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A review of methods to improve power transmission for energy efficiency of both electric and hybrid vehicle

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Abstract. In recent years, many optimization methods have been raised to deal with the fuel and cost efficiency problems of the new generation cars. This study reviews two primary optimization methods, one for pure electric cars and one for hybrid vehicles, with detailed explanations. For electric vehicles, methods for designing electric powertrains that are energy efficient while sustaining vehicle dynamics and ride quality are discussed. The three characteristics of energy consumption, dynamic performance, and ride comfort are optimized using modeling, and the final optimization method is determined, which can achieve a 93.5% improvement in lightweight and a 92% improvement in power transmission. Four standard powertrain transmissions are mentioned for hybrid vehicles with advantages and limitations. The most promising multimode information is selected to work with a single EM instead of the dual EMs that conventional hybrid cars contain. The simulation results of the single-EM HEV with the MMT model and its comparison test with the "THS II-LIke" vehicle, holding the same parameters except having dual EMs, show the well-performance of this method in energy loss. In the end, a more efficient engine, the Atkinson engine, for hybrid vehicles is illustrated to substitute the traditional otto cycle engine.

Keywords: power transmission, energy efficiency, electric vehicle, hybrid vehicle.

1. Introduction

The most significant problems that all the human-beings need to address immediately are the environmental crisis that threatens our health and lives, specifically, the increasing pollution and the severe climate change. Through the emissions from the combustion of fossil-derived fuels, vehicles, which create about 8,887 grams of CO_2 per gallon of gasoline, is the major contributor to global warming [1]. To cope with the serious environmental problems, vehicle manufacturers and automotive laboratories work hard to develop new energy cars. Currently, electric vehicles are considered to be the most eco-friendly models among all new energy vehicles. Therefore, optimizing and improving electric vehicles has become the primary goal nowadays. However, many complicated problems related to technology and society still hinder EVs from entirely overtaking the automotive market and being accepted by the majority. Thus, hybrid electric vehicles, the mid-products between the gas century and pure electric century are another preferred option for reducing pollution on the road in a short time.

In this context, methods of improving the powertrain of electric vehicles will be discussed to optimize motor efficiency, improve the driving range of electric cars, and maintain dynamic vehicle performance and ride comfort. One way to maximize motor efficiency is to design an innovative powertrain layout. Lei's team considers vehicle ride comfort, power performance, and energy consumption, resulting in requirements for in-wheel motor systems, which are explained by the motor torque, efficiency, and weight models. According to the corresponding torque output requirements, motor efficiency, and lightweight, a constraint energy method is raised to determine the ultimate optimal value at the vehicle level for improving vehicle performance and limiting energy consumption [2].

In addition, two powertrain optimization ways for hybrid electric vehicles will also be reviewed to aim for fuel efficiency, emission reduction, and cost-saving goals. The major components of current cars are the engines, transmissions, and the driveshaft. Considering the main difference between traditional vehicles and HEVs is the electric components inside the powertrain, this paper will focus on the electric machines of HEVs. One method to lower the cost and increase efficiency is to apply only a single electric machine to the hybrid electric vehicle rather than two electric engines [3]. Allowing the HEV to have a lower energy loss and the advantages of compactness, this method can help to realize more operations and excellent performances. Besides, a new engine is also introduced based on its thermal efficiency. A typical Otto-cycle engine contains limitations in lower compression ratio, resulting in lower thermal efficiency [4]. An Atkinson engine with an over-expansion cycle, a modified Otto cycle by expanding more burned gasses in expansion strokes, is realized by variable valve timing (VVT) technology [4]. The comparison of the thermal efficiency between the hybrid vehicles with Atkinson engines and Otto-cycle engines is provided.

This study aims to achieve the energy efficiency, emission reduction, and cost-saving goals of the new-generation cars. Many articles have previously mentioned the many solutions according to these goals. However, none of them provides optimization methods for both electric vehicles and hybrid vehicles. Instead of dealing with a specific type of car, this paper contains two primary optimization methods, including improving the overall powertrain structure and a detailed description of the components. In general, the ultimate purpose of this paper is to provide ways for automotive industries to improve the new energy vehicles, thus, making it possible for the new energy vehicles to substitute the traditional cars.

2. Hypothesis

For electric vehicles, a brand-new power system layout can increase the driving range of Evs and maintain ride comfort.

