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The research for the auxiliary power unit APU and its work characteristics of BJD6100HEV series hybrid electric bus

***Abstract**. In this paper, the auxiliary power unit APU and its work characteristics of the BJD6100HEV Series Hybrid Electric Vehicle (SHEV) is mainly researched. Through comparing calculation, the type selection designs of auxiliary power unit APU and other key parts are determined.*

*Streszczenie. Zbadano zewnętrzny układ APU w zastosowaniu do hybrydowych samochodów elektrycznych. Zaproponowano kryteria doboru parametrów układu. (**Badania układów zasilania typu APU w zastosowaniu do samochodów hybrydowych**)*

Keywords: APU; hybrid; electric bus.
Słowa kluczowe: układy zasilania APU, samochody hybrydowe.

1. Introduction

Due to the requirements of environmental protection and the development of new materials and new technology, the electric vehicle enters into the high peak of development today again [1-2]. However， since the delayed battery technology becomes a main barrier, the popularity of traditional electric vehicle is limited, which seriously restrict the development of the electric vehicle. So the electric vehicle is unable to completely replace the fuel engine vehicle temporarily [3-5]. In this case, a kind of integrated scheme combining the advantages of internal combustion engine and electric vehicle came into being, that is the development hybrid electric vehicle (HEV). However, the research and development of hybrid electric car is still in the initial stage, and the key technology (such as battery system and transmission assembly system) is still room for improvement and innovation [6-9]. Moreover, the cost need to be further reduced and performance needs to be raised, which can meet to the technology and market demand for replacing the traditional fuel the car[10-14].

This paper mainly researches the auxiliary power unit APU and its work characteristics of the BJD6100HEV Series Hybrid Electric Vehicle (SHEV).

2. The determination of control strategy for the APU unit

The typical length of the paper should be limited to no more than 5 pages. The whole paper is written using type size 9 and Arial font with the indentation set at 5 mm. Directly after section headings (type size 9 using Arial bold), place the text in justified style. For figure captions, names of the tables and footnotes use Arial font with type size 8. When symbols need to be inserted into the text, use option "insert/symbol" (for example $\Delta\alpha$ or $\vartheta\in\infty$). Please do not use the equation editor for this purpose. The equation editor should only be used if a symbol does not exists in the symbol list – for example $\hat{H}$. Although the whole text is written using Arial font, for symbols please use the Times New Roman italic – for example J and not J (i.e. the same symbols as in the equations).

2.1 The design of SHEV control system

The control system scheme of series hybrid buses is shown in figure 1. The system is composed of four parts: vehicle controller, the battery management system, the engine generator controller and motor controller, respectively;

The vehicle controller: implementing decision of vehicle work model and outputting the control signal of subsystem controller;

The battery management system: implementing the prediction calculation of the battery charged state and outputting to the complete vehicle controller;

The controller of engine-generator set: implementing generator excitation control and the control of the throttle valve of engine according to the output signal of the vehicle controller, and outputting appropriate current according to the actual battery output voltage;

Motor controller: controlling motor and realizing vehicle driving according to the output of the control signals of vehicle controller, actual terminal voltage and the battery bus-current.

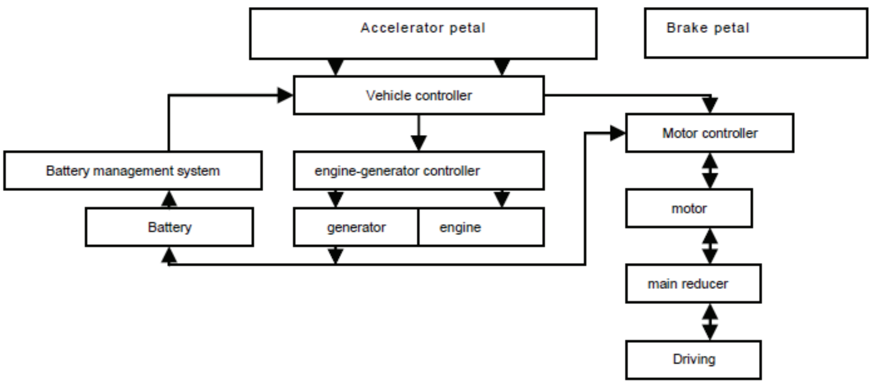


Fig. 1 The control system design for hybrid bus

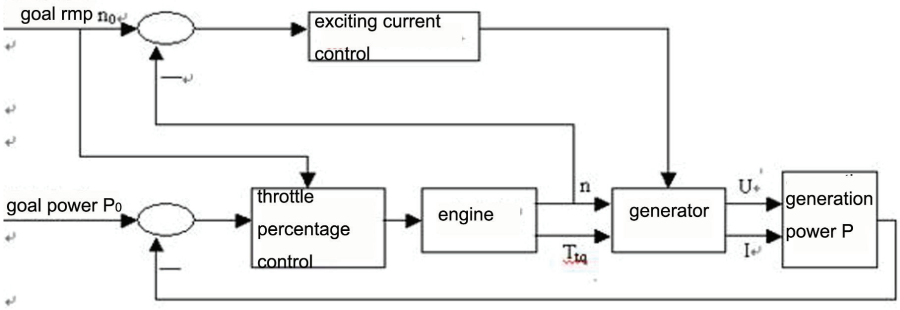


Fig. 2 The engine-generator set integrated control diagram

2.2 The specific implementation of control strategy for the engine-generator set

The engine-generator set connected the battery packs and traction motor form a whole of electromechanical system. To ensure that the engine generator can output corresponding power according to demand, the integrated control scheme is adopted for the engine-generator set (figure 2.). The engine and generator is controlled by the throttle and the excitation current respectively. The feedback quantities are output speed n and output power p of the engine. The generator output power is equal to the product of the output current I and output voltage V. The control strategy is as follows:

