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The Design and Simulation Research of Mazda6 Hybrid Electric Vehicle

Abstract: *Based on power system of the designed Mazda6, this paper presents a model of hybrid electric vehicle transmission system and control system in Matlab/Simulink environment. It was described the vehicle performance simulation research in CYC_UDDS circulation conditions when the component have been selected and matched .The results have shown that the design can meet the requirement of Hybrid Electric Vehicle which provides a new way of thinking and research methods for the development of electric vehicles.*

Streszczenie. *Bazując na projekcie samochodu Mazda6 przedstawiono model hybrydowego elektrycznego układu napędowego z symulacją w środowisku Matlab/Simulink. (**Projekt i symulacja hybrydowego pojazdu elektrycznego na bazie samochodu Mazda6**)*

Keywords: Hybrid electric vehicles, Transmission, Brake energy recovery, Modeling and Simulation
Słowa kluczowe: elektryczne pojazdy hybrydowe, napęd, odzyskiwanie energii.

Introduction

The emergence and the development of Vehicle have promoted human civilization, at the same time, it is the culprit for bring the world's energy crisis and environmental pollution. To ensure the sustainable development of the automotive industry, the research and the development of new electric vehicle with clean energy become a national consensus. The major car companies in the world are competing to study electric vehicle that pollution-free emissions, as well as china [1]. However, the driving range of pure electric vehicle cannot be compared with the fuel car. Before finding the ideal vehicle power in pure electric vehicle, the hybrid electric vehicle as a new type are being developed when the development of pure electric vehicles come up with obstruction for the time being. As usual, the final evaluations about the dynamic performance and fuel economy levels of hybrid car are given after the real vehicle road test due to the road complexity. This not only need a long cycle and high cost, but also has a certain blindness in the product design stage to determine the vehicle and the assembly program, the choice of structural parameters, transmission system parameters and the matching engine, which may be miss the better design and cause wastage [2]. This paper study the vehicle fuel economy by choice of uncontrolled road test and analysis the vehicle operating conditions by simulation which will be the foundation for the next stage of experimental study.

1 Hybrid electric vehicle drive system design

The design that based on the Mazda 6 of the structure of drive system is shown in Fig 1.

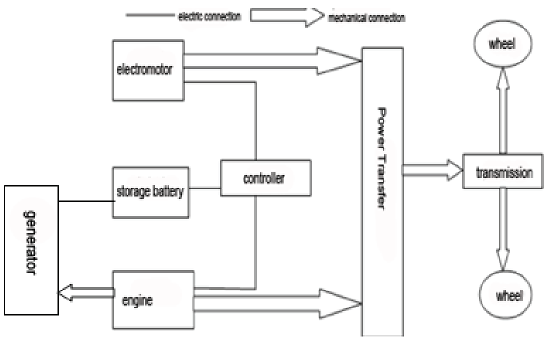

Fig.1 Hybrid vehicle drive system structure

2 Power matching of Hybrid electric vehicle power source

The power of vehicle is determined with the vehicle dynamic performance(maximum speed, acceleration, climbing capacity) [3]. The requirements for the design of the hybrid electric vehicle's power are: (1) the maximum speed of vehicles v_{max} > 150 km/h ; (2) acceleration :from 0 to100km / h acceleration time t ≤ 16s; (3) maximum gradability i ≥ 30%.

Depending on the vehicle's maximum speed, acceleration and climbing performance determined respectively the maximum power are:

$$P_{max1} = 81.25KW \quad P_{max2} = 69.37KW \quad P_{max3} = 69.53KW$$

Then we can determine the maximum power that the vehicle required are: $P_{all} \geq P_{max} = \max(P_{max1}, P_{max2}, P_{max3})$. At the same time, there will be additional power consumption during the running of vehicle, so we take: $P_{all} \geq$ 90 kW.

2.1 Design parameters of battery pack

The key performance of the electric battery currently be used in the world are shown in the table 1.

Table 1 Battery main performance

	Specific energy /Wh.kg^{-1}	Energy density /Wh.L^{-1}	Specific power /W.kg^{-1}	Charging time /h	Cycle life /80%DOD	Reference price /100%
Lead-Acid Battery	35	80	75	8~16	>700	1
Nickel-Cadmium Battery	40	80	100	4~8	800	7
Nickel-Hydrogen Batteriy	70	150	150	4~8	800	10
Lithium-Ion battery	100	160	300	2.5	>120	20

This paper uses Nickel-hydrogen battery for capacity of 84Ah. Capacity of single cell is 8.4Ah, each unit connected with 10 single cells that voltage of 24V and resistance of 0.025Ω in series. Comprehensive consideration of the mileage and power [4] we take the number of cells is n = 34.

