Driver's Intention Identification for Battery Electric Vehicles Starting Based on Fuzzy Inference

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Abstract **— The starting control strategy of the target vehicle is formulated based on the vehicle dynamics. A double fuzzy logic identification system of driver's intentions was designed using fuzzy logic theory. The effects of the developed system on vehicle performance were analyzed by a simulation model which was established in MATLAB/Simulink software. It is expected to achieve dynamic performance improvement, jerk reduction and ride comfort increase.**

Keywords - battery electric vehicles; fuzzy control theory; driver's intention identification; fuzzy inference

Ⅰ.INTRODUCTION

In recent years, with the increasingly serious global energy and environment issues, many countries have issued appropriate laws and regulations to limit the traditional internal combustion engine vehicles emission and promote the development of new energy vehicles. Battery electric vehicles (BEVs) have the advantages of high efficiency and zero emission, which can help to improve the air pollution problem and alleviate dependence on fuel[1-2].Starting control is one of the key technologies of BEVs. The ECU in the BEV sends commands to motor controller to meet the driver's requirements by identifying the driver's intentions and ensures driving safety and riding comfort during starting process.

Many researchers have deeply studied about vehicles starting and the driver's intention identification in recent years. In [3], three different strategies were used to simulate engine starting process respectively: starting in constant speed with torque compensation, starting in constant speed without torque compensation, normal starting. Reference [4] proposed the starting and acceleration control strategy of BEVs based on the starting and acceleration performance of a vehicle equipped with automatic transmission. And in [5], the authors presented a driving intention intelligent identification method for hybrid vehicles based on fuzzy inference. The input of fuzzy logic inference system were opening of the accelerator pedal, opening rate of the accelerator pedal and vehicle speed， and the output was driver's intention.

In this paper, for a target BEV, the control strategy of vehicle starting process was established by analyzing the vehicle dynamics. A double-fuzzy driver's intention identification system was designed by the fuzzy logic theory. The starting expected torque was obtained to ensure the vehicle starting smoothly and be consistent with the driver's intention. Then the simulation of starting process was performed and the results were verified by experiment

Ⅱ. VEHICLE DYNAMICSANALYSIS DURING STARTING

The starting process of the BEV refers to that the BEV accelerates from stationary to a certain velocity. During the starting and accelerating process, the forces which applied to the BEV are shown in Fig. 1.

On a slope road, the forces applied to the BEV are the driving force F_t, rolling resistance F_f,aerodynamic dragF_w, upgrade resistanceF_i and acceleration resistance F_j[6].

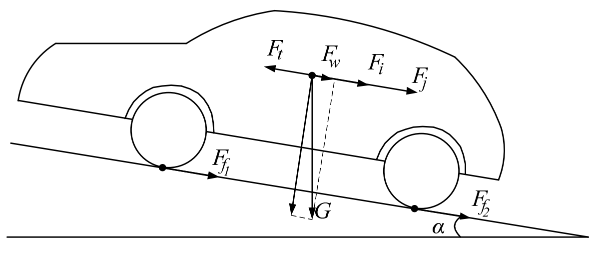

Fig. 1. Forces on the BEV

At this time, the torque needed can be expressed as:

$$T = \frac{r}{i\eta}\left(mgf\cos\alpha + mg\sin\alpha + \frac{C_D A v^2}{21.15} + \delta m\frac{dv}{dt}\right) \quad (1)$$

Where m is the full mass; r is the wheel radius; g is the gravitational acceleration; f is the rolling resistance coefficient; C_D is the aerodynamic drag coefficient; A is the frontal area; v is velocity; $\frac{dv}{dt}$ is the vehicle acceleration; i is the transmission ratio; η is the efficiency of the transmission system; δ is the coefficient of rotating mass.

III.CONTROL STRATEGY OF BEVS STARTING

The BEVs starting conditions can be divided into two working conditions, namely starting with zero opening of accelerator pedal and starting with stepping the accelerator pedal.

