THE SLIP CONTROL OF A TRAM-WHEEL TEST STAND MODEL WITH SINGLE NEURON PID CONTROL METHOD

Abdulkadir ZIREK[1], Bekir Tuna KAYAALP[2]

Abstract

In this study, a single neuron PID (proportional, integral, and derivative) control algorithm is proposed for longitudinal slip control of a tram-wheel test stand. Hebb learning algorithm was employed for tuning the control parameters. The main advantages of the proposed algorithm are adaptivity, self-organizing, and self-learning. The performance of the control strategy is simulated using the mathematical model of the tram-wheel test stand that is developed in MATLAB environment. The simulation results show that the proposed algorithm has better closed-loop performance compared to traditional PID control method.

Keywords

Adaptive, single neuron, slip, learning algorithm, control, adhesion, traction

1 INTRODUCTION

Slip control systems are safety and control devices that are implemented in vehicles to prevent wheel slip during low adhesion conditions, especially high wheel acceleration and deceleration cases. Advanced slip control systems are available in the current field of study [1-4]. Watanabe and Yamashita proposed a pattern method for the control of longitudinal slip [5]. The controller detects the slip through a threshold value. If the actual exceeds the threshold value, the motor torque reduces according to a specific pattern. Dankan and Ramachandra [6] proposed a control method based on bang-bang control strategy to keep the slip at an optimum value. The control principle based on error value which is obtained by difference between actual and desired slip. This value is used to keep the motor torque between defined maximum and minimum. Yamashita and Soeda [7] proposed a slip control method through the early detection of wheel slip convergence. The method uses less delayed rotational acceleration signal for slip detection. Above mentioned slip control strategies have effective results for slip control, however, they still do not guarantee re-adhesion if the low adhesion condition continues for long period. Furthermore, the excessive torque drops, and frequent torque oscillations are some of the weakness of above mentioned strategies.

In order to suppress the disadvantage of above discussed methods, in this study, a single neuron PID control method is proposed to control longitudinal wheel slip. The performance of the proposed control method is simulated using the mathematical model of tram-wheel test stand that is developed in MATLAB environment. The control algorithm is tested for two different cases. In first case, the control method is tested for variable reference slip value. For the second case, variable

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adhesion conditions are considered. The simulations results shows that the proposed control method has good adaptibility, and strong robustness. The response of the control algorithm regards to slip control had better performance compared to the conventional PID control method.

2 SIMULATION MODEL

To evaluate the performance of the single neuron PID controller, a numerical model of the Tram-wheel test stand have been built in MATLAB environment. The test stand which is located in VVCD, Doubravice, Pardubice built by VUKV. Stand has a full-scale tram wheel with diameter 695mm which is used in operation at present in public transportation in Prague. Wheel is driven by a torque controlled PMSM (Permanent Magnet Synchronous Motor) with a nominal torque of 852 Nm. Wheel is attached to the stand frame with a swinging arm allows the vertical movement and a pneumatic spring is located top of arm which supplies the normal force and the quantity of the force by pressure control. Roller rail with diameter 904 mm is mounted to bottom of stand with a base plate which is driven by an ASM (Asynchronous motor) with nominal torque 891 Nm. Rotational movements are measured by rotary encoders and a torque sensor is embed in the shaft between ASM and roller for measuring the confronting torque on roller rail. Illustration of the test stand can be seen in Fig. 1 with additional measuring and processing components.

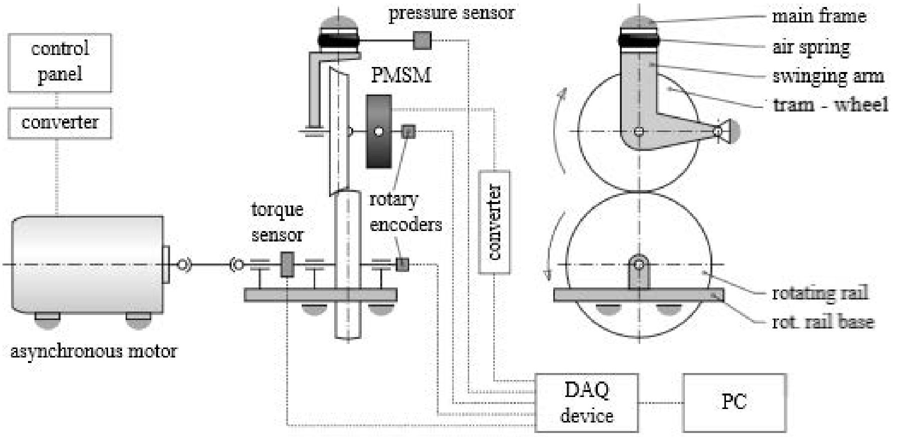

Fig. 1 An illustration of full-scale tram-wheel test stand [8]

A block diagram of the simulation model is summarized in Fig. 2. The simulation model consists of four main parts which are a PMSM, an ASM, a Polach/Freibauer contact force calculation block and a single neuron PID controller block. The former three parts of the simulation were explained in detail in previous study by Zirek et al. [9]. This paper focused on the description and performance evaluation of a single neuron PID controller. Although iterative step time for the simulations is selected as 20 μs, the response time of the controller is selected 40 μs due to limitation of the response time of the actual test stand.

