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Research Article

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Design of Electromagnetic Brake Controller based on Accelerometer

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Abstract An electromagnetic brake controller based on accelerometer applied to trailer-mounted RV is designed, which uses acceleration as the control target for braking force control. The brake controller uses Freescale microprocessor MC9S08FL8 as the main control chip, which receives data such as tractor brake signals and acceleration signals, processes and analyzes, controls the output of trailer-mounted RVs and distributes braking torque to achieve synchronous braking and differential braking. In addition, the brake controller can switch between manual control mode and automatic control mode, and in automatic control mode, a certain degree of adaptive control can be realized, and the current braking status can be displayed through the digital tube. Real-time detection of power supply voltage to improve the reliability of brake controller. After the actual vehicle test, after the intervention of the brake controller, the lateral acceleration, roll angle and yaw angle speed of the vehicle are reduced by different amplitudes than when it is not controlled, which improves the driving stability of the trailer-mounted RV.

Keywords MC9S08FL8; accelerometer; differential braking; adaptive; brake controller; trailer-mounted RV

1. Introduction

With the rapid growth of China's economy, China's RV market has developed rapidly, among which, trailer RVs have great potential for development due to their significant advantages in price, repair and maintenance. Compared with self-propelled RVs, trailer RVs are connected to the tractor through ball head pins and ball hoods, and the movements of the two are coupled with each other and affect each other, and instability such as folding, tail flicking, and lateral swing vibration may occur during driving, and the driver cannot make effective regulation in time. Therefore, it is an important development direction to study the brake control of trailer RVs, design related electronic control systems, improve the braking performance of trailer RVs, and improve their driving stability and safety.

The electromagnetic brake controller designed in this paper uses the acceleration sensor to collect vehicle data[Error! Reference source not found.], and actively controls the braking state of the trailer RV through the PID algorithm and braking torque distribution strategy [2].[Error! Reference source not found.] When the tractor brakes, the trailer RV can generate braking force to achieve synchronous braking with the tractor; During driving, when the trailer RV has a tendency to flick its tail and oscillate laterally, the trailer RV can reduce the lateral instability trend through differential braking.

2. Overall system framework design

The system designed in this paper is mainly composed of five parts, namely MC9S08FL8 minimum system, braking and acceleration signal acquisition module, power system circuit part, electromagnetic brake drive module, and button and display circuit.

The MC9S08FL8 integrates a timer/pulse width modulator (TPM), an analog-to-digital converter (ADC), rich hardware resources such as serial communication interface modules and 30 general-purpose input and output interfaces (GPIOs). The MC9S08FL8 obtains external information through the IO function and the input capture function of the TPM module, and then outputs PWM wave control electromagnetic brake drive circuit through the pulse width modulation output function to achieve braking.

The two-axis accelerometer MXD2020 is selected to collect real-time data of longitudinal and lateral acceleration of trailer RVs, combine with the tractor brake signal, perform data processing, and add the processed data to PID control, so as to control the braking force of trailer RVs and achieve effective braking.

The power module is used to power the entire system, and the voltage output by the 12V on-board power supply is divided into two channels after passing through the power protection circuit, one of which passes through the step-down circuit to power the control system, and the other way supplies power to the electromagnetic brake drive module through the relay. The supply voltage is detected to further prevent abnormal voltage shocks from damaging the controller.

As the power supply and braking force control unit of the electromagnetic brake, the drive module controls the output of the drive current through PWM waves, and isolates the signal from the large current to ensure stable and efficient completion of the control function.

The controller is operated by pressing a button, and the current working mode is displayed by the digital tube. The overall system framework is shown in **Fig.1.1**.