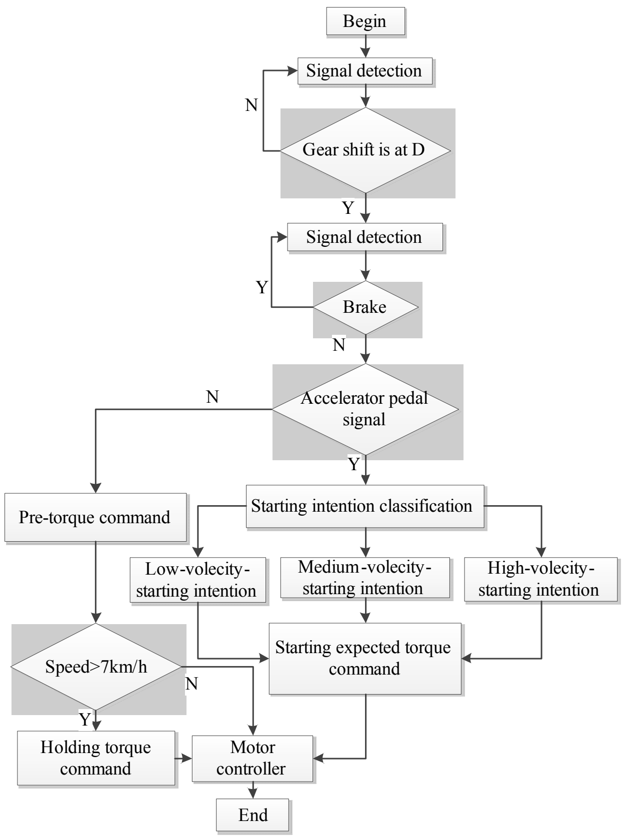

Fig. 2. Control flowchart of BEVs starting

The working condition of starting with zero opening of accelerator pedal is that when gear shift is at D and brake pedal is released, ECU will immediately sends torque commands to motor controller according to the strategy. At this time, motor will produce corresponding pre-torque T_S to realize the vehicle starting. Maximum pre-torque T_{Smax} should ensure that the vehicle can maintain still on a road with certain slope to prevent the vehicle from slipping. T_{Smax} can be determined according to (1). When starting on a flat road, produced T_S is larger than the torque which the driver expected. It is obvious that T_S should be reduced with the increase in velocity. The maximum stable velocity ruled by the strategy in zero opening of accelerator pedal condition is 7km/h as reference for the target vehicle(which is a passenger car). When the maximum velocity is stable, motor torque will be reduced to holding torque T_D, which can be obtained according to (1).

The working condition of starting with stepping the accelerator pedal is explained as when gear shift is at D and brake pedal is released, the driver steps the accelerator pedal and the vehicle will start. In this condition, motor output torque should consistent with the starting intention of the driver just-in-time, which is different from condition of starting with zero opening of accelerator pedal. Driver's starting intention is divided into low-velocity-starting intention, medium-velocity-starting intention, and high-velocity-starting intention. Driver's intention identification system will infer the expected torque T_{exp} according to the driver's starting intention then send signals to the motor controller. The control flowchart of BEVs starting is depicted as Fig. 2.

There are three common calibration methods for accelerator pedal and motor expected torque as shown in the Fig. 3[4]. The first calibration method is named hard-pedal strategy, which has good acceleration quality under medium or high load, but poor controllability under low load; the second calibration method is named linear calibration strategy, which is relatively simple but with poor acceleration performance; the third calibration method is named soft-pedal strategy, which has good controllability under low load, but slow starting acceleration and poor driving feeling. This paper will calibrate motor expected torque based on fuzzy theory and driver intention identification.

