RESEARCH ON THE SHIFT PREDICTION OF ELECTRIC TRACTOR TEST BENCH BASED ON FUZZY CONTROL

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In order to improve the accuracy of the results of electric tractor test bench and reduce the dependence of manual shift on driving experience of operators, a method of shift prediction control based on fuzzy inference is proposed. Based on the characteristics of electric tractor test bench, a two-input and single-output fuzzy system with the speed and change of speed as input and shift as output is set up, and the fuzzy control rules are developed. Simulation is carried out to verify the feasibility of the developed fuzzy control system. Based on the characteristics of the test and control system of LabVIEW, an external script program for shift prediction fuzzy control is written. An experimental study was carried out on the purpose of developing an electric tractor. The results show that the developed shift prediction fuzzy control system can accurately predict shift position and ensure that the motor is always running in the range of high speed, avoiding shift delay in the process of shift. The shift prediction system based on fuzzy control can correctly predict shift gears, improve the accuracy of test results and meet the design requirements.

Keywords: Fuzzy control; electric tractor (ET); test bench; shift prediction.

1. Introduction

The electric tractor has many advantages with high efficiency, low noise, low pollution, convenient operation and more; it is new high-tech equipment with integrated mechatronics. Therefore, the simulation test is very important in the development of electric tractors. Although the electric tractor has a wide step-less speed regulation characteristic and the driving force cannot meet the needs of field operation. In order to meet the needs of the complex working conditions of the tractor in field, the power drive system of the electric tractor needs to be equipped with the gearbox and driving axle in addition to the motor in order to achieve the effect of reducing the speed and increasing torque. At present, in order to carry out the parameter matching test of the driving system, most of the electric drive test benches are modular design [1, 2]. Therefore, correct prediction of the gearbox shift

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to achieve the optimum matching of the drive motor speed and gearbox shift is one of the important factors to determine the accuracy of the results of electric tractor test bench.

In recent years, around the key technology of automatic shift control in gearbox, a lot of research has been carried out by universities and scientific research institutes at home and abroad. Some technologies have been widely used in engineering [3-8]. Presently, the automatic shift rule applied to automobiles is mainly parametric method [9-11]. For example, Shen Shuiwen introduced the information of the curve and ramp of vehicle running on the basis of Petrov's two parameters, and used fuzzy logic to correct the shift of two parameters to achieve shift [12]. Yan Lei considered the change of power consumption of the working pump and put forward a four parameter shift strategy [13].

Tractor has a great variety, complicate working conditions and many factors influencing the shift, such as operation speed, load size, motor speed, wheel slip rate and more. Therefore, the automatic shift rules of tractors are much more complicated, such as dynamic shift, economic shift rules and more [14, 15]. For example, by analyzing the main factors that affect the tractor shift, Zhang Long obtained the tractor shift rule aiming at the optimal dynamic performance or the optimal fuel economy [16]. Fu Ran set up the dynamic three-parameter shift model of the tractor and the three-parameter shift model of economy, and put forward the comprehensive shift strategy considering the demand of economy and power [17] .

According to the above information, different types of gearboxes have various kinds of automatic shift control strategies and each has their own advantages. Different from the automatic shift control of the traditional vehicle transmission, the electric tractor test bench is a completely open test system. It is one of the functions of the test bench to realize the matching of different gearboxes and power systems. Therefore, the modules of the electric tractor test bench are independent of each other, and the traditional gearbox automatic control strategy is difficult to match the different test systems quickly. Based on the above reasons, this paper proposes a gearbox shift prediction method based on fuzzy control, which is suitable for the open test bench of electric tractor with different gearbox modules, which reduces the dependence of the bench shift on the shift experience of the operator, to improve the accuracy of the test results.

2. Design of electric tractor test bench

Since the research foundation of electric tractors in China is relatively weak, it is very necessary to carry out laboratory bench test for electric tractors in order to carry out the research on the performance of electric tractors.