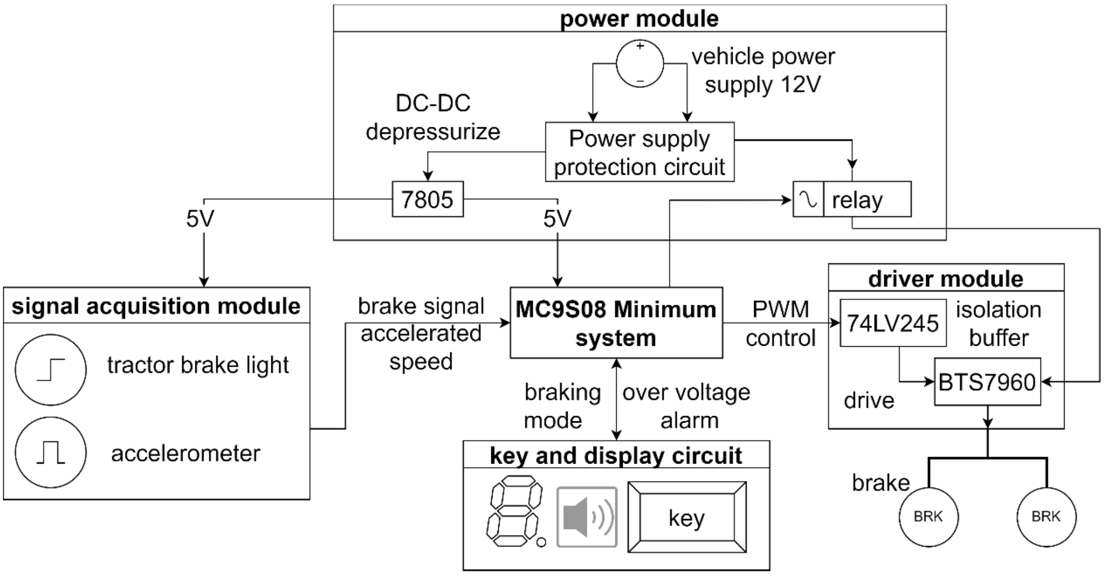

Figure 1.1: Overall system framework

2 Hardware circuit design

2.1 Minimum system circuit

As shown in Fig.2.1, the minimal system circuit consists of Freescale's MC9S08FL8 and an external clock circuit and Background Debugging Mode (BDM) circuit.

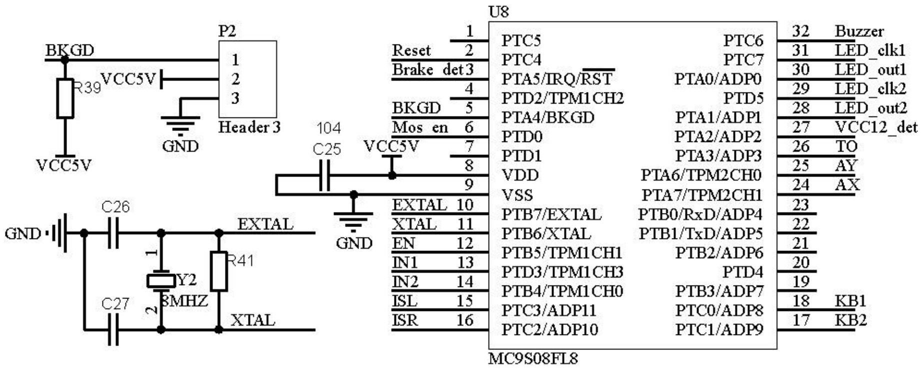

Figure 2.1: Minimum system circuit

2.2 Power system circuit

According to the requirements of the international standard ISO7637 for the power supply of automotive electronic equipment, the power supply system mainly includes five parts: anti-reverse connection, anti-surge, overvoltage protection, voltage stabilization circuit and drive circuit power supply. As shown in Figure 2.2, PMOS is used for the anti-reverse circuit design, and inductors, thermistors, and transient diodes are used to prevent severe voltage fluctuations and overcurrent damage to the control system circuit. Overvoltage protection uses PMOS, transistors, and regulator transistors to fulfill its function, and diode D8 and transistor Q4 when the supply voltage is too high Successively conduction, so that the potential difference between the gate and source of PMOS Q5 does not reach the turn-on threshold voltage, and Q5 is cut-off.

The output voltage of the on-board power supply is 12V DC, while components such as microcontrollers and accelerometers require 5V DC operating voltage, so the design uses 7805 The voltage regulator chip outputs the step-down output to the control system to ensure the normal operation of the control system. The electromagnetic brake drive module requires a working voltage of 12V, and the microcontroller conducts power to the drive module through the output signal control relay. The power system circuit is shown in Fig. 2.2.