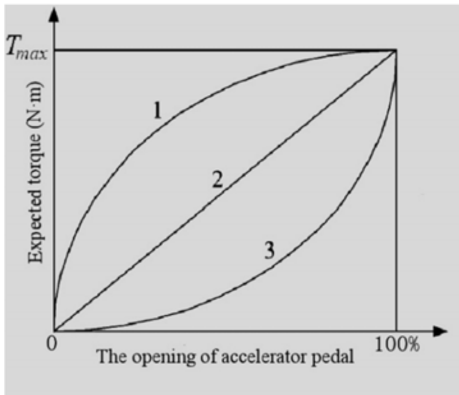

Fig. 3. Calibration curves of motor expected torque and the opening of accelerator pedal

IV. DESIGN OF DOUBLE-FUZZY DRIVER'S INTENTION IDENTIFICATION SYSTEM

During the starting process, the driver should consider the driving environment and starting requirement comprehensively. The opening of accelerator pedal θ and the opening rate of accelerator pedal $\dot{\theta}$ reflect the urgency

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of the driver's starting intention. At this time, the opening of accelerator pedal and its rate are both positive. The larger $\theta$and$\dot{\theta}$are,the stronger accelerating intention the driver has; otherwise, the driver's accelerating intention is weaker. However, when starting with zero opening of accelerator pedal, the driver has no action to the pedals; the vehicle velocity increases slowly to reach the maximum stable velocity, and the vehicle acceleration is small. In conclusion, driver's intention can be reflected by different accelerator pedal data.

It is unnecessary to know the internal structure, working mechanism or mathematical model of control object [7] when analyzing and designing the fuzzy control system. It's difficult to describe the driver's intention identification with accurate mathematical models, which belongs to empirical model. Therefore, fuzzy control theory is applied to driver's intention identification. When identifying driver's intention according to θ and $\dot{\theta}$, it is difficult to define θ or $\dot{\theta}$ accurately. With fuzzy control system, the driver's operation experience can be interpreted as fuzzy rules with fuzzy language, which can be identified, managed and used by the controller.

The structure of double-fuzzy driver's intention identification system is depicted as Fig. 4, which is composed of two fuzzy subsystems. Subsystem (I) takes θ and $\dot{\theta}$ as input and its output presents starting condition (which is quantified by vehicle starting expected acceleration). Subsystem (II) takes θ andstarting expected acceleration as input; the driver's starting intention (which is quantified by T_{exp}) is output.