2.2 Design parameters of the electromotor

Requirements for the main electromotor of hybrid electric vehicle are that it can independently drive the car when the battery power is sufficient ,meanwhile, meet the following two conditions during the independent working: (1) vehicle gradability i ≥ 15%; (2) from 0 to 100km / h acceleration time is t ≤ 20s.After calculated, the result are P_{max} = 55.62 kW.

The motor maximum power determined finally for $P_{electromotor} \geq 60$ kW as taking into account the power consumption of the vehicle add-on devices. The main electromotor chosen permanent magnet motors with rated power of 40KW and maximum power of 62KW.

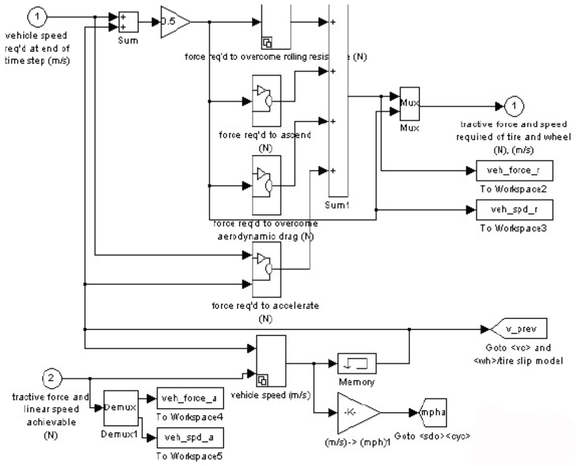

Fig.2 The model of hybrid vehicle on MATLAB

3. The model based on MATLAB / simulink for the vehicle control

As shown in Fig. 2 there is the model of hybrid vehicle and this model is a inherent model in simulation system. Drive modes includes five categories:

(1) Electromotor separate drive mode: When the vehicle speed is less than the set speed, engine will be turned off and the electromotor will provide the required driving torque. According to the engine characteristic curve we can know that when working at low speed the engine has the worst fuel economy so that the minimum engine speed must be limited and to set the minimum vehicle speed with 20Km / h.

(2) Engine separate drive mode: when the vehicle speed is higher than the set speed, the electromotor will shut down, there is the engine separate driving.

(3) Combined drive mode: When requires a large driving torque, the vehicle should keep the engine working within the region where have the highest fuel efficiency and be driven by the electromotor as an auxiliary power source ,which could realize united drive.

(4) Battery charging mode: When the battery state of charge (SOC) is below the lower limited point, the engine will provide additional power to drive the generator to charge the battery pack so that the SOC values always remain within a certain range which good for extending battery using life. This design of the battery SOC value set in the range from 0.3 to 0.7.

(5)Braking control mode: In the design it is using the way of combining the electric brake and the hydraulic brake for vehicle brake and the priority is electric brake as the reason for ensuring vehicle safety, maximizing the recovery of braking energy and increasing the vehicle's driving range. Braking energy stored by the generator in the battery though the way of electric brake[5] ;When the break force that the vehicle need is greater than the electric brake system can provide, the electric brake and hydraulic brake will work together for vehicle; When it is in emergency, the hydraulic brake system will be taken as the main way for braking and electric brake as auxiliary force.

4. The simulation of hybrid electric vehicle's main performance

It is carried out vehicle performance simulation under the urban road cycle of CYC_UDDS that established by the U.S. Environmental Protection Agency(EPA). The simulation results are shown in Fig. 3, Fig. 4 and Fig. 5 as well as fuel consumption and emission are shown in Table 2 and Table 3.

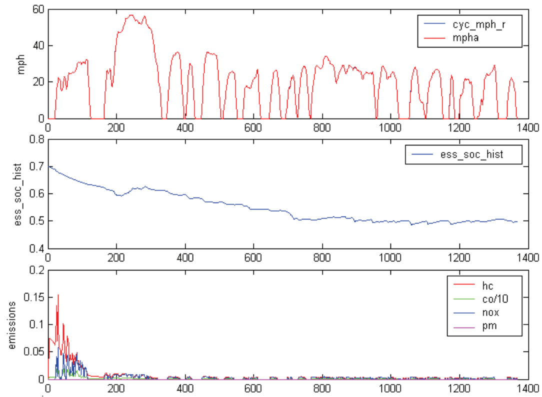

Fig. 3 Battery SOC changes and emission curves in operating conditions of CYC_UDDS