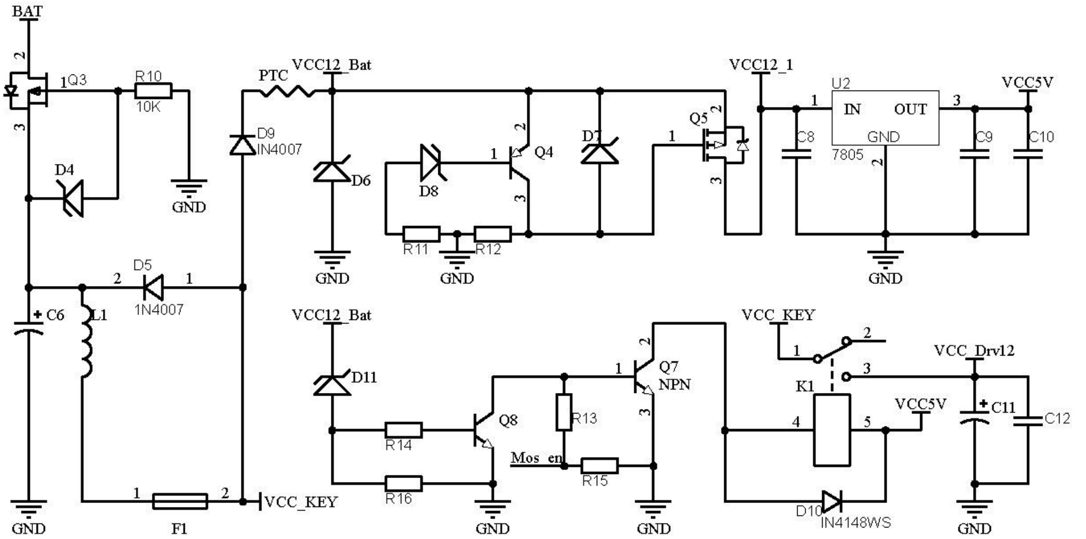

Figure 2.2: Power system circuit

Using the analog-to-digital converter (ADC) of the single-chip microcomputer, the power supply voltage detection circuit shown in Fig. 2.3 is designed to detect the vehicle power supply voltage in real time, further prevent the impact of high voltage on the control system, and better control the relay on and off. And implement a certain fault detection function.

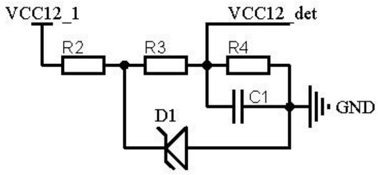

Figure 2.3: Power supply voltage detection circuit

2.3 Brake signal and acceleration sensor circuit

Since the driver's braking intention is an important basis for the trailer RV to take braking measures, the brake signal detection circuit shown in Fig.2.4 is designed, and when the driver brakes, Break_in is high level, and the transistor Q is high 1 On pulls the Break_det level low. The two-axis accelerometer MXD2020 has a measuring range of ±1 g, a resolution of 0.001 g, and can withstand 50000 g of shock, with stable and reliable performance. The output frequency is a digital signal of 100 Hz to meet the controller design requirements. The accelerometer circuit is shown in Fig.2.5.

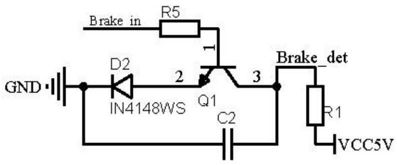

Fig.2.4: Brake signal circuit

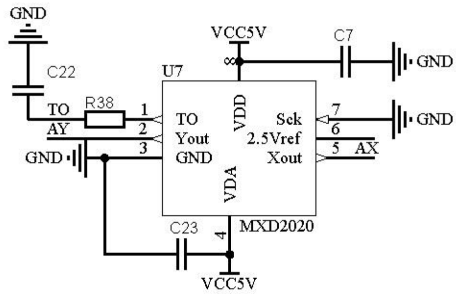

Fig.2.5: Accelerometer circuit

2.4 Electromagnetic brake drive module

The electromagnetic brake controller designed in this paper needs to control the electromagnetic braking of the wheels on both sides of the trailer RV separately, and select the intelligent power chip BTS7960 to build two drive circuits. As shown in Fig.2.6, the enable and input terminals of the BTS7960 are controlled by a single-chip microcomputer. The maximum sinking and pulling current of the single-chip IO port is only 25mA, and the driving circuit current can reach more than 3A in a single channel, so in order to protect the single-chip microcomputer and improve the anti-interference ability of the circuit Galvanic isolation is required, and the 74LV245 chip is used to design as shown in Fig.2.7 The circuit shown, the $\overline{OE}$ terminal and the DIR terminal are grounded and kept low so that the signal is followed The B side flows to the A side, and the PWM signal output by the microcomputer is from IN1 and IN2 Input, from OUT1, OUT2 output control BTS7960 chip.