According to the needs of modular test bench construction, the electric tractor test bench is shown in Fig.1. Hardware of the test platform consists of battery group and its management system, motor and its controller, clutch, gearbox and rear axle drive assembly, magnetic powder brake, data acquisition card and several signal sensors. The software part is a measurement and control system produced based on LabVIEW platform. In addition to the acquisition and processing of the torque speed, voltage and current and more, it also completes the real-time control on the loading load of magnetic powder brake through the output channel of the data acquisition card. Speed regulation of the transmission system of the test-bench is completed by the motor and the gearbox. The motor controller can realize the speed regulation in a wide range of the motor. At the same time, the speed control of the gearbox can be changeable by changing the gearbox. Therefore, the final speed of the driving wheel of the electric tractor test bench is decided by the coordinated speed regulation of the motor controller and the gearbox.

Fig.1 Structure of electric tractor test bench

When driving a normal travelling vehicle, the driver can change the shift by observing the speed meter or the speed sense and working condition; however, all the information cannot be obtained on the test bench. In the test, it often appears that the shift is not timely, which causes the motor working for a long time under the non rated state and reduces the accuracy of test results. In order to ensure the accuracy of test results and improve the transmission efficiency, it is necessary to predict the gear shift ahead of time according to test conditions.

3. Fuzzy control system of gearbox shift prediction

The electric tractor takes battery as power source, and it is the key to study how to maximize the efficiency of the existing battery without breaking through the bottleneck of battery technology. Therefore, this study determines the shift strategy

based on the optimal economy. The shift rule is to ensure the lowest battery consumption rate of electric tractors.

Based on the characteristics of test and control system, the developed shift prediction fuzzy control system mainly consists of the fuzzy controller, the Simulink simulation model, the LabVIEW node and more.

3.1 Principle of gearbox

The objective prototype of the electric tractor is six-stage gearbox. The mechanical principle diagram is shown in Fig. 2. The gearbox is composed of four axes, and the gear Z1 is fixed on the input shaft 1. Double gear Z2, Z3 for high and low gear, mounted on the shaft 2 through the sleeve. Gear Z6, Z7, Z8 installed on the shaft 3 respectively by the spline. And the double gear Z9, Z10 and Z11 installed on the shaft 4 by the spline. When Z8 and Z9 meshing, shift I and III can be realized by adjusting the high and low gear Z2, Z3. When Z6 and Z11 meshing, shift II and Ⅴ can be realized by adjusting the high and low gear Z2, Z3. When Z7 and Z10 meshing, shift Ⅳand Ⅵ can be realized by adjusting the high and low gear Z2, Z3.

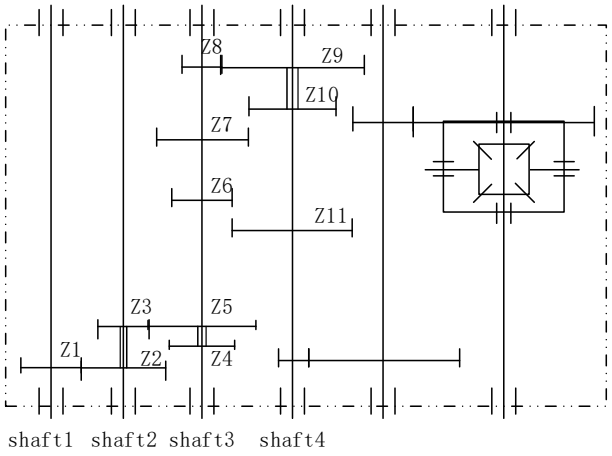

Fig.2 Mechanical principle diagram

3.2 Design of fuzzy controller

The design of fuzzy controller mainly includes the establishment of fuzzy rules, membership functions and selection of normalization factors. The design process is shown in Fig. 3. Firstly, the input variable is normalized, and then the non fuzzy quantity is converted into fuzzy value; the fuzzy value is obtained through fuzzy reasoning, and then the fuzzy value is converted to the non fuzzy value, that

is, the fuzzy value is defuzzification. Finally, the values obtained by fuzzy inference are normalized and the output values are obtained.