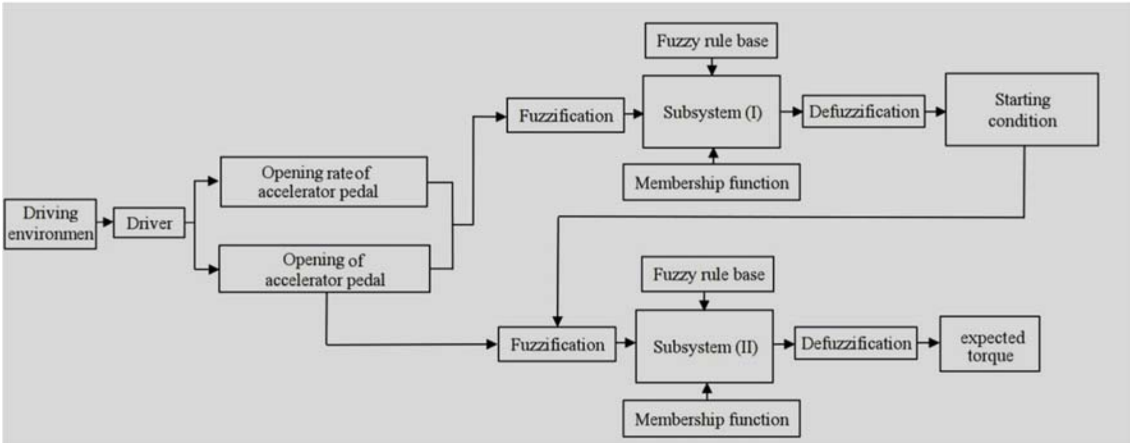

Fig. 4. Double-fuzzy driver's intention identification system structure

θ,$\dot{\theta}$and T_{exp} are fuzzed into five grades separately, which include {NB, NS, M, PS, PB}, representing negative large, negative small, medium, positive small and positive large respectively. Starting conditions are fuzzed into three grades which are {S, M, B}, corresponding low-velocity-starting condition, medium-velocity-starting condition and high-velocity-starting condition respectively. Membership functions of θ , $\dot{\theta}$ and T_{exp} adopt trigonometric membership function and starting conditions adopt trapezoid membership function.

Actual experiment data reflect the range of each identification parameters when vehicle velocity reaches starting requirements in different starting conditions. The physical domain of θ,$\dot{\theta}$, T_{exp}, and the vehicle expecting acceleration are [0, 100] [0, 60][0, 144]and [0.7, 1.8]separately. However, the physical domains of θ and$\dot{\theta}$ are relativelylarge,to guarantee system stability, fuzzy domains are respectively equivalent to [-10, 10] and [-5, 5] by quantified factors. Fuzzy domains of other parameters are equal to their physical domains. Linguistic truth-value of each parameter can be determined according to the range of each parameter in limited working condition.

Fuzzy rules are formulated according to the experience of skilled driver, and the fuzzy rule table is described as "if$\theta$is A and $\dot{\theta}$ is B then $\frac{dv}{dt}$ is C; if θ is A and $\frac{dv}{dt}$ is C then T is D". During simulation, fuzzy control rules should to timely calibrate and adjust according to the simulation results. The starting condition and T_{exp}three-dimensional fuzzy control images are shown as Fig. 5 and Fig. 6.

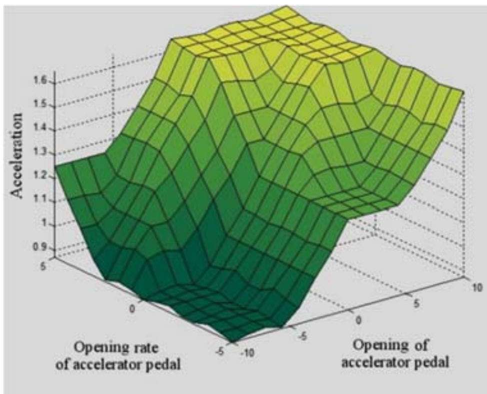

Fig. 5. Three-dimensional fuzzy control image of the starting condition

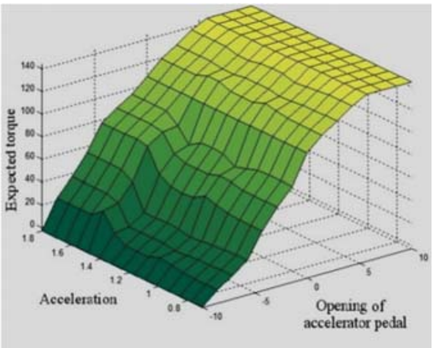

Fig. 6 Three-dimensional fuzzy control image of the starting expected torque

Ⅴ.SIMULATION AND ANALYSIS

A. *Simulation Model*

According to the double-fuzzy driver's intention identification system which is designed by starting control strategy, dynamical model of BEVs starting stage is built by MATLAB/Simulink, which is shown as Fig. 7.The double-fuzzy identification system of driver's intention which is shown as Fig. 8 is packaged in the fuzzy inference module which is in Fig. 7.