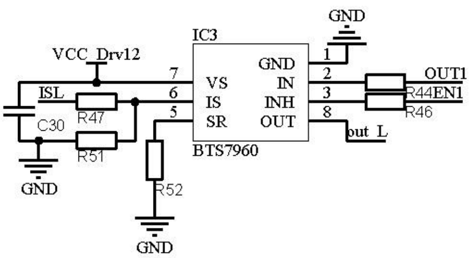

Figure 2.6: Single BTS7960 driver circuit

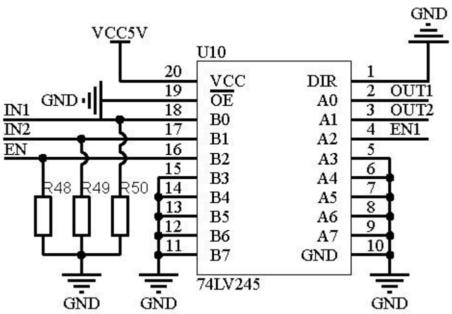

Figure 2.7: Isolation circuit

2.5 Buttons and display circuits

The brake controller is designed with automatic control and manual control two modes, switching by buttons, the button circuit is shown in Fig. 2.8, and the current control mode is displayed by the digital tube, and MC74HC164 chip is used to complete the construction of digital tube circuit as shown in Fig. 2.9.

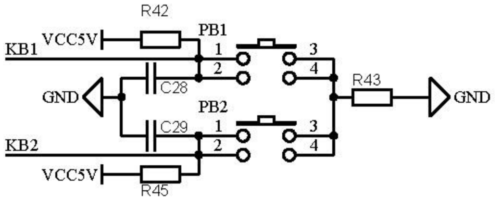

Figure 2.8: Key circuit

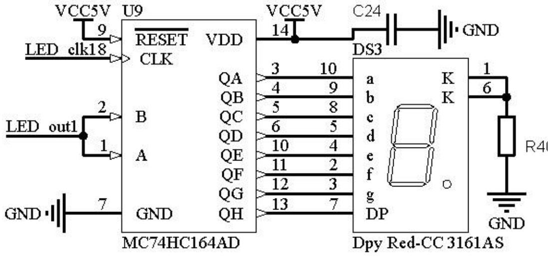

Figure 2.9: Digital tube circuit

3 Software Design

3.1 System Main Program

The brake controller designed in this paper includes two main functions, one is to reduce the longitudinal deceleration through braking, that is, to reduce the longitudinal hook force of the trailer RV and the tractor, so that the two vehicles brake synchronously and shorten the braking distance; Second, when the lateral oscillation trend occurs during the operation of the trailer house train, differential braking is performed to improve the driving stability of the trailer RV train and the trajectory tracking ability of the front and rear cars. The software part of the system mainly includes the initialization of the single-chip microcomputer, the acceleration detection program, the pattern recognition program, the PID control program, the interrupt function of the ADC module and the TPM module.

After the brake controller is powered on, first initialize the MC9S08FL8 clock, GPIO, TPM, ADC and other modules. In this paper, an external crystal oscillator is selected as the MC9S08FL8 clock source, and 16M system clock is output. After initialization, the tractor brake signal, power supply voltage, and acceleration sensor signal are detected and the acceleration signal is filtered to exclude the influence of various noise and jitter. When the voltage is abnormal, immediately turn off the relay and send an alarm through the buzzer in time to avoid abnormal voltage damage to the brake controller and then affect driving safety. The two TPM modules acquire two axial acceleration signals and output two PWM signals through four channels. When the TPM interrupt function captures the accelerometer signal, the acceleration value is calculated and the two PWM outputs are controlled in combination with the tractor brake signal. When the tendency of lateral oscillation occurs, the controller enters the differential braking mode, so that the brakes of the wheels on both sides of the trailer RV generate different braking forces, and adjust the driving attitude of the trailer RV by attaching the swing torque on one side.

The block diagram of the main program system of the controller is shown in Fig. 3.1, and the program is written in C language in the CodeWarrior development environment.