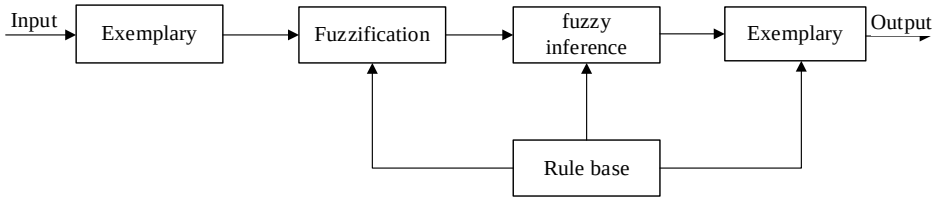

Fig.3 Design process

The basic principle of shift is to obtain the optimal economy and power. In order to improve the precision of the shift prediction, the driving speed *u* and change of the driving speed *du* are as output variables; its output variable is the gearbox *shift.*

Therefore, the shift prediction system is a two-input and single-output system, and the fuzzy rules are as follows:

$$\text{If x is A and y is B, then z = k} \tag{1}$$

Where, x and y are input language variables; A, B and k are fuzzy sets of inference events; z is output language variable.

According to the gearbox number, there are six values of u, that is, {lower big (LB) lower medium (LM), lower small (LS), High small (HS), high medium (HM), high big (HB)}. Input variable *du* has three language values, that is {negative (NN), zero (ZE) and positive (PP)}. Output variable shift has six fuzzy set, that is{sh1(I), sh2(II), sh3(III), sh4(IV), sh5(V), sh6(VI)}. According to the external characteristic curve of the motor, the highest point of efficiency is at the rated speed; thereby, when the speed of the motor is higher than the rated speed, take upshift; and on the contrary, take downshift. The control rule of gearbox shift prediction controller is shown in Table 1.

Table 1

Fuzzy controller rules of gearbox

du	*u*					
	LB	LM	LS	HS	HM	HB
NN	sh1	sh1	sh2	sh3	sh4	sh5
ZE	sh1	sh2	sh3	sh4	sh5	sh6
PP	sh2	sh3	sh4	sh5	sh6	sh6

The maximum driving speed of the target prototype of the electric tractor developed is 30km/h, so, we can see that the fundamental domain of *u* is [0,30] and

du is [-30,30]. If *u* and *du* are quantized, the membership functions of input variables *u* and *du* are shown in Fig. 4 and 5 respectively.

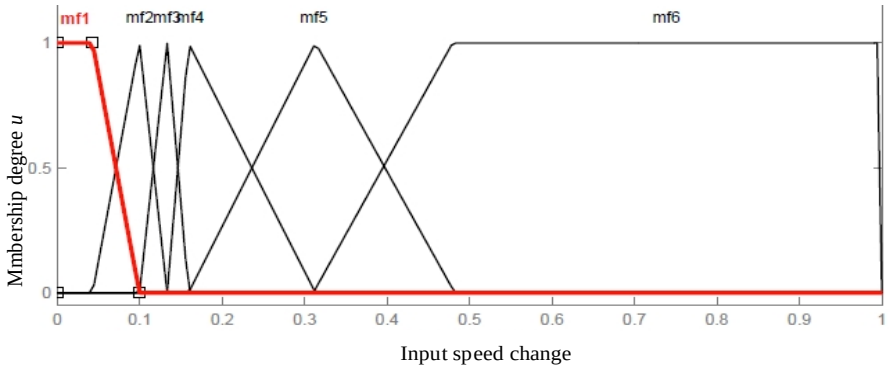

Fig.4 The membership function of input variable *u*
(mf1—The membership function of *u* for LB, mf2—The membership function of *u* for LM, mf3—The membership function of *u* for LS, mf4—The membership function of *u* for HS, mf5—The membership function of *u* for HB, mf6—The membership function of *u* for HB)