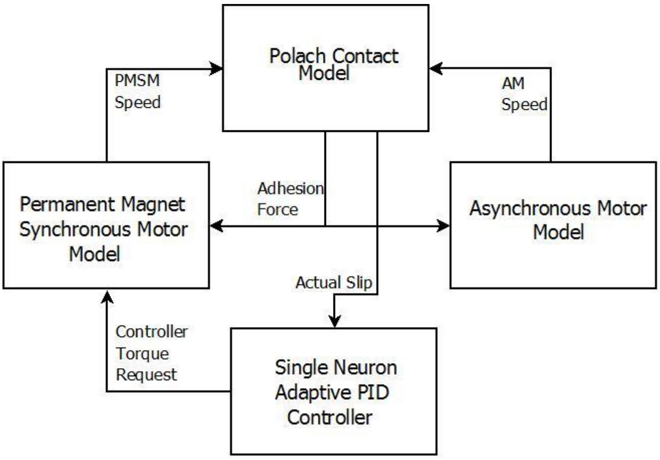

Fig. 2 Block diagram of tram-wheel test stand simulation model

3 STRUCTURE OF SINGLE NEURON PID ALGORITHM

PID is the most common control method using feedback in engineering systems. The PID controller calculates the error between the desired and actual value and applies correction based on proportional, integral, and derivative terms. The mathematical description of the controller in discrete time can be written as equation (1) [10]:

$$u(k) = u(k-1) + K_p\big(e(k) - e(k-1)\big) + K_i e(k) + K_d\big(e(k) - 2e(k-1) + e(k-2)\big) \tag{1}$$

where u is controller output, K_p, K_i and K_d are the gains of the proportional, integral and derivative terms of the PID controller, respectively, k is iterative step and T_s is sampling time. e is process tracking error and can be written as equation (2).

$$e(k) = s_{ref} - s_{act}(k) \tag{2}$$

where s_{ref} is reference slip value and $s_{act}(k)$ is actual slip.

The vital part of the PID control is the correct selection of the precise control parameters. However, this selection is not an easy process without using a special tool such as MATLAB-Simulink tuning block. Moreover, the conventional PID controller has difficulties about keeping the system stable, due to a nonlinear slip-adhesion characteristic of the tram-wheel test stand. To overcome the described issue, single neuron PID control algorithm can be used. The Single neuron control method has been implemented in numerous applications [10–13]. In this work, the single neuron PID control method will be investigated for slip control of a tram wheel-test stand. The sketch of single neuron PID controller proposed is provided in Fig.3.

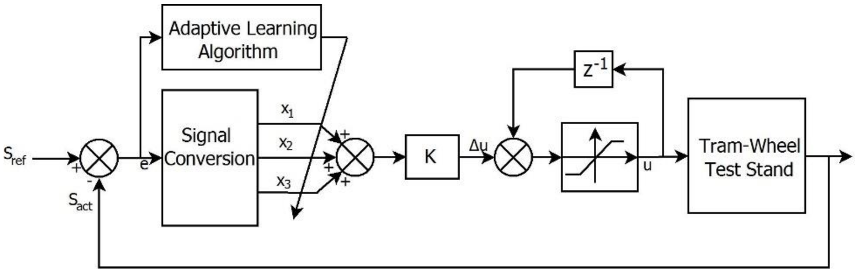

Fig. 3 Sketch of single neuron PID controller

The input of the system is error $(e(k))$ which is converted to three state variables $(x_1, x_2,\ and\ x_3)$ as can be seen in equation (3).

$$\begin{aligned} x_1(k) &= \mathrm{e(k)} \\ x_2(k) &= \mathrm{e(k)} - e(k-1) \\ x_3(k) &= \mathrm{e(k)} - 2e(k-1) + \mathrm{e(k-2)} \end{aligned} \tag{3}$$