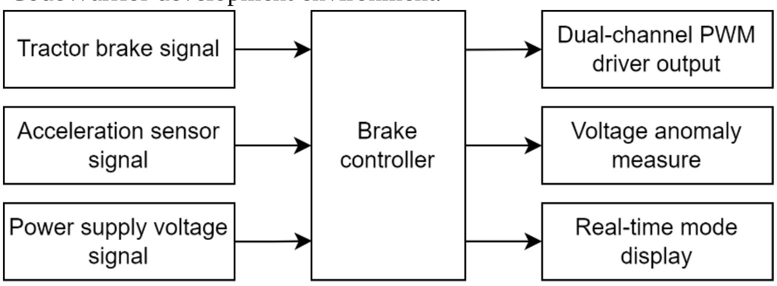

Figure 3.1: Block diagram of the controller main program system

3. 2 Synchronous braking

According to the relevant provisions of the national standard GB12676-2014 **Error! Reference source not found.**, the average deceleration speed d (m/s^2) of the fully issued automobile train and the sum of the wheel flange braking force of the trailer F_r (N) and The relationship between the sum of the P_r (N) static reaction forces of the road to the trailer wheels needs to meet the requirements shown in Fig. 3.2.

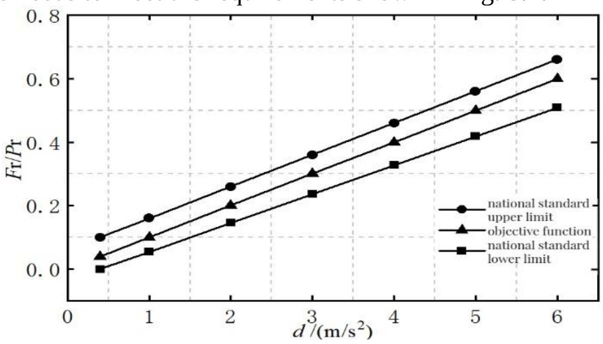

Figure 3.2: Trailer synchronization coordination interval

The upper and lower limits of the trailer synchronization coordination interval are as shown in the equation (3.1), equation (3.2) shown. The objective function shown in equation (3.3) is taken within the national standard range to facilitate the determination of synchronous braking force.

$$\frac{F_r}{P_r} = 0.1d + 0.06 \tag{3.1}$$

$$\frac{F_r}{P_r} = 0.09091d - 0.03636 \tag{3.2}$$

$$\frac{F_r}{P_r} = 0.1d \tag{3.3}$$

Under the linear braking condition, two control modes, automatic and manual, are designed according to the actual use. By manually pressing the button PB1 shown in Figure 2.9, you can switch the default automatic mode to manual mode, and pressing PB2 will adjust the braking force. The two digits of the controller display the control mode and the current gear respectively, the manual mode has a total of four gears, each time PB2 is pressed, the output duty cycle increases by 25%, and the digital tube 2 displays the gear plus 1. Table 3.1 and Table 3.2 are instructions for the digital tube display when switching the control mode and manually adjusting the gear.

Table 3.1: Control mode selection

Mode selection	**Digital tube 1**
Automatic mode	0
Manual mode	1

Table 3.2: Manual gear adjustment

Gear	**Nixie tube 2**				
	0	**1**	**2**	**3**	**4**
Duty cycle	0	25%	50%	75%	100%

In automatic mode, synchronous braking is divided into normal braking and emergency braking depending on the longitudinal acceleration. When braking normally (Flag=1), adjust the output PWM duty cycle according to the braking force requirements of the national standard for automobile trains; In the case of emergency braking (Flag=2), the PWM with the largest duty cycle directly outputs the electromagnetic brakes on both sides of the RV to brake vigorously, and the synchronous braking process is shown in Fig. 3.3 is shown.

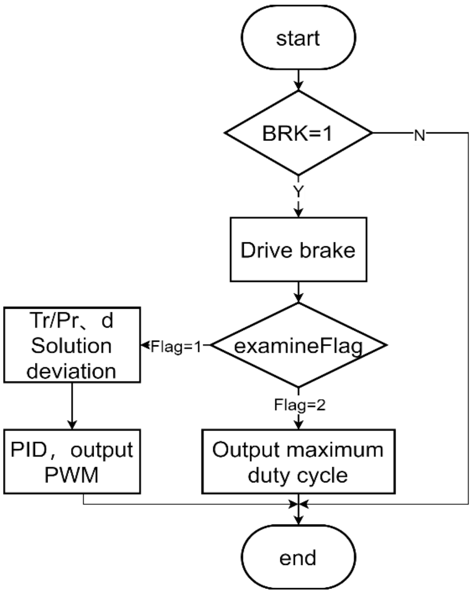

Figure 3.3: Synchronous braking flowchart

3.3. Differential braking torque distribution strategy

By formulating reasonable rules and distributing the braking torque to the target wheel, the driving stability of trailer RV trains can be significantly improved. Braking the exterior front and exterior rear wheels of the car will give the vehicle insufficient steering characteristics; Braking the inner front and inner rear wheels of a car gives the vehicle excessive steering characteristics **Error! Reference source not found.**. The trailer motorhome has only one axle, so when the trailer RV exhibits insufficient steering characteristics, braking force is applied to the inner wheels; When the vehicle exhibits excessive steering characteristics, braking force is applied to the outer wheels **Error! Reference source not found.** **Error! Reference source not found.**.