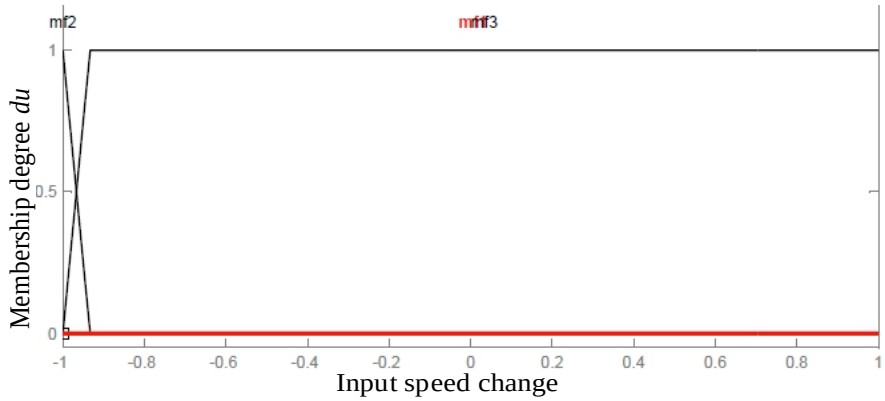

Fig.5 The membership function of input variable *du*
(mf1—The membership function of *du* for NN, mf2—The membership function of *du* for ZE, mf3—The membership function of *du* for PP)

Taking the actual needs of shift prediction of the electric tractor test bench into account, the center-of-gravity method is used to carry out the precision of the fuzzy inference process. The method extracts the center of gravity of the fuzzy membership function curve and the area of the abscissa as the final output value of the fuzzy inference. The transfer surface of the fuzzy inference controller is shown in Fig. 6.

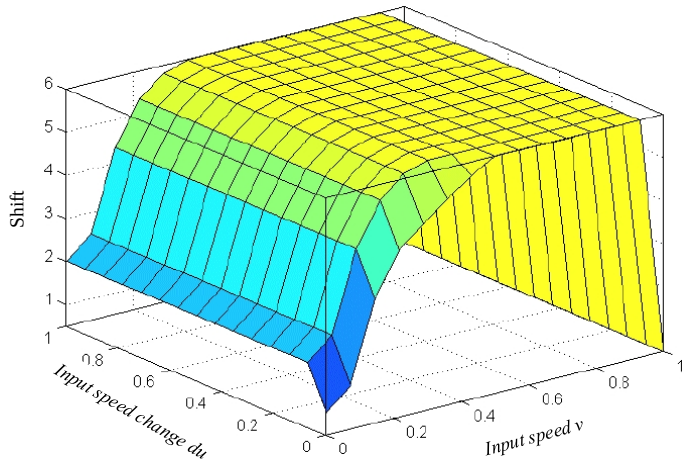

Fig.6 fuzzy inference curve

3.2 Simulink simulation model

In order to verify the correctness of the fuzzy controller, the designed fuzzy controller of gearbox shift prediction is embedded into the Simulink simulation model, and the simulation control model of gearbox shift prediction is established as shown in Fig. 7.

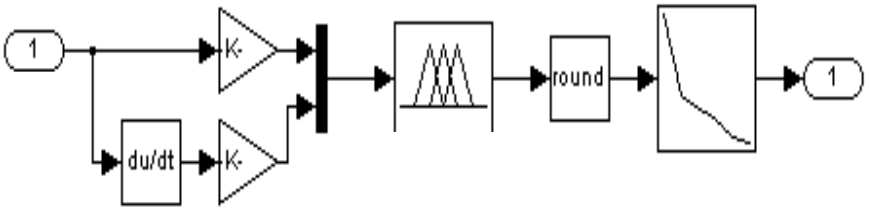

Fig.7 Fuzzy controller model

Fig. 8 is the simulation results of the fuzzy controller of shift prediction. It can be seen that the fuzzy controller outputs the shift and shift transmission ratio corresponding to the speed with the change of target. For the sudden change in the speed of target, the fuzzy controller can still output the correct transmission ratio, which shows that the fuzzy controller has a strong anti-interference ability to the sudden change.

