CRIMSON PUBLISHERS
Wings to the Research

Evolutions in Mechanical Engineering

ISSN: 2640-9690

Mini Review

Analysis of Hybrid Power Train System Based on Degree of Freedom

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Submission: July 18, 2018; **Published:** July 31, 2018

Abstract

The hybrid power train is one of the most important technologies that have been developed to satisfy the challenging fuel economy and emission standards. A suitable configuration of hybrid power train should not only meet the requirements of vehicle kinematics and dynamics, but also meet the requirement of fuel economy and emission. For this purpose, a hybrid power train system should contain multiple power sources so that the speed and torque of the power sources can be properly distributed to achieve high system efficiency. To achieve optimal distribution of speed and torque, the system should have more speed DOF and torque DOF. Therefore, the hybrid power train system can be analyzed based on the viewpoint of degrees of freedom.

Keywords: Configuration; Hybrid; Degree of freedom

Introduction

With the increase of environmental and economic interests, improving fuel economy of vehicles has becomes an important topic in recent years. One of the most promising technologies to satisfy these fuel economy or emission is the hybrid vehicle (HV) technologies, various architectures for hybrid power train have be studied, and some showing merit in cost and efficiency have been selected. Therefore, the studies for hybrid vehicle (HV) have attracted considerable attention. A hybrid vehicle adds an additional power source (e.g. battery, etc.) and one or multiple actuators (e.g. electric machines) to the conventional power-train. The additional power devices help to improve system efficiency and fuel economy by engine right-sizing, load leveling.

In general, typical engines operate at their peak efficiency only in a small speed and torque range. Hybrid vehicle has multiple power sources that allow for flexible vehicle power-train operations, so it is possible to fully realize the potential of the power train and achieve better fuel economy and efficiency. In order to achieve this goal, the output speed or torque should not be uniquely determined by the engine so that the engine can operate in a high efficiency range. For example, the load leveling of hybrid electric vehicle can be achieved by adding the electrical path, which enables the engine to operate more efficiently, and independent from the road load. The key to achieve this goal is that the engine is decoupled from the vehicle speeds and can operate efficiently. To achieve this purpose, the engine and the motor should be independent in their speed, which implies that the speed degree of freedom should at least be equal to 2.

The study of possible HV configurations is of interest both industry and academia [1-4]. For example, Ford and Nissan are licensing the THS technology from Toyota while Chrysler and BMW are licensing the GM dual-mode technology. Hybrid vehicle have different configurations with different numbers of operating modes; for example, the Prius has no clutch and has a single operating mode, whereas the Chevy Volt uses three clutches and has four modes. To achieve these operating modes, these systems have different speed DOF and torque DOF.

Degree of Freedom of the Hybrid System

The hybrid power train system is a multi-input and multi-output system and can be a system including inputs, outputs and a function of transmit. The (operating) degree of freedom of a system is defined as the number of independently and arbitrarily presentable parameters or states for a definite operating condition. According to Mueller the operating DOF equals the sum of its kinematic DOF and static DOF. For hybrid vehicle, presentable speeds and torques exist. In this paper, f_ω and f_T are used to denote the speed DOF and torque DOF, respectively. For a reasonable configuration of hybrid power train system, the configurations need to have a reasonably mode so that the vehicle operates at different speed. From the viewpoint of degree of freedom, to achieve the function to regulation the output speed and torque, the system should have at least speed

DOF 2 and torque DOF 2. The following are two configurations of hybrid power train system (Figure 1a).

Figure 1b shows AHS-2 hybrid system, and the system has two modes. The first mode is obtained by engaging the brake Z. In this mode, the output speed is determined by the engine and the Motor A, and the output torque is determined by the engine and the Motor B. The second mode is obtained by engaging the clutch C. In this mode, the output speed and torque are determined by the engine and the two motors. In this mode, the speed and torque distribution of the two motors are more flexible and can achieve better system efficiency. For these two modes, both the speed DOF and torque DOF of the system are 2.

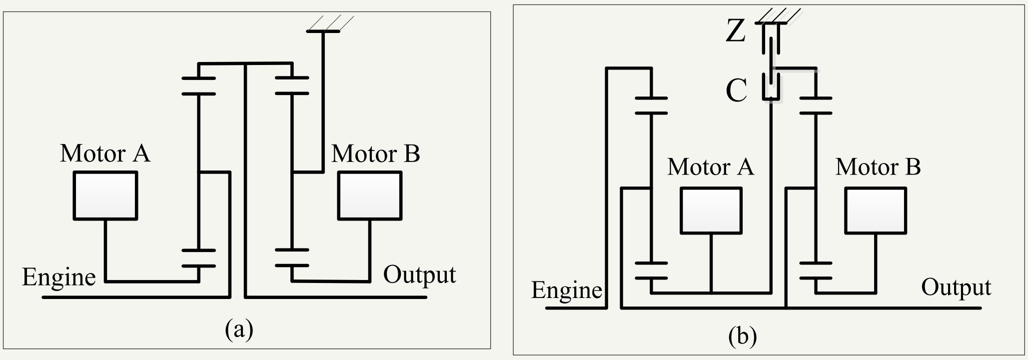

Figure1: Two configurations of hybrid power train system. (a)Toyota hybrid system; (b) AHS-2hybrid system

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How to cite this article: Kun Z, Mingfei G. Analysis of Hybrid Power Train System Based on Degree of Freedom. Evolutions Mech Eng . 1(1). EME.000504.2018. DOI: 10.31031/EME.2018.01.000504