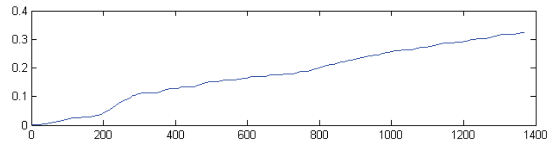

Fig. 4 The engine fuel consumption of hybrid vehicles in CYC_UDDS (L)

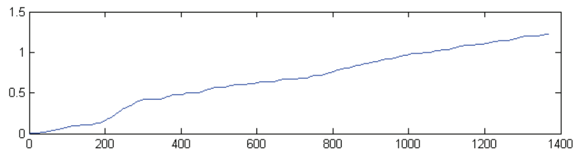

Fig. 5 The brake energy recovery of Hybrid vehicles in CYC_UDDS (kwh)

Table 2 Changes of acceleration, deceleration, and fuel consumption in CYC_UDDS

battery initial SOC	end the simulation SOC	average speed	Maximum accelerat -ion (m/S2)	average acceleration (m/S2)	maximum deceleration (m/S2)	average deceleration (m/S2)	engine fuel consumpti -on (L)	brake energy recovery (kwh)
0.7	0.498	32	7.78	2.67	-7.78	-3.06	0.336	1.248

Table 3 Emissions of the vehicle in CYC-UDDS

HC emissions (g/km)	CO emissions (g/km)	NOx emissions (g/km)
0.062	0.085	0.028

As the result that the dynamic process of the battery system SOC values can be seen from Fig 3, the initial value is 0.7 and the minimum is 0.498. Changes of dynamic process are stable.

Fig.6 shows the electromotor operating point and the torque output in CYC_UDDS. The simulation results demonstrate that the working point of the electromotor mainly distributed in the 20-100Nm, the peak is about 200Nm. At the same time, the required maximum torque output by electromotor in cycles is about 159Nm and the required torque less than 159Nm in often working region of electromotor. The motor can work normally. In addition, motor can meet peak demand for the vehicle dynamics as its ability to work overload.

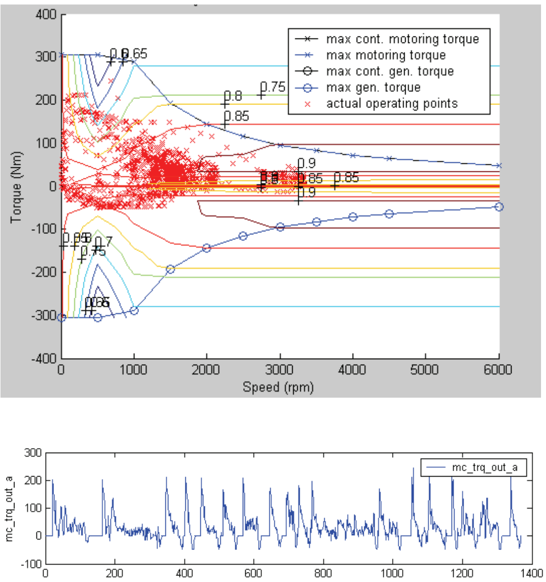

Fig.6 Electromotor working point and the torque output in CYC_UDDS

Fig. 7 shows the condition of engine operating point and the output torque in CYC_UDDS. From the Figure it is conclude that operating point of the engine mainly ranges from 45 Nm to 85Nm and the peak torque is close to 100 Nm. Designed of the engine maximum power is greater than 50kw, so engine can work normally and have higher efficiency in CYC_UDDS.