The key element of the control the method is learning rule. Hebb learning algorithm is implemented as provide in equation (4):

$$w_i(k) = w_i(k-1) + n_i e(k) u(k-1) x_i(k) \tag{4}$$

where $n_i\ (i = 1,2,3)$ are integral, proportional and derivative learning rate, respectively. Selecting low value of learning rate will cause system to learn slowly, while excessively high value of learning rate make the controller weights diverge [11]. The weighted coefficients are calculated as follows:

$$\bar{w}_i(k) = \frac{w_i(k)}{\sum_{i=1}^{3} |w_i(k)|} \tag{5}$$

The output control torque of the single neuron PID controller is calculated as in equation (6).

$$u(k) = u(k-1) + K \sum_{i=1}^{3} \bar{w}_i(k)\, x_i(k) \tag{6}$$

where $u(k)$ is the final torque request of the controller, and K is the proportional coefficient of neuron which has to be selected bigger than zero. K affects the closed-loop gain of the systems. Choosing bigger K makes the system more robust, however, it will result overshoots in systems even may lead the system unstable. The optimum value of K is determined by trial-error method (TEM) via simulations. Moreover, the initial values of the weights are required to start the controller [10].

4 SIMULATION RESULTS

The performance of single neuron PID control has been investigated through the numerical model of the tram-wheel test stand developed in MATLAB environment. Polach/Freibauer theory is considered for calculation of contact forces that occurs between tram-wheel and roller. The initial speed of the tram-wheel and roller is selected as 20km/h. The control parameters of the traditional PID control method are set as $K_p = 4500$, $K_i = 1800$, and $K_d = 700$ by the trial and error method (TEM). The learning rate parameters of single neuron PID method are selected as $n_1 = 0.4$, $n_2 = 2$, $n_3 = 0.05$, and $K = 7000$. After trial and error (TEM), the initial values of the weights are set as

$w_1 = 8$, $w_2 = 25$, and $w_3 = 8$. The simulations were carried out for two cases. In the first case variable reference slip and in the second one variable adhesion conditions are considered.

4.1 Results

In the first part of the simulations, the slip control ability of the proposed control method and conventional PID control are tested through variable reference slip ratios. The reference slip is varied in three steps. In the first step, the reference slip is selected as 1%, for the second step, reference slip increased to 10%, and for the third step, the reference slip is decreased to 2%. The Variation of the PID control parameters during the tuning process parameters is shown in Fig. 4. It can be observed in Fig. 5, both control methods stabilize the slip at defined reference values in very short time with small overshoots, however, the results from single neuron PID control have lower overshoots and stabilize the slip faster compared to conventional PID method.

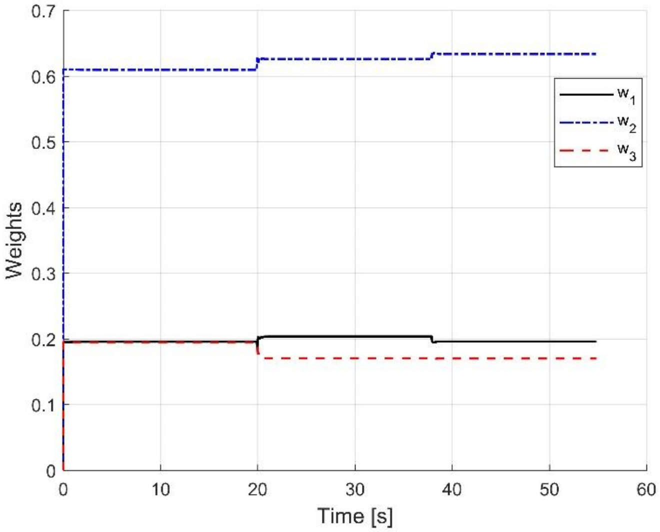

Fig. 4 Variation of the PID control parameters during the tuning process parameters

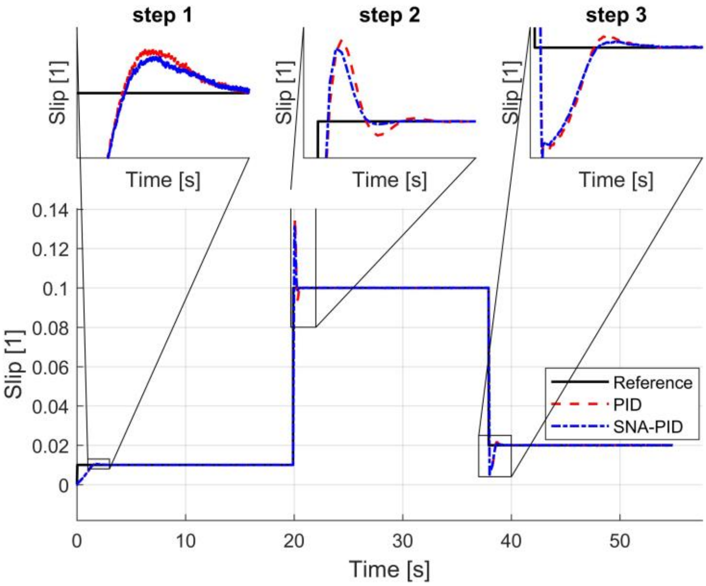

Fig. 5 Performance of conventional PID and single neuron PID controllers for variable reference slip ratio with detail of the oscillation in by particular steps

