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Control strategy analysis of the hydraulic hybrid excavator

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Abstract

Applying the electric hybrid technique on the off-road vehicle is one popular method to reduce the fuel consumption. However, the high cost, low energy conversion efficiency and disposal of used batteries are still the main problems. This paper is focusing on one alternative choice which is hydraulic hybrid off-road vehicles. Among the most typical off-road vehicles, the excavator is chosen as the prototype to study the control strategy. First, the basic principle of the hydraulic hybrid excavator based on Common Pressure Rail is introduced. Then, the mathematical model of the whole excavator is created. Moreover, the dynamic programming algorithm is used to solve the optimal control variable trajectory under a given circle. Finally, the adjustable single point under quasi constant pressure strategy is presented. The simulation result shows that the proposed strategy can reduce the fuel consumption clearly without deteriorating the performance.

1. Introduction

In recent years, the electric hybrid vehicles are making a big progress and there are already many mature products which can reduce the fuel consumption and be environmentally friendly [1,2]. Moreover, the electric hybrid technique has been implemented in the off-road vehicles which have the lower efficiency and worse pollution, especially due to the increasing energy crisis and environmental deterioration recently [3]. In the electric hybrid system, normally, the

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Electric Motor/Generator (EMG) is adopted to drive the load, hence the braking energy can be recovered when the EMG is working on the generator mode, and the battery or capacitance is chosen to store the recovery energy.

In 2003, Hitachi launches the first electric hybrid wheel loader whose architecture is shown in Fig. 1 [4]. Actually it can be called a parallel-serial system. The engine drives the pump and the EMG through a gear box and a serial structure, as the subsystem, for driving the wheels. Hence the traveling braking energy can be recovered and reused to alleviate the engine load. The fuel consumption can be saved 30% by comparing with the traditional type.

Later, Kobelco introduced another series of the hybrid excavator which is using engine to drive the generator and supply four subsystems [5]. In this structure, there are one pump and one electric motor in each subsystem to control the hydraulic cylinders, moreover, the swing is driving by a EMG. The hybrid excavator from Komatsu was presented in 2008 [6,7]. The basic principle of the cabin is similar to Kobelco. Furthermore, CX 2110B hybrid excavator is introduced from Case cooperated with Sumitomo, then Volvo also shows their own electric hybrid off-road vehicles [8,9]. However, there is no large-scale industrialization for all of these products. The main problems for the electric hybrid off-road vehicles are not popularly used in the market because of the different working conditions between them and the high cost of on-road ones. Moreover, it is difficult to recover the potential energy of the linear load [10]. In general, the characteristics of off-road vehicles can be included as the high power demand which is considered from both rated power and instantaneous power aspects with the cyclical working condition. Hence, the popular storage components of the electric hybrid system are batteries, whose low power densities are hard to meet the high instantaneous power requirement. Then, how to deal with the waste battery is an important problem. It means that the initial purpose to save energy by installing the battery will be discounted because of the chemical pollution of the waste battery. Moreover, the off-road vehicles are mainly based on the hydraulic system, it is difficult to modify the existing manufacturing system into an electric hybrid one. However, the most disadvantage of the electric hybrid off-road vehicle is the low efficiency resulted by the energy conversion among mechanical energy, hydraulic energy and electric energy. In summary, if there is one system possesses the high power density and is easy to modify based on the existing condition integrated with the environment friendly component, it should be an alternative technique for the electric hybrid off-road vehicle. Until now, there are already some researchers trying to use the hydraulic hybrid technique though the papers are limited. Such as Lars Bruun from Caterpiller presented a system which can recover the boom gravitational potential energy and applied on a 50 t excavator, in this setting, a 100 L hydraulic accumulator is used to store the energy [11]. Karl Pettersson investigated the architecture by using secondary controlled swing drive of excavators and presented some useful circuits for improving the structure safety [12].

Nevertheless, the excavator research above is mainly focused on one subsystem which is not an overall research design. Moreover, the research result is hard to apply on other styles of off-road

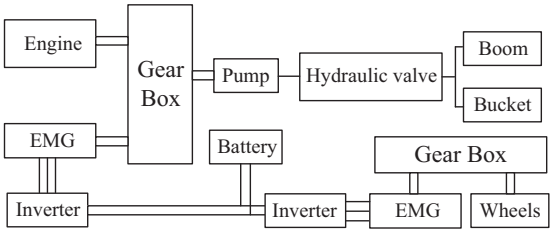

Fig. 1. The architecture of Hitachi hybrid wheel loader.

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