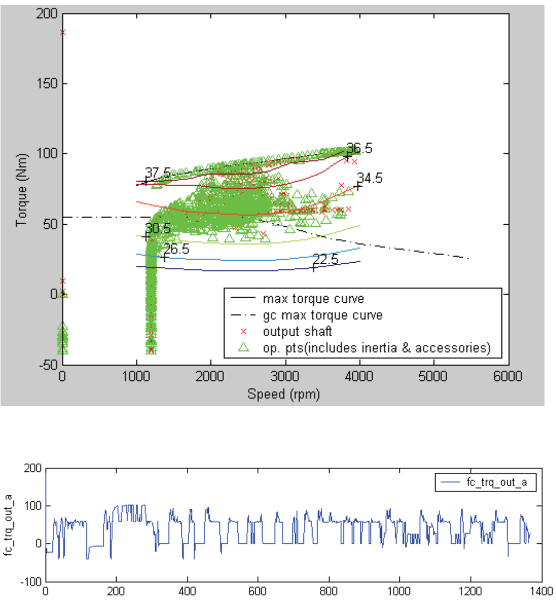

Fig. 7 The engine working point and the torque output in CYC_UDDS

Fig.8 shows the battery charge and discharge efficiency in CYC_UDDS. The energy of battery charge comes mainly from the braking energy recovery during this condition. Simulation turned out that the charging efficiency of battery mainly focus on 0.9 because the frequently speed changes and more often deceleration in this condition so that lead to improve the battery charging efficiency. From the simulation results, the battery discharge efficiency are mainly in 0.9-1,it can prove that not only the battery energy have a higher use rate, but also the engine, electric motor, generator and battery are working coordinated with together.

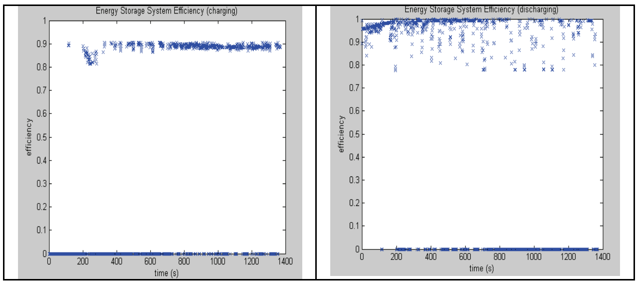

Fig.8. Efficiency of battery charging and discharge in CYC_UDDS

5 Analysis economy and emission of Hybrid electric vehicle

The main purpose of research about hybrid electric vehicles is to improve vehicle fuel economy and emissions. Discussion about the vehicle fuel economy and emissions performance in CYC_UDDS are show as follows.

5.1 Analysis of vehicle fuel economy

As shown in Table 4, it is the energy consumption of the hybrid vehicles in CYC_UDDS. Simulation turned out that the equivalent fuel consumption is 5.9L/100km, the saving rate is up to 24%. From the above data it is obvious that the vehicle's fuel efficiency is perfect.

Table 4 Energy consumption of hybrid vehicles

cycle conditions	simulation mileage (km)	the initial SOC of battery	end the simulation SOC	electrisity consumption (kwh)	engine fuel consumption (L)	energy recovery (kwh)	fuel consumption of 100km	the original fuel consumption of 100km
CYC_UDDS	12	0.7	0.498	8.62	0.336	1.248	5.9	7.8

5.2Analysis performance of vehicle emissions

Table 5 have shown that the exhaust emissions of hybrid vehicle in CYC_UDDS. Analysis and compare with"GB18352.3-2005 light-duty vehicle emission limits and measurement methods" (China Ⅳ stage) could draw a conclusion that the vehicle exhaust emissions is lower than the national standards for emission limits.

Table 5 Emission of hybrid vehicles

cycle conditions	HC emissions g/km	Gb HC emissions	CO emissions	Gb CO emissions	NOx emissions	Gb NOx emissions
CYC_UDDS	0.062	0.13	0.085	1.81	0.028	0.1

6.Conclusions

(1) In this paper redesigned the structure of the Mazda 6 and designed a new composition of hybrid electric vehicle that adapt to the requirement in a new stage of China's social development. This paper was also designed and theoretical calculated the parameters of the main components of the transmission system, then on this basis created model in MATLAB for control strategy about the whole vehicle and the vehicle braking energy recycle respectively.

(2) The performance simulation of the vehicle operating conditions in CYC_UDDS can conclude that the fuel saving ratio can reach 24% and the performance of emission also had greatly improved respectively, the

emission performance has been greatly improved as result of that emissions of HC, CO and NOx significantly are lower than the values specified by national standards.

(3)Although in this paper the control strategy model of hybrid electric vehicle can meet the design requirements, it didn't reach optimization. The control strategy that must be determined by collecting and analyzing a large amounts of data as well be proved in the actual car driving experiments. Reaching optimization will be a new direction that the research and development of electric vehicles moving toward.

(4) Used for the simulation of the loop condition is formulated according to the foreign conditions, it is not sure whether the cycle can applicable to the specific conditions in China. Hope that our country will develop a new set of cycle conditions for ourselves as soon as possible so as to simulating the operation conditions of the hybrid vehicle and promoting the development of electric vehicles.

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