For the second part of the simulations, variable adhesion conditions are considered for the performance evaluation of the control methods. Polach/Freibauer contact parameters selection is provided as in Tab. 1. The corresponding dynamic coefficient of friction is illustrated in Fig. 6. The friction between the tram-wheel and the roller rail is suddenly dropped after 20 seconds and returned to the previous level after 38 seconds. It can be observed from the Fig. 7, both strategies have a robust reaction to sudden changes, however, there are lower overshoots in the response of the Single neuron PID control. Moreover, the single neuron PID control method stabilize slip slightly faster than the conventional PID control method.

Tab. 1 Selection of Polach/Freibauer contact parameters

	f	**k_{red}**	**A**	**B** (s/m)
Step 1	0.30	0.5	0.1	0.3
Step 2	0.26	0.1	0.2	0.3
Step 3	0.30	0.5	0.1	0.3

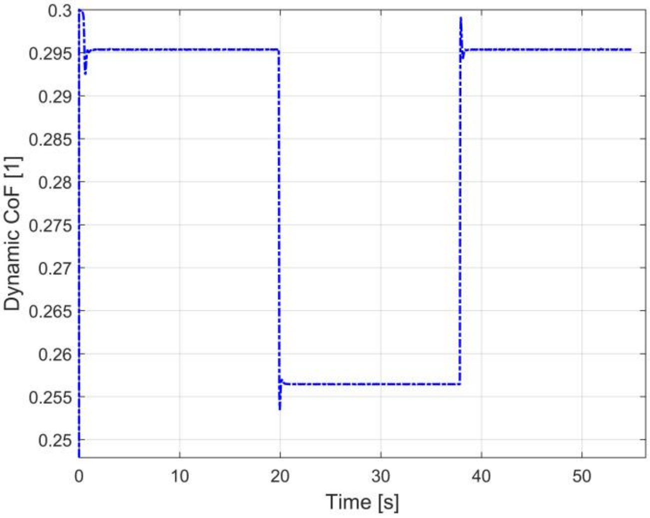

Fig. 6 The change of dynamic coefficient of friction

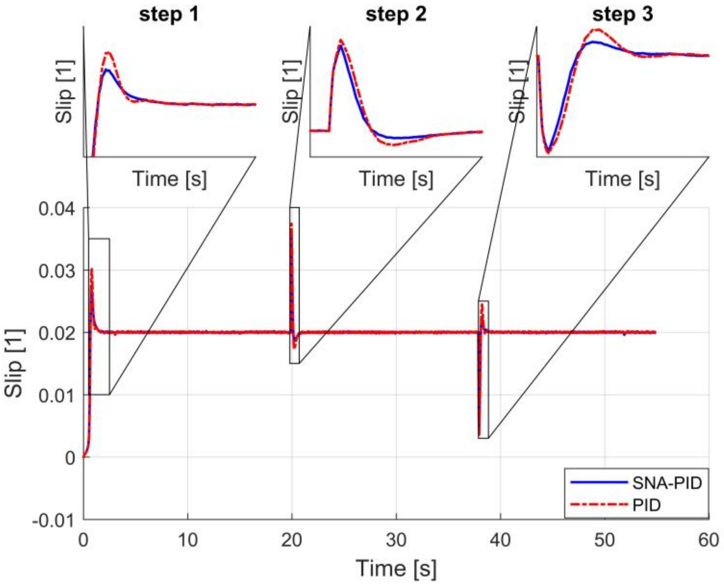

Fig. 7 Performance of conventional PID and single neuron PID controllers for variable adhesion conditions with detail of the oscillation in by particular steps

5 CONCLUSION

In this study, a single neuron PID (proportional, integral, and derivative) control algorithm is proposed for longitudinal slip control of a tram-wheel test stand. Hebb learning algorithm was employed for tuning the control parameters. The main advantages of the proposed algorithm are adaptivity, self-organizing, and self-learning. The performance of the control strategy is simulated using the mathematical model of the tram-wheel test stand that is developed in MATLAB environment. The performance of the control method was tested with variable slip ratio and variable adhesion conditions. The simulation results show that the proposed algorithm has better closed loop performance compared to traditional PID control method. The performance of the control method can be improved further by designing an adaptive proportional coefficient of neuron. Then, the single neuron PID control method can be tested with an experimentally tram-wheel test stand in the future.

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