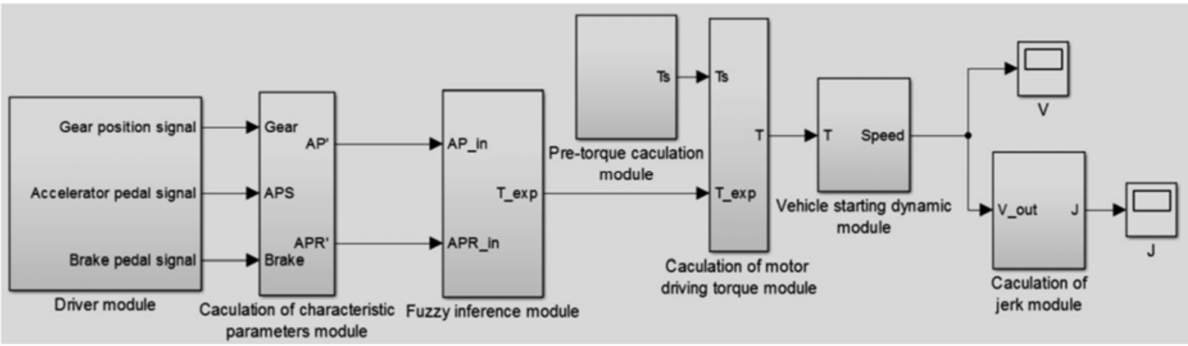

Fig. 7. Fuzzy inference simulation model for starting process

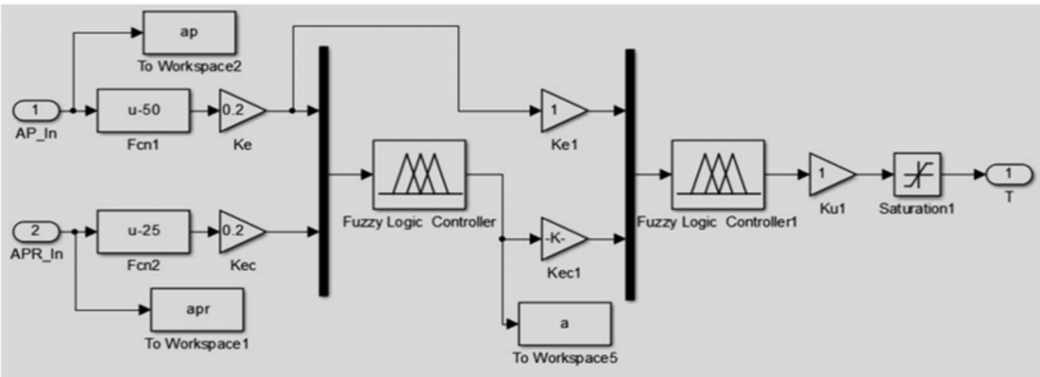

Fig. 8. Double-fuzzy driver's intention identification system

B. *BEVs Starting Performance Evaluation*

BEVs starting performance is evaluated by no sliding in hill-start and the value of jerk during starting process.

To guarantee no sliding in hill-start, the maximum parking slope of the vehicle which is 9% [8] should meet the maximum longitudinal gradient value of urban road. Thus the maximum parking slope in this paper is 9%.

Ride comfort during vehicle starting is evaluated by jerk, which is the rate of vehicle longitudinal acceleration. For a highly comfortable ride, the maximum allowable jerk experienced by the passengers, j is suggested as 18m/s^3 [9] and described as:

$$j = \frac{da}{dt} = \frac{d^2v}{d^2t} \qquad (2)$$

C. Analysis of Simulation Results

Fig.9shows the simulation results which compared with the experiment results when driving on a flat road. The accelerator pedal signals which include $\theta$and$\dot{\theta}$ are used as input of simulation model as shown in Fig.9 (a). In Fig. 9(b), the expected torque inferred by fuzzy identification system becomes more stable, which can effectively reduce the impact caused by torque change. The control strategy designed in this paper can reduce the starting time and gain the better starting acceleration character as shown as Fig. 9(c) which is the velocity of experiment and simulation graph. According to Fig.9 (d), the jerk can be reduced effectively by the fuzzy identification system during starting, which is helpful to improve the comfort.