For hybrid vehicles, a single-EM HEV with multimode transmission can lower production costs and increase fuel efficiency and compactness. Besides, a new type of engine, the Atkinson engine with an over-expansion cycle, a modified otto cycle by swelling more burned gasses in expansion strokes, is realized by variable valve timing (VVT) technology.

3. Pure electric vehicle

The innovative powertrain layout mentioned by Lei's team uses the in-wheel motor as the drive system. It carries out innovative design through the compact form of the in-wheel motor. Due to the use of the in-wheel motor, the vehicle can be directly driven without introducing a transmission. When transmission components are omitted, the vehicle structure is simplified, and various complex driving methods can be realized. The unsprung weight will affect the ride comfort of the vehicle. Therefore, Lei's team wanted to maximize the comfort of passengers in the car while optimizing the efficiency of the motor. Lei's team established a model that can improve the motor's dynamic performance by using explicit constraints on multi-physics models, an integrated approach to minimize size, energy consumption, and torque constraints, and proposing new energy management strategies. Weight optimization, size, and topology optimization of permanent magnet synchronous motors (PMSM), in-wheel active motor suspension control systems with sprung mass changes, actuator failures and control input constraints, and vibration and noise issues involved in in-wheel motors developed another model that optimizes motor weight and powertrain vibration are all aimed to improve ride comfort [5-13]. Riding quality and dynamic performance significantly affect the vehicle's energy consumption. A third model can be established.

Considering how to improve the three characteristics (energy consumption, dynamic performance, and ride quality), Lei's team used a modeling approach, using the models built to obtain the optimum for each characteristic and then transforming the models constructed for the three parts—building subsystems. According to the transformation connecting each subsystem feature, these three aspects mentioned above are fully satisfied to achieve the optimum powertrain. As the conversion is done in the data of each model, the optimal powertrain obtained with this method is applicable. Using the data obtained from the subsystems, Lei's team eventually learned that motor efficiency plays a dominant role in energy consumption and that, although efficient motors are always heavier, motor weight has no significant effect on energy consumption. Lighter hub motors, however, offer better ride comfort. Lei's team, therefore, chose to optimize in three parts. The first thing was to install the ride comfort constraint to the Pareto front. Then the second thing was to delineate the high-efficiency region. Finally, choose the lightest motor in that region. The result is a remarkable 93.5% increase in lightweight and 92% in motor efficiency.

4. Hybrid vehicle

4.1. Transmission

4.1.1. Current scenario of hybrid vehicles. Architecture designs of the powertrains have a necessary impact on the development of the new-generation cars since the overall structure will affect every aspect of the hybrid vehicles, especially the fuel efficiency. In the current hybrid vehicles market, there are mainly four different powertrain configurations: series, parallel, power-split, and multi-mode [14]. Series powertrain (Fig. 1), the most straightforward configuration, only depends on a large electric motor to power the car; however, this type of powertrain configuration requires multiple energy conversions (engine power–electricity–power), causing enormous energy losses [15, 16]. A parallel powertrain (Fig. 2) makes the ICE and MG work together to generate the power, which means that the mechanical output and electrical output are linked together; unfortunately, the considerable problem of a parallel powertrain is the high risk of battery depletion [15, 14]. The power-split powertrain focuses on the planetary gear (PG) sets, also named the power split device (PSD). The downside of this configuration is that the electric path, the power flowing inside the PSD, generates high energy losses [15, 17]. Above all, the Multimode powertrain is the most promising HEV structure since it allows greater fuel efficiency, lower emission, and better performance. Multimode powertrain contains different combinations of different systems (e.g., series, parallel, and power-split) [18].

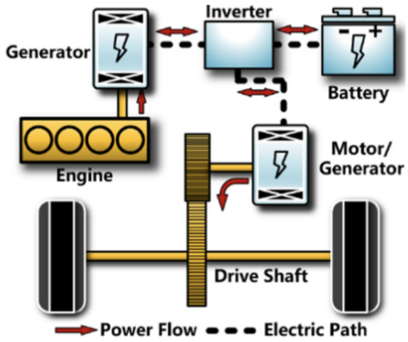

Figure 1. Configuration of series powertrain [15].