(1)The target power control: determining the best working point of the engine according to the target power, that is determining the output power and speed of the engine; controlling the throttle valve of engine according to the deviation feedback between the actual APU output power and target power.

(2) The speed control: By adjusting the generator excitation current, to use closed loop control and ensure the stability of the target speed.

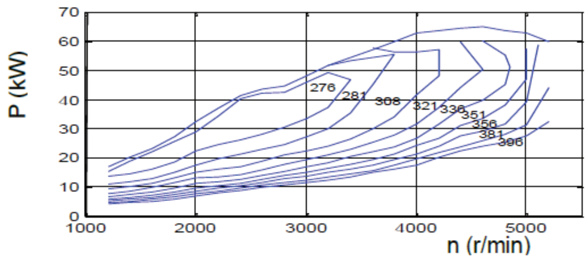


Fig.3 the CA4G22E universal characteristics graph of electronic injection gasoline engine 4G22E

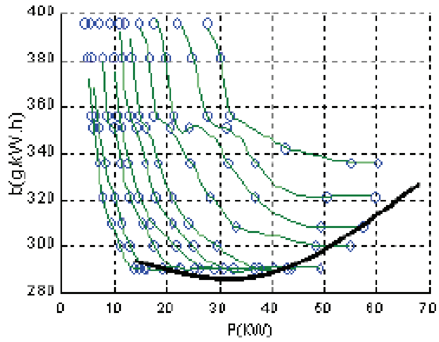
3 The working characteristics analysis for the APU unit

3.1 The working characteristics analysis for the engine

The working characteristics of a four stroke electronic injection gasoline engine 4G22E are as shown in figure 3. From the external characteristic diagram, it is known that there exists a minimum fuel consumption points corresponding to the fixed working speed of engine, which also corresponds to a fixed throttle valve. The attachment of all these points becomes the minimum specific fuel consumption curve for the engine.

All characteristics of the CA4G22E electronic injection gasoline engine are shown in figure 3. By the characteristic graph, the most economic point (speed and load) can be found out as the engine provides certain of power. The envelope curve of figure 4a is minimum fuel consumption curve for the engine with the certain power. Under the conditions of various power operations, the speeds and load rates of the most economic are labeled in the external characteristic graph, and a "minimum fuel consumption characteristic" is obtained, as seen from the labeled curve in the figure 4b.

a)



b)

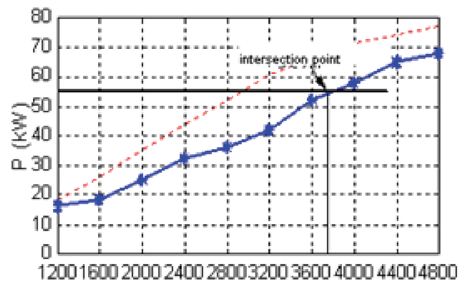


Fig. 4. Working point determined for the engine: a) The minimum specific fuel consumption curve for the engine, b) The working point of the engine

The most economic zone of the gasoline engine is in the high load working area, and usually can be observed by the measurement of the universal characteristic curve for the engine, as shown in figure 3. Using characteristics of phase separation between the engine and road surface load in series type HEV, the engine working can completely be controlled in this range.

In any city, there always exists low load road conditions for working cycle. If the work mode of HEV is only generator work and don't need batteries providing energy, it will lead to low efficiency of the engine and high fuel consumption. A feasible solution is used to switch control for generator set, and only control generator working in high load working area, that is, outputting the higher power. The switch control variable is usually the battery SOC [15-16].

However, considered from emission performance, keeping the engine in the heat engine state is always benefit to maintain the activity of the catalyst, and without cutting off the supply of oil can also prevent catalyst worse. In other words, in order to reduce emissions, the continuous work of engine should be maintained. However, this situation must exist in the low work efficiency stage for the engine, and damages fuel economy. So, consideration to the two kinds of circumstances of switch and continuous work, the engine should be guaranteed at high load economic area for long work time as much as possible, and reduces the switch frequency of engine. At the same time, the engine output power is not also too much. If the generator charges batteries because of the output power frequently meeting the load demand, the loss of energy transformation will be increased caused by the charge/discharge of battery. At the same time, due to continuous fluctuant changes of the batter SOC, the switch frequency of engine generator set would be increased, and also emissions.