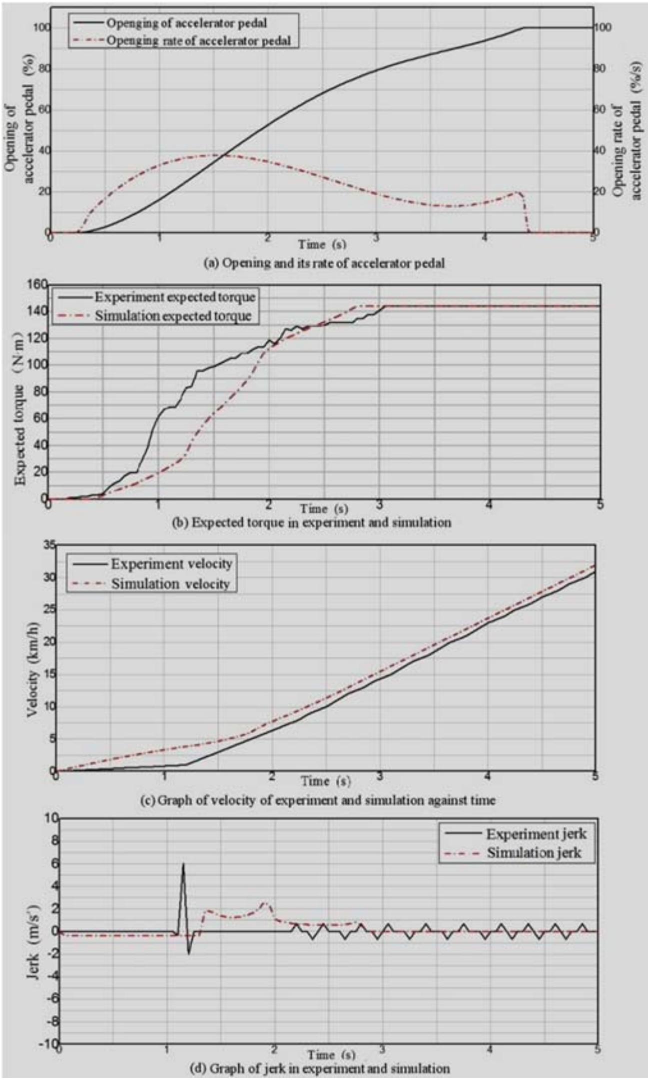

Fig 9. Experiment and simulation results

When driving on an uphill road, in order to meet the maximum parking slope 9%,Pre-torque and starting expected torque are depicted in Fig.10.Outputtorque of the motor is the larger one of them.

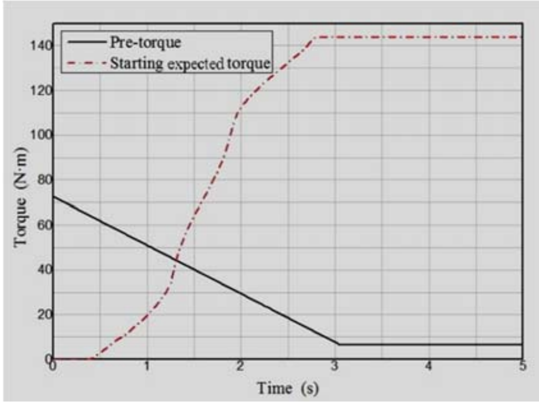

Fig. 10 Graph of pre-torque and starting expected torque

Ⅵ.CONCLUSIONS

The BEVs starting control strategy was formulated by the vehicle dynamics. Based on the fuzzy logic theory, the double-fuzzy identification system of driver's intention was designed. With the experiment accelerator pedal signals as input, the simulation was modeled. Results show that the double-fuzzy driver's intention identification system can accurately identify the driver's intention and infer the starting expected torque. To compare with the target BEV experiment, the starting time is shorter and the riding is more comfortable, which have practical significance in engineering practice.

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