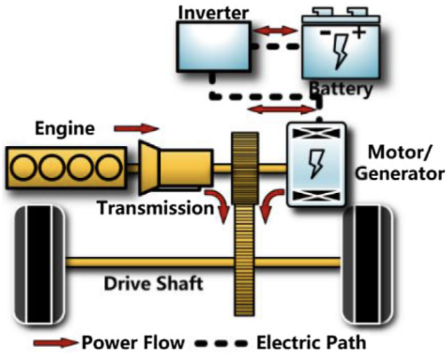

Figure 2. Configuration of parallel powertrain [15].

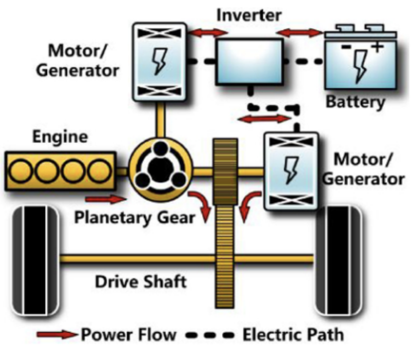

Figure 3. Configuration of power-split powertrain [15].

4.1.2. Dual EMs and single EM. Among the current automotive market of HEVs, HEVs with two electric machines (EMs) are the most popular type, e.g., Toyota Hybrid System [19]. Although the two EMs systems can provide good driving performance and enough propulsion, it still has several downsides: complicated and expensive. The newly developed single-EM HEVs solve the problems that two EMs HEVs face. With only one EM, these HEVs have the advantages of compactness, cost-competitive and fuel-efficient [3, 20]. However, unlike the two EMs systems that can work as a driving motor and the other as a generator, single-EM HEVs are confronting a significant challenge: one EM cannot work as a motor and a generator synchronously. To cope with this challenge, a matched and well-operated transmission architecture is required to work with a single EM. A single-EM HEV with a multi-mode transmission is introduced in the next section.

4.1.3. A Single-EM HEV with Multi-Mode Transmission. There are mainly two subtypes of MMT

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transmission: series-parallel and PG coupling [15]—the F. Zhu, L team. Chen and C. Yin have revised the PG coupling multimode transmission (MMT) for the single-EM HEV, applying two planetary gears (input and output), four clutches, and two power resources (the engine and the EM). The topology of this MMT is similar to the MMT of the conventional four-speed ATs since it adopts many parts of the well-refined and developed ATs. This MMT allows five basic power flow modes (i.e., Motor_only driving, Engine_only driving, Compound driving, Braking, and Charging while parking). Furthermore, with several different coalitions of clutch operations, the five power flow modes can be come up into 16 distinct operation modes (Fig.4). The single-EM functions as a motor in the first three Engine_only modes and works as a generator in the Reg_braking mode [3].

