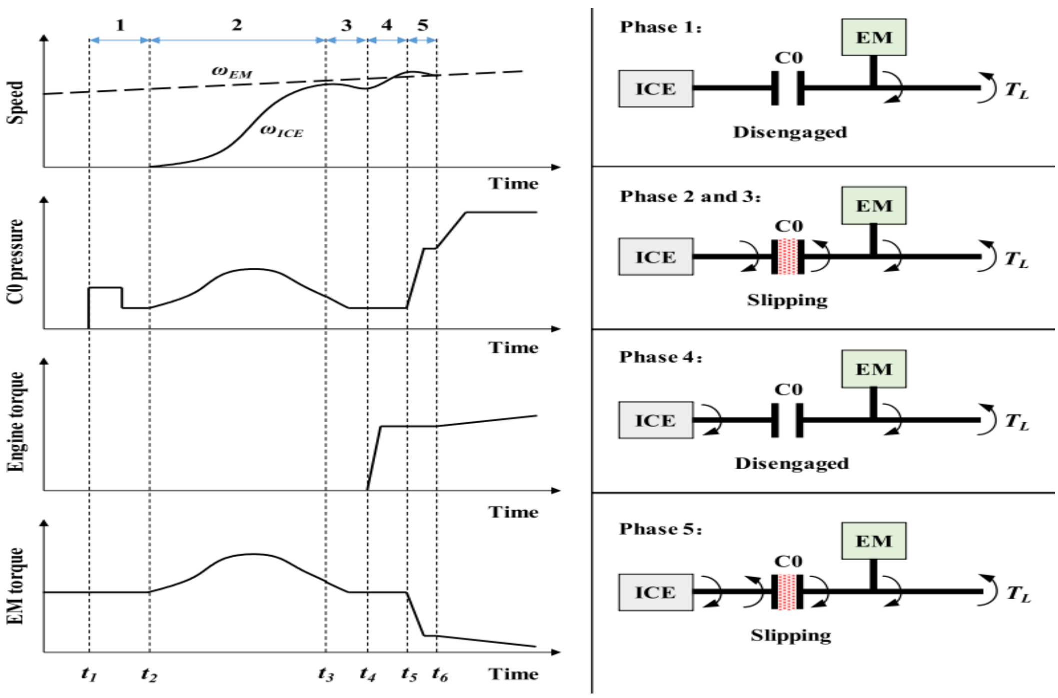
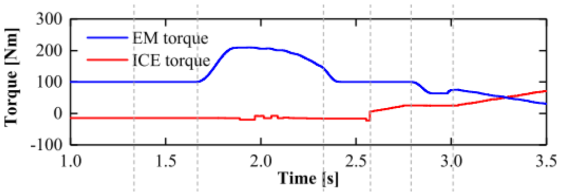


Figure 3: the control step and logic of strategy [16]

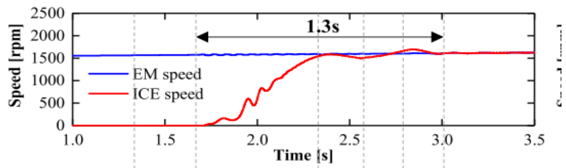
2.3.2. A novel dual-loop control strategy (DLCS)

Yang and Shi proposed a novel dual-loop control strategy to improve the vibration in phase three and four where the clutch engagement occurs [17]. These two phases is crucial to the driving comfort of the HEV. The new adaptive dual-loop control framework consists of a outer loop and an inner loop. These two loops are isolated from the coordinated control with engine and EM. For the outer loop, as the speed and transfer are already known, two ways are proposed in designing its control law. The first is optimal method and the second is practical method. The optimal method faces problems in actual use, so practical method is taken. This method achieves fast and smooth clutch engagement by balancing between jerk and slipping power. The inner loop design aim to realize trajectory tracking. In later experimental validation the parameters used by outer loop is carefully selected, and the inner loop is compared with a traditional PID controller for clutch actuator. The result suggest that this adaptive dual-loop control strategy is able to realize smooth drive mode transition for a parallel HEV. Also, vibration can be reduced by using control parameter of the outer loop [17].

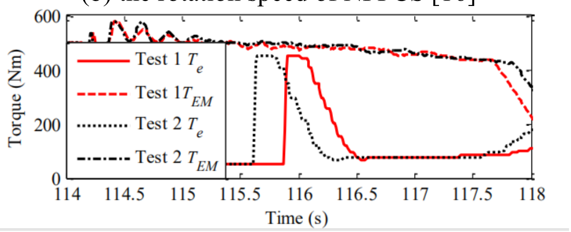
2.3.3. Comparision of these two control strategy



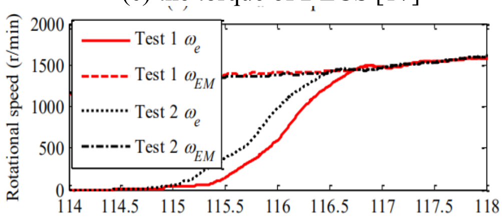
(a) the torque of NFFCS [16]



(b) the rotation speed of NFFCS [16]



(c) the torque of DLCS [17]



(d) the rotation speed of DLCS [17]

Figure 4: the torque against time diagram.

Based on Figure 4, there is 0-200 torque for (a) and about 80-500 torque range for (c). Besides, (b) and (d) compare the time consumption of model transmission, which is 1.3 seconds for (b) and 2.5 seconds for (d). As a result, the the nonlinear feedforard-feedback control strategy shows the better torque stablility and time consume towards the dual-loop control strategy, and the NFFCS performs better drive comfort and smooth transmission. However, considering the complexities of real-life driving, such as tolerances of transmission, changing of friction and pressure, the NFFCS could only operate with a fixed and designed reference trajectory. In the research of dual-loop control strategy, adaptation is one of the key aspects of it. Gear backlash that varies according to time and operation environment change are taken into consideration in DLCS [17]. An adaptive controller with uncertain parameters is designed by using backstepping method. The result was that the clutch actuator system can function without converging adaptive estimations into actual values. Comparing with NFFCS, which is not able to function well with time-varying factors, the dual-loop control strategy has advantage in adaptation. As a result, although the NFFCS have good driving perfomance, the trajectory is fixed. The control precision would be highly affected by the transmission tolerance, friction, and wear which are main problems caused by prolonged use of vehicle. On the contrary, the DLCS has the capacity of tracking error use to adapte the tolerance and other problems. The self-adaptive gets wider application area and occupies the better perspective in the future. More investigate could be processed to increase the transmission performance and time consumption of DLCS.

3. CONCLUSION

In this study, the NVH control strategy optimization of PHEV is focused. Four typical driving models and the configuration layout of PHEV are shown to introduce the fundamental information. Next, the NVH problems have been estimated, engine start/stop is regarded as one of the main causes of NVH. Then, two control strategies are listed and explained to compare the advantages and disadvantage. There is no the better one between these two strategies. Both strategies show advantage under different circumstances. NFFCS shows better stability and time consumption at model transmission, but DLCS with an adaptive controller which has more driving flexibility at various circumstances. The development of DLCS allows the vehicle maintain high precision control ability after a long period of use. More investigation about the DLCS control strategy could be processed to reduce the time consumption during transmission.

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