According to the above analysis, it is considered that the output power of engine-generator set need corresponding to the power of vehicle by average speed to drive cycle, and the added power of the car accessories such as the consumption of the air conditioning and certain battery. According to the design goal, the battery charge power may be set especially. In order to improve fuel economy, the value can be set small to reduce losses; In order to reduce emissions, the value can be set some bigger, and ensured full of the battery as soon as possible, and realize the pure electric drive without emissions. At the same time, in order to ensure a high working efficiency of the engine-generator set, its output power should be controlled in the interval of its high efficient work at this time.

Considering that the efficiency of the generator is about 85%, 48 kW of the generator output power will be converted to 56 kW of the engine terminal output power. Seen from the Figure 4b, the horizon line of 56 kW power intersected with the minimum fuel consumption characteristic curve is at the point of speed for 3600 r/min and load rate about 85%. At this point, the CA4G22E gasoline electronic fuel injection engines can be get minimum fuel consumption. Therefore, the control strategies should try to control engine constantly working at this point of getting the minimum fuel consumption.

3. 2 Work characteristics analysis for the generator

The generator adopts adjustable brushless exciting way with an ac exciter, and the working principle is shown in figure 5.

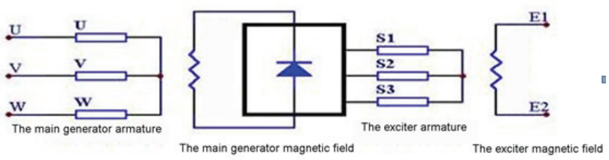


Fig. 5 The brushless exciting principle diagram

The brushless exciting way possesses these advantages such as: compact structure, convenient maintenance, and small communication interference. Due to the addition of the ac excitation with amplification functionality, the excitation capacity may be decreased greatly, and therefore smaller exciter current can be used to control excitation magnetic field.

In a resistance load, the load current increases, and the terminal voltage drops; As an inductive load, the load current increases, and the terminal voltage declines more serious; With a capacitive load, the load current increases, and terminal voltage doesn't fall and rises instead. For engine generator set of a series hybrid electric vehicle, its loads are the lead-acid battery packs and dc motor in parallel connection. The Dc motor is inductive load. For the battery, it is inductive load. However, in hybrid electric vehicle, according to the control strategy, the output current of generator set mainly flows through the dc motor, and only a small minority of residual current flows to recharge the battery. At this time, the battery can be as resistive load. Therefore, on the whole, the generator load is the inductive load. When electricity flows pass through, the terminal voltage of the generator will be led to lower. Such external characteristics are favor to keep the generating sets and the battery voltage consistent during the HEV accelerate and climbing, and make them together provide power to drive the car.

3. 3 The performance characteristics analysis for battery

The system adopts a seal lead-acid battery. As the HEV is running, the battery set will carry charge/discharge according to the requirements of the power. To improve the efficiency of battery charge/discharge, the state of charge of battery should be controlled in a certain range. The working rang of battery is determined according to the type and capacity of battery. Also a few aspects should be considered: preventing overcharge and overdischarge for battery. A Long time overcharge can cause damage to the battery; Overdischarge will influence the performance of a car, and eventually cause the battery damage for a long time.

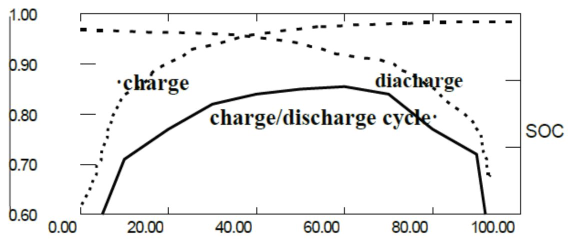


Fig.6 The relation of charge-discharge efficiency with state-of-charge of lead-acid battery

The state-of-charge of Battery is characterized by the percentage of residual capacity battery C1 occupying the total battery capacity C0. The Figure 6 shows charge-discharge and cycle efficiency graph for systems with sealing lead-acid battery through 3 h charge/discharge tests. As seen from the graph, the SOC is within 40%~ 70%, and the efficiency of lead acid batteries is above 80%. Moreover, the determination of the upper limit of battery state-of-charge must ensures that it can make a battery bear larger power of regenerative braking or the total sum of generator output and regenerative braking power in short time, and must prevent overdischarge occurring. The lower limit of battery charged state makes sure that overcharge is avoided, which affects the battery life. Therefore, the work scope for the battery charged state is eventually determined within 40% ~ 70%.

According to BJD6100 HEV, a thermostat control strategy is elaborated as below: allowing generator set running in 3600 r/min before the battery SOC is more than 70%, and outputs constant 48 kW power. Then, the generator is turn off, and the car is pure electrically drove with zero emissions. When the SOC dropped to below 40%, the generating set is start according to the constant power output again.

4. Conclusion

In this paper, the BJD6100EV electric bus is made as the research object, and the target is modified to hybrid electric bus BJD6100HEV. Through comparing calculation, and the type selection designs of auxiliary power unit APU and other key parts are determined. The results show that the engine-generator set can satisfy the demand of pavement, and emissions and fuel economy is also good and achieves expected target.

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