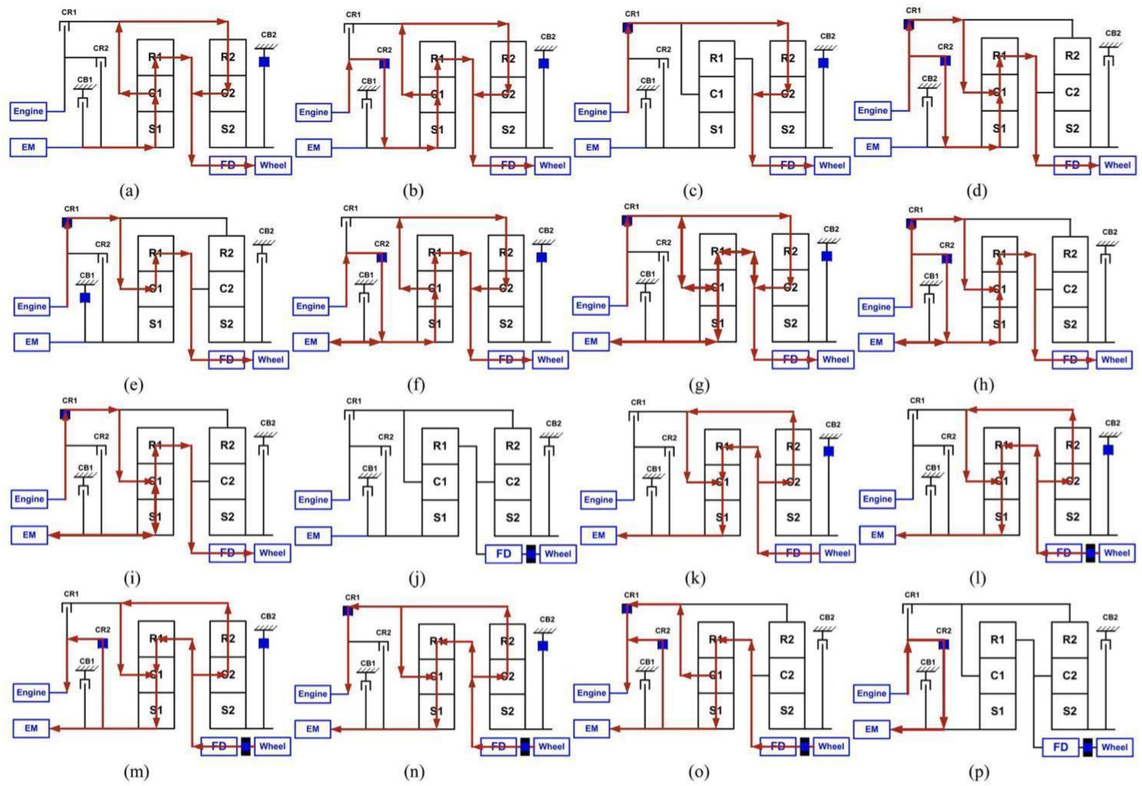

Figure 4. Power flow diagrams for operation modes of MMT. (a) Motor_only. (b) Engine_only_1. (c)Engine_only_3. (e) Engine_only_4.(f) Compound_1. (g) Compound_2. (h) Compound_3. (i) Compound_4_EVT. (j) Mech_baking. (k) Reg_Braking. (1) Compound_Braking_0. (m) Compound_Braking_1. (n) Compound_Braking_2. (o) Compound_Braking_3. (p) Charging while parking. [3]

A single-EM HEV with an MMT model is built in the MATLAB/SIMULINK environment [3]. The performance of this MMT mode is shown by its comparison with the "THS II-like" vehicle that contains the same parameters, except for the two EMs. The results prove that the single-EM HEV with MMT does improve fuel efficiency to some extent.

4.2. Engine

Aimed to improve the performance of the Atkinson cycle gasoline engine and test its energy-saving ability on different hybrid electric vehicles, Li's team utilized several advanced software (e.g., GT-Power software, MATLAB/Simulink software) and multi-objective optimization method with the non-dominated sorting genetic algorithm. The result of Li's team's study shows that the optimization method they applied did a great job of identifying the finest conditions of a vehicle and helped enhance the vehicle's overall fuel efficiency. Moreover, the combined simulation platform for both engine and vehicle can work to show the energy distribution and performance throughout the cars in the future. In conclusion, these outcomes from Li's team provide a theoretical basis and digital model for future vehicles [21].

When considering the high energy–saving and fuel economy performance of the Atkinson engine, another essential fact that needs to be concerned is the temperature of the surroundings. Akash's team concludes that the power density, which is the ratio of the power output to the maximum cycle-specific volume, indicates a significant role in affecting the performance of the cycle over the constant specific heat model [22].

5. Conclusion

To optimize electric vehicles, a multi-objective optimization method is proposed for the powertrain, which is divided into three steps and concludes that for electric vehicles equipped with hub motors, energy consumption is the primary consideration, and ride comfort can be optimized to meet vehicle performance.

The goal of the final optimum is to improve vehicle performance and energy consumption, with 93.5% lighter weight and 92% higher power transmission, respectively.

To optimize hybrid vehicles, a single EM HEV with multimode transmission containing two planetary gear sets and four clutches is proposed to increase fuel efficiency and compactness. The simulation test of the model of the single-EM HEV and its comparison with "THS II-LIke" vehicle show that the single-EM takes less running time and performs well. Thus, this proposed optimization method reduces the energy conversion loss in electric components and avoids spin loss with the help of the clutches.

To fully optimize the energy efficiency of the Atkinson engine, based on digital twins by GT-Power software, MATLAB/Simulink, and related systems, the combined simulation platform is introduced, which can be worked for evaluating and optimizing the energy distribution and performance of vehicles. In addition, the temperature should be considered because the Atkinson engine's power output is proportional to the specific heat values.

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