Add positional PID algorithm to carry out differential control of trailer RVs, and the algorithm expression is shown in equation (3.4).

$$\Delta u(n) = K_{\mathrm{p}}\left\{e(n) - e(n-1) + \frac{T}{T_{\mathrm{I}}}e(n) + \frac{T_{\mathrm{D}}}{T}[e(n) - 2e(n-1) + e(n-2)]\right\} \tag{3.4}$$

where is the deviation of the $e(n)$ current given value from the controlled variable, the T sampling period is controlled for PID, and the control variable $\Delta u(n)$ for output is the control variable. The operation principle of positional PID is shown in **Fig. 3.4**.

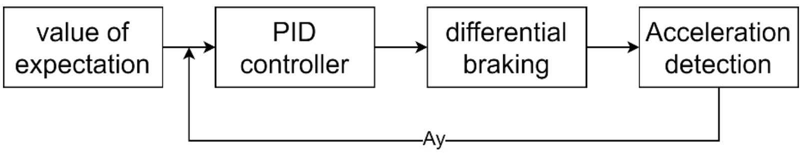

Figure 3.4: Operating principle of PID

The difference between the actual value of lateral acceleration and the expected value is used as the input of the PID controller, when the $e(n)$ lateral acceleration and its increment exceed a certain range (Flag=3), indicating that the RV has an instability trend the brake controller takes differential braking measures and accurately applies the PWM signal to the target wheel to achieve differential brake control, and the differential brake mode workflow is shown in **Fig.3.5**.

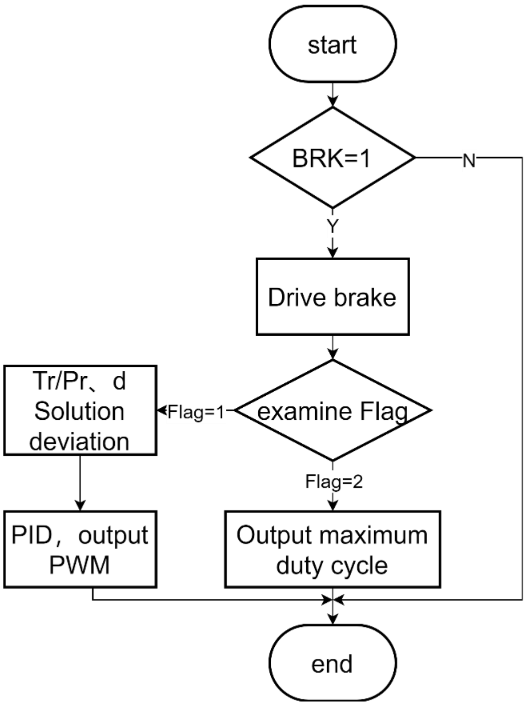

Figure 3.5: Differential brake flowchart

4. Controller real vehicle test

4.1 Test platform construction

The real vehicle test platform is composed of attitude azimuth XW-GI7660, GPS antenna, 12V DC power supply, laptop, brake controller, mobile power supply and other equipment and test vehicles, the test vehicle is a trailer RV independently designed by an enterprise, and the tractor is selected to be an Isuzu D-MAX, the test site is a dry and flat concrete pavement, which meets the relevant regulations of GB/T6323-2014[7]on the test site environment.

The test equipment is installed on the test vehicle, and the test system is shown in Fig. 4.1.