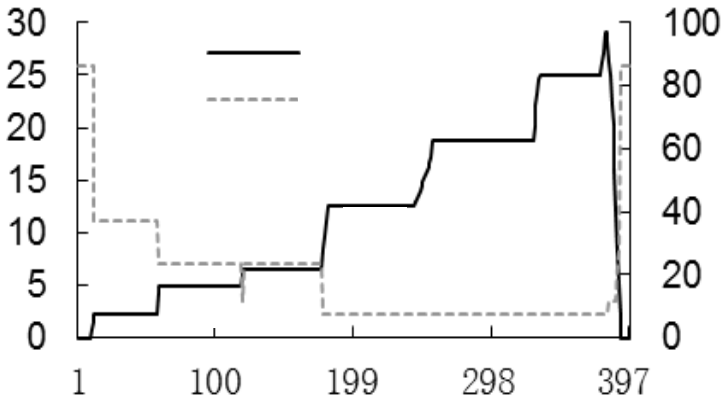

Fig.8 simulation results of fuzzy controller

3.3 The realization of shift prediction fuzzy controller

The measurement and control system based on the LabVIEW platform has MATLAB nodes, allowing users to execute external scripts. Therefore, the shift prediction fuzzy control algorithm is written in MATLAB language beforehand, and the simulation test is carried out. The algorithm is embedded into the LabVIEW after the algorithm is unmistakable. The block diagram of the program is shown in Fig. 9. Input different driving wheel speed, shift prediction module will reminder the operator the present change gearbox shift and display the corresponding speed ratio. In addition, in order to prevent the phenomenon of flying cars in the test, the high-speed warning function is added in the program block diagram, and the measurement and control system automatically sends out alarm cue when the speed exceeds the preset speed.

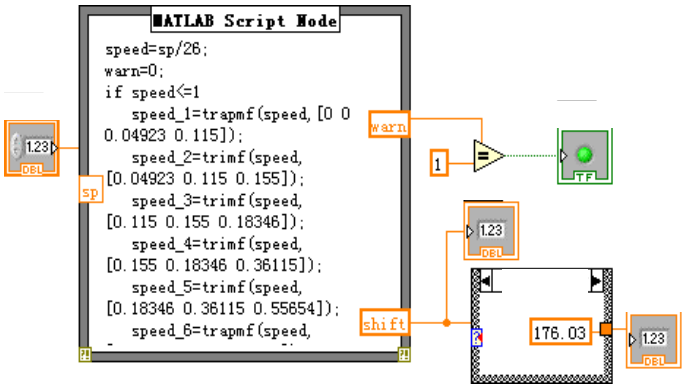

Fig.9 block diagram of shift prediction control module

4. Test results

In order to verify the feasibility of the developed electric tractor shift predictive control, a prototype of the electric tractor developed is taken as the test object, and the test is carried out. The main parameters of the electric tractor are shown in Table 2. The main test content is to test the shift prediction gear and driving motor speed of the electric tractor under transport operation condition. The transport operation condition is low-speed EUDC(Extra Urban Driving Cycle) test condition(the running time is 400s, the running distance is 1.39km, the average speed is 12.51km/h, the maximum speed is 17.83km/h, the maximum acceleration is 0.18m/s^2, and the idle time is 42s, and it occupies 10.5% of the total running time).

Table 2.

Main parameters of electric tractor

Parts	Parameters	value
Battery	Rated power/V	72
	Rated capacity/A·h	210
	Weight/kg	396
DC motor	Rated power/kW	5
	Rated speed /(r/min)	1500
	Rated torque/N·m	31
Whole machine	Weight/kg	780
	Working time/hour	4
	Rated traction/N	1960
	Plowing efficiency/(m^2/h)	5360

