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Configuration synthesis of parallel hybrid transmissions

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ABSTRACT

This paper presents a systematic design approach to synthesize feasible configurations of parallel transmissions for a hybrid electric vehicle using single electric motor/generator. Based on the studies of existing parallel hybrid systems, four main types of parallel hybrid transmissions are classified and studied. The mechanisms, which were studied in present research, are two degrees of freedom compound planetary gear trains consisting of two simple planetary gear trains. By applying the proposed design approach, twelve feasible mechanisms for parallel hybrid transmissions are generated. Then, four potential mechanisms, which are used in existing designs, are employed to systematically synthesize 37 corresponding feasible parallel hybrid transmissions, including some existing parallel systems. To demonstrate the feasibility of the synthesized systems, a new parallel hybrid transmission is taken arbitrarily as a numerical example to illustrate its working principle with operation modes, and kinematics and power flow analysis.

1. Introduction

Hybrid electric vehicles (HEVs) are becoming more and more popular today, especially in developed countries where fuel consumption and emission are required to decrease. Three main types of hybrid vehicles have been developed so far, namely series, parallel, and series–parallel hybrid. The series system is suitable for heavy vehicles and shuttle vehicles running in cities since it requires the electric motor (EM) big enough to run the vehicle at different operation modes with efficient power. In addition, the system requires at least two EMs for operation. In contrast, the parallel system is appropriate to use in passenger vehicles. It comprises an engine and one or more EMs which can both provide power simultaneously to drive the vehicle by using non-conventional transmissions; therefore, the EM size is considerably reduced. The series–parallel system can both operate as series or parallel system; however, it needs at least two EMs for operating as a series system.

Toyota's first hybrid vehicle was the Prius which uses the original Toyota Hybrid System (THS) [1–3]. The THS utilizes a simple PGT as power split device and two EMs are included to control the system in different operation modes. One of the two EMs mostly works as a driving motor and the other works as a generator. However, both EMs can be switched into motor mode or generator mode, depending on system control. Many automakers and individual researchers have proposed their own hybrid systems using two EMs, such as Toyota's second and third generations of THS [4,5], GM-two modes [6,7], Timken EVT [8], and Chen's transmission [9].

Besides series–parallel HEVs using two EMs, a variety of hybrid transmissions using only one EM have been developed [10–21]. The systems therefore have the advantages of lower cost, lower power loss, and more compactness over the systems using two EMs. However, since an EM cannot work as a motor and a generator simultaneously, the system cannot perform series mode. And power flow control is still a big challenge that might lead to limitation of the systems. Fig. 1(a)–(d) show

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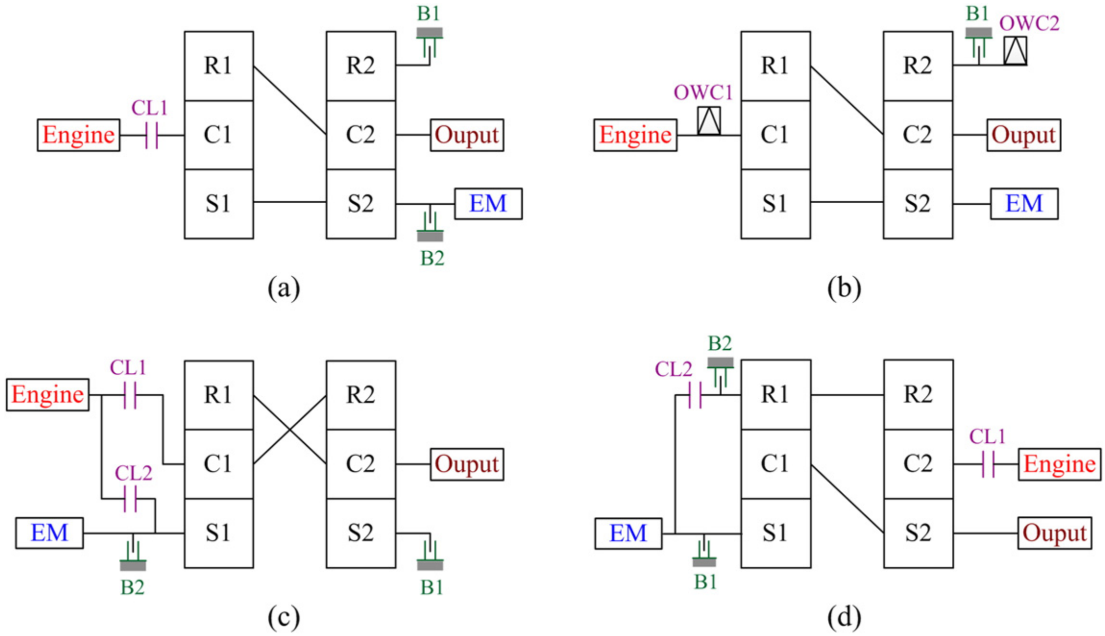

Fig. 1. Schematic diagrams of parallel hybrid transmissions developed by. (a) Tsai [15], (b) Esmail [18], (c) Zhu [21], and (d) Chachra [17].

the kinematic diagrams of four existing parallel hybrid transmissions. Clutches (CLs) or one way clutches (OWCs) [18] and brakes (Bs) are employed to control the systems' operation modes.

Many hybrid transmissions have been developed and analyzed based on traditional automatic transmissions [9,13,21] leading to limitation of new configurations. Liu et al. proposed a systematic design approach for two planetary gear split HEV [22]. However, system dynamic models need to be constructed in advanced. Then a screening process was carried out to search for feasible configurations from all possible systems leading to high computational load. Some systematic analysis methodologies were proposed for searching suitable configurations from a variety of possible configurations [23–25].

This paper presents a systematic design approach to synthesize parallel hybrid transmissions using single EM. The mechanisms used for the transmission systems are 2-DoF compound PGTs, which contains two simple PGTs connected by two common members. Twelve feasible mechanisms for parallel hybrid transmissions are generated based on Yan's creative mechanism design methodology [26,27]. Since there are too many mechanisms to be all shown here, four potential mechanisms, which are used in existing designs, are selected for next synthesizing process. Then power and clutch arrangement techniques are developed for synthesizing parallel hybrid transmissions. Since 432 configurations using the compound PGTs can be listed [23], the design approach decreases the required computational load and minimizes the number of clutches and brakes added to each system. Finally, a new configuration is arbitrarily taken as a numerical example to illustrate the system working principle with operation modes and kinematics and power flow analysis.

2. Analysis of parallel hybrid transmissions

A hybrid transmission can be analyzed by separating the system into mechanical structure and operation control. The mechanical structure is characterized by topological characteristics of the mechanism which is employed in the system, while operation control is characterized by the system operation modes.

2.1. Topological characteristics

Based on a study of available existing parallel hybrid transmissions, the characteristics of PGTs for parallel hybrid transmission systems are:

1. Two degrees of freedom (2-DoF) compound PGT that consists of two simple PGTs.
2. Seven members, consisting of one ground link (member 1), one carrier (member 2), two planet gears (member 3 and 6), one sun gear (member 4), one ring gear (member 5), and a seventh member (member 7). The seventh member can be a ring gear, sun gear or carrier of the second simple PGT.
3. Ten joints, namely four gear joints (J_G) and six revolute joints (J_R).
4. Four separated members adjacent to the ground link (gear box), with at least one member connected to the engine, one connected to the motor, and one connected to the output shaft.
5. All gears are spur gears.