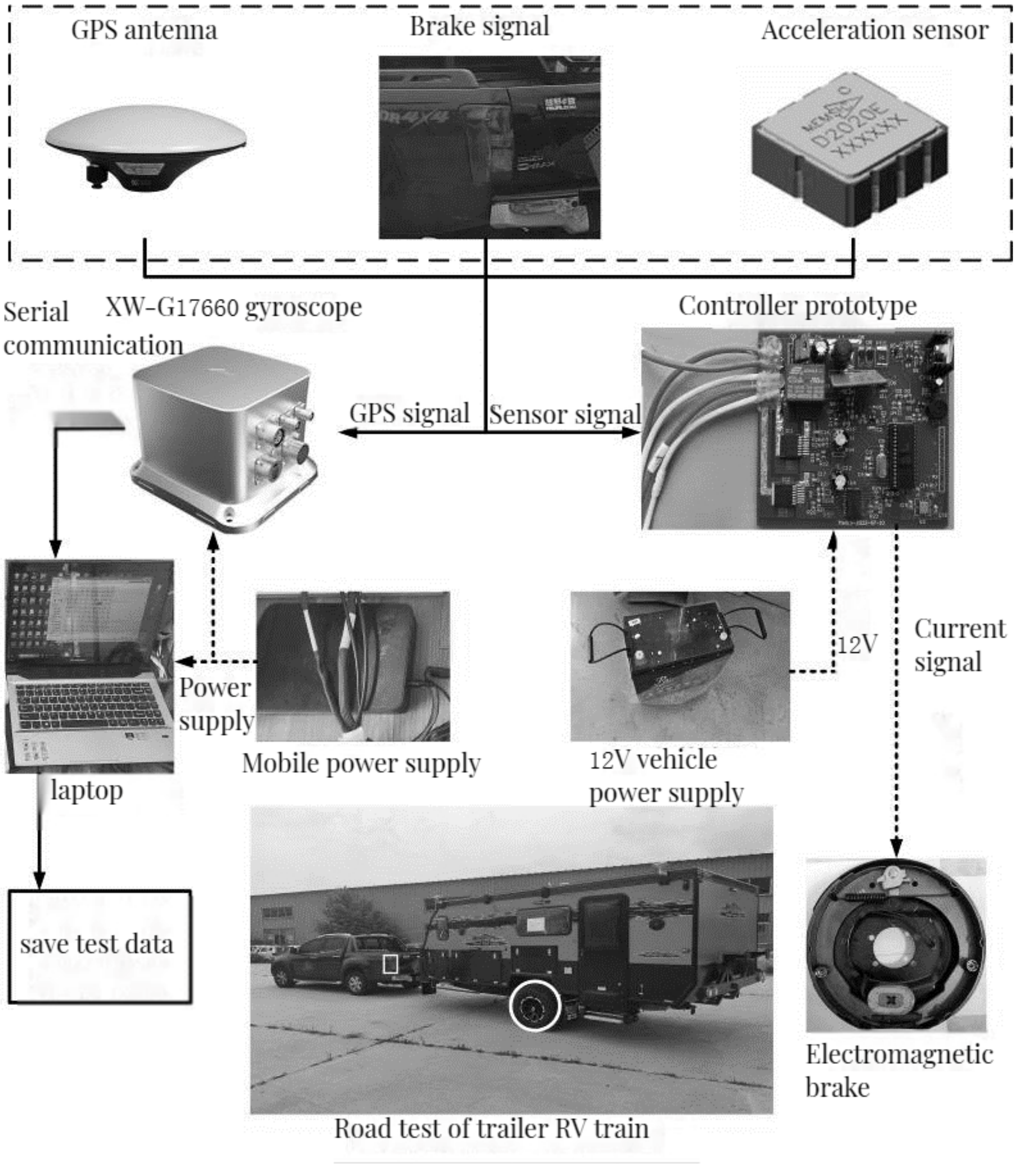

Figure 4.1: Vehicle test system

4.2 Single-lane transformation experiment

According to the requirements of GB/T 25979-2010 for the single-lane change test, the actual vehicle test of brake controller participation and brake controller not participating in braking is carried out by driving a trailer RV through the arranged road pile at a speed of 30Km/h.

4.3 Test Results

The experimental data such as lateral acceleration, roll angle, and yaw angle velocity of the RV during the test were obtained by the attitude azimuth XW-GI7660, and the test data were preliminarily processed by Butterworth low-pass filter, and the data were further processed by sliding average filtering. Fig.4.2, Fig.4.3 and Fig.4.4 are respectively the lateral acceleration, roll angle, and yaw angle velocity response curves of the RV before and after the brake controller participates in braking.