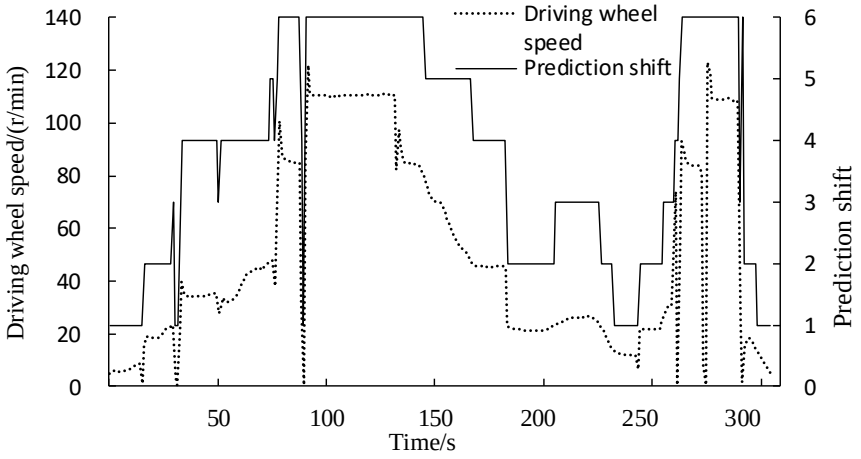

Fig.10 Shift Prediction of transportation operation test

Fig. 10 shows the prediction chart of the shift under simulated transport operation conditions. It can be seen from the diagram that in the economic speed range corresponding to a certain position, the prediction position is not constant with the change of the driving wheel speed. When the speed exceeds or below the corresponding economic speed, the corresponding shift or reduction is predicted, and the prediction position is in line with the theoretical position corresponding to the speed of the driving wheel at this time.

Fig. 11 shows the output speed diagram of the driving motor of the electric tractor test bench in the simulated transportation operation. The rated speed of the driving motor used in the test prototype is 1500r/min, and the efficiency of the motor is highest under this speed according to the external characteristic curve provided by the manufacturer. It can be seen from the diagram that the motor output speed fluctuates up and down with the rated speed as center, indicating that the motor works in the range of high speed during the whole simulated transportation operation. This indicates that the developed shift prediction fuzzy control system achieves the desired results.

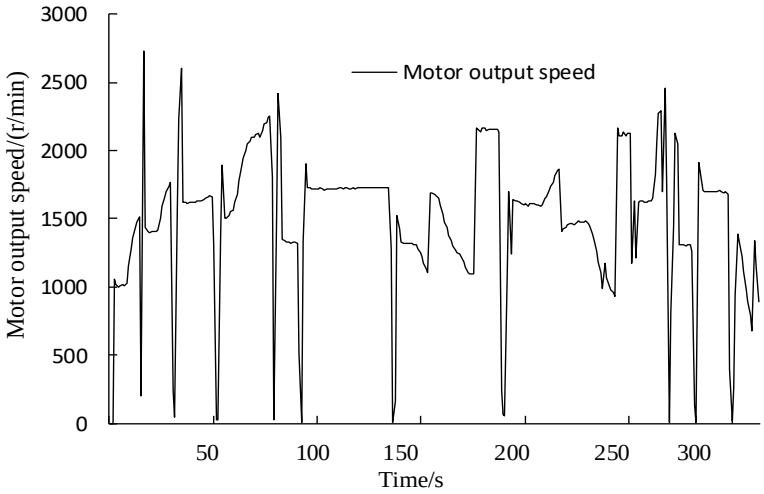

Fig.11 Motor output speed of transportation test

5. Conclusions

At present, the research on gearbox fuzzy control technology is mainly applied to automobiles and engineering vehicles, and there are few solutions for agricultural electric tractors. In this paper, the fuzzy control technology of gearbox is applied to the open electric tractor test bench in order to achieve shift prediction of different types of gearboxes. The main conclusions are as follows:

1) According to the external characteristic curve of the motor adopted in the electric tractor test bench, the real-time speed of motor is taken as the control target, which makes up for the lack of transmission efficiency.

2) Making full use of the advantages of the measurement and control system of the electric tractor test bench, using the function of sensors and LabVIEW nodes to realize the fuzzy control, the cost is saved, and the development cycle of the prototype is shortened.

3) The test results of two typical operating conditions of electric tractors show that the developed shift prediction fuzzy control system can predict the shift gear accurately, ensure that the motor is always working in the range of high speed and improve the accuracy of the results of the test bench.

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