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Optimization of Power Management Strategy for Parallel Air-Fuel Hybrid System

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Abstract

Air Engines (AE) are commonly designed to work in combination with internal combustion engines (ICE) due to low energy density. The emission of heat from ICE boosts the efficiency of Air Engines, whereas the high-pressure gas from AE serves as a form of turbo charging for ICE, increasing its efficiency. Unlike batteries, the air tank that AE requires is not limited by certain restrictions in order to prolong its lifetime, therefore, the Air Hybrid System is believed to have great potential. There has already been quite some research on power management strategy of electric hybrid systems, however, little is done on Air hybrid systems. A numerical models of Air Hybrid Systems is established using MATLAB in this study, the characteristics of the model, such as the efficiency map and driving cycles are further analyzed to obtain the optimal energy management strategy for Air Hybrid Systems. These findings are expected to help the realization of physical models and the establishment of controller design. Through genetic algorithms, the optimal system structures, operation modes and power management strategies are found to ensure that both engines are operating within the most efficient range. Simulation results suggest that the efficiency of the Air Hybrid System is 26.13% higher comparing to a lone Air Engine.

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Keywords: Genetic algorithm, Air Engine, Hybrid System, Optimization, Power Management Strategy, Numerical Simulation

1. Introduction

The maximum efficiency of the internal combustion engine is 30~40%, the excess energy dissipates in the form of waste heat. As automobiles accelerate and decelerate quite frequently in cities, a huge amount of energy is depleted, and the efficiency of energy usage go as low as 15%. In recent years, researchers have proposed a concept where high pressure air is used as the power source of vehicles. Air tanks take little time to refill, has low cost and almost never breaks down when overloaded, leading to a longer

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lifespan. However, the energy density of high pressured air is relatively lower comparing to other energy sources [1, 2], which results in a short cruising range. Therefore, it is best to couple high pressure air with other power sources in order to achieve the best performance. Air engines (AE) work most efficient in low rotating speeds [3, 4, 5], by coupling it with internal combustion engines (ICE), which works best at high rotating speeds, we can obtain a hybrid system optimal for a wider working range. Additionally, air engines can regenerate the braking energy [6, 7], and work as idle start. Moreover, recycling the waste heat from ICE can enhance the air engines output power [8, 9]. By supplying additional high pressured air into ICE, a turbo charging effect occurs and therefore improves the efficiency of the ICE. By heating the AE using wasted heat from ICE, we can also boost the efficiency of AE [10].

Similar to Electric Hybrid Engines, the best configuration of two energy sources and coupling perfectly the output power of two sources must be put into consideration to achieve best efficiency [11]. Since the hybrid system is able to operate in various modes [12, 14], a power managing system which controls the usage of both power sources is of great importance [15]. The characteristics of the Piston-type air engine were analyzed in this research, a power management method is also proposed and is expected to help the design of controllers in the future.

2. Method

In the present research, a configuration of an Air Hybrid engine is made in order to determine possible working modes. A simulation on Piston-type air engine is carried out using MATLAB in order to study the efficiency map of the Air Hybrid engine, this simulated result is then compared to experimental results. The ECE-40 Driving Cycle is applied to simulate the performance of the Air Hybrid engine on automobiles. All variables were taken into consideration using genetic algorithm at first to achieve an approximate power managing method on Air Hybrid engines, then variables were singled out one at a time in order to optimize and finalize the proposed power managing method. Lastly, the efficiency of the Air Hybrid engine applying the proposed power managing method is compared to pure ICE and AE respectively.

2.1. System configuration

This paper select parallel hybrid powertrain as the system to discuss. Referring Zhang's configuration [1], the relation between clutches and operating modes is concerned. From table 1. , '1' means that the clutch is closed, and '0' means that the clutch is open. There are eight possible states for controlling clutches, but only four states are feasible. The mode 1, 5, 6, and 7 are locked by the ground, and the output shaft can not be rotated. Mode 2 is a pure air engine mode (AE). In this mode, only air engine can drive the powertrain. However, while the power flow is passed through from wheels to the air engine, this mode can be operated as regenerative braking (RB). Mode 3 is a pure internal combustion engine mode (ICE). Mode 4 is a power split mode (PS). The two engines are all connected to the powertrain, both as the power sources to drive the vehicle. But this mode can perform as cruise recharging mode (CR) when the power generated by ICE exceeds the loading from wheels. The spare energy can charge the air tank. Mode 8 is idle start mode (IS). The ICE only connects to the air engine, and then the air engine can replace the traditional starting motor to drive the ICE. This mode will not be discussed in this paper. Moreover, when the ICE is charged with high pressured air, it is super charge mode (SC). And if the ICE