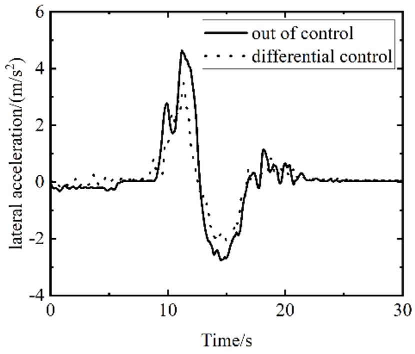

Figure 4.2: RV lateral acceleration response curve

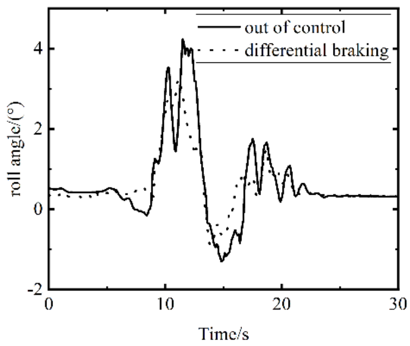

Figure 4.3: RV roll angle response curve

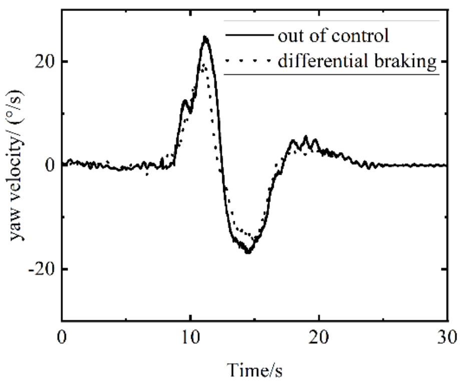

Figure 4.4: Motorhome yaw velocity response curve

As can be seen from Fig. 4.2, the peak lateral acceleration of the RV before and after differential brake control is reduced from 4.62m/s^2 to 3.68m/s^2, and the peak lateral acceleration is reduced by 21.4 % or so. As can be seen from Fig. 4.3, the peak roll angle of the RV before and after differential brake control is reduced from 4.13° to 3.24°, and the peak roll angle is reduced Around 22.6%. From Fig. 4.4, it can be seen that the peak yaw angle velocity of the RV before and after differential brake control has been reduced from 24.88°/s to 19.72°/s, the peak of the yaw angular velocity is reduced by 21.8%. At the same time, it is not difficult to see that in the whole single-line shift process, after differential braking, the RV's lateral acceleration, roll angle, and yaw angle speed are reduced.

Therefore, under the condition of single line shift, according to the lateral acceleration, roll angle, and yaw angle speed response curves of the RV, it can be seen that the designed RV brake controller significantly improves the driving stability of the trailer-mounted RV.

5. Concluding remarks

In this paper, an accelerometer-based electromagnetic brake controller applied to trailer RVs is designed to improve the driving stability of trailer RVs by controlling the longitudinal and lateral acceleration values to tend to the desired value. The hardware circuit of the brake controller was designed, and the corresponding program was written through the formulated control strategy to realize the active braking of the trailer RV. The actual vehicle test shows that the electromagnetic brake controller can actively intervene in the braking process of the trailer RV train, and reasonably distribute the braking force to improve the driving stability of the trailer RV.

References

[1]. LIANG jinchang, PAN shenghui, HAN junfeng, et al. Design of acceleration data acquisition system for automobile[J]. Transducer and Microsystem Technologies, 2011, 30(07):126-128.

[2]. GU shifu, JIN tao, FAN peiei, et al. Research on deviation rectification cotrol of automated guided vehicle based on improved fuzzy PID [J]. Transducer and Microsystem Technologies, 2019, 38(12):50-53.

[3]. National Technical Committee of Auto Standardization. GB12676-2014. Technical requirements and testing methods for commercial vehicle and trailer braking systems [S]. Beijing: Standards Press of China, 2014.

[4]. ZOU Zijie, YAN Yunbing. Rsearch on Anti-Rollover Control Combined Steering and Braking of Steer-by-Wire Vehicle [J]. Machinery Design & Manufiture. 2023, 383(01):145-149.

[5]. ZHANG Lei. Research of Active Trailer Steering and Differential Braking for Tractor-semitrailer [D]. Nanjing: Nanjing Forestry, 2019.

[6]. Shi Bingming. Research on Lateral Stability of Semi Truck Train Based on Differential Braking and Active Sttring Control [D]. Qingdao: Qingdao University of Technology, 2021.

[7]. National Technical Committee of Auto Standardization. GB/T6323-2014. Controllability and stability test procedure for automotive [S]. Beijing: Standards Press of China, 2014.