Simulation Research For Air Power Drive System Based on PI Control

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Abstract. It established APD(Air power drive) starting drive dynamics model. The APD system is put forwarded to improve the vehicle starting drive efficiency. We analyzes the APD working principle, adds a air power and researches for the basic simulation of control model with slip-rate based on PI control theory. The academic feasibility of air power drive system is expatiated, that is based on the principle of compressed air power which is applied to the starting drive system, then establishes dynamics model of a new automotive anti-slip drive system and simulation model of ASR＆APD by the Simulink. The simulation tests are designed to compare with the curves of vehicle speed and driving wheel velocity using the APD. The curve proves that APD can reduce starting drive distance at 21%~79% and starting drive time at 13%~73%. Augmentation rate of vehicle slip ratio did not exceed 5%. The results show that APD can increase the efficiency during starting drive .

Introduction

Anti-slip Regulation (ASR) was an active safety system, which cause the driving wheels of the vehicle on the complex sueface conditions to produce the best longitudinal driving force according to mathematical algorithm and control logic of automobile driving behavior. When the vehicle starts and accelerates on low adhesion coefficient surface, the automotive driving wheel occurs dangerous operation conditions such as slip, sideslip, idling and loss direction. In order to solve this problem, automobile driving anti-slip regulation (ASR) was put forward[1]. It was an active safety system, which cause the driving wheels of the vehicle on the complex sueface conditions to produce the best longitudinal driving force according to mathematical algorithm and control logic of automobile driving behavior. Starting drive efficiency is very low on adhesion coefficient surface such as ice or snow surface[2][3]. There is no other way to improve the efficiency besides reducing engine output torque and implementation part braking torque. In order to improve starting dive efficiency, we establish the air power drive system (APD) which it is an assistant starting unti-slip system through insufflation compressed air stream to produce a air power during the starting drive system works.

Driving power of air air is applied to vehicle body by control air duct air force and air time to reduce effectively starting drive distance and starting drive time, and improve vehicle active safety. Driving force of driving wheel is reduced so that the tire has more time to work on the maximum adhesion condition ground. we put forward automobile APD control system with slip ratio as the target of PI control on ice and snow road. The PI control is a kind of manner which can achieve continuum manipulative arithmetic. The control method adopts PI control algorithm, simulates vehicle speed and driving wheel velocity curve of starting anti-slip regulation. APD is a new drive type of vehicle assistant driving unti-skid regulationn to reduce drive distance and drive time. It is very important to vehicle drivability stability and driving safety.

APD Structure Model

APD Structure. APD structure diagram is established as shown in Fig. 1. The work process is that compressed air jets through a pressure regulator, control valve to the jet duct. The jet force as jet driving force is made from nozzle exit. APD makes the anti-slip drive system actualize actively jet driving force, and controls jet driving force to reach ideal driving effects according to the slip rate and vehicle speed. APD is working with ASR on low adhesion coefficient road. Vehicle ASR controller uses PI control module which is a practical continuous control algorithm belong to a control mode of direct digital control[7][8]. The PI control slip rate as control target, and control inputs are actual slip rate of driving wheel and optimal slip rate error.
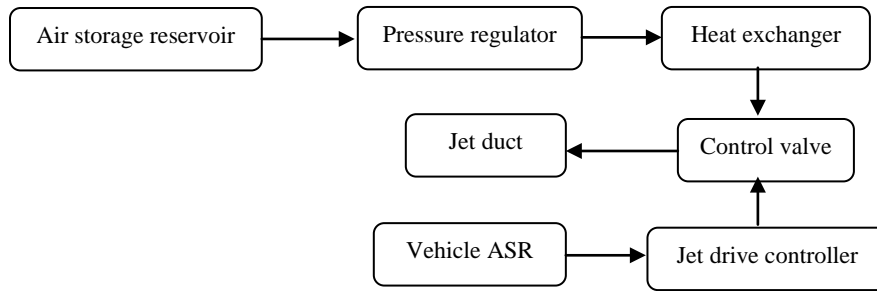

Fig. 1 APD sketch map

APD Starting Drive Dynamics Model. In order to described simply quarter vehicle APD, we maked necessary assumption and simplification. Automotive quality was distributed uniformly at each wheel; when the vehicle runs on the flat ground; we could not consider wind resistance, lateral and rolling resistance in linear vehicle kinetics and single wheel rotational dynamics, and athletics dynamics which was caused by the vehicle rotates around beeline or other wheel drives irregularily. There was not tire lateral force in a straight driving condition. The control system was a linear dynamic system without transmission delay[4][5][6]. APD starting drive dynamics model of quarter vehicle equations are expressed as given below.

$$\frac{m}{4}\dot{v} = F_x + F_j \tag{1}$$

$$I_\omega \dot{\omega} = T_t - F_x \cdot r \tag{2}$$

$$F_z = \frac{mg}{4} \tag{3}$$

$$F_x = F_z \cdot \mu \tag{4}$$

$$F_j = V_j q_v + (P_j - P_a)A \tag{5}$$

$$V_j = \sqrt{2k/(k-1)RT_j[1-(\frac{P_a}{P_j})^{(k-1)/k}]} \tag{6}$$

Where, r is the wheel radius, m is the vehicle quality, v is the vehicle speed, I_ω is the driving wheel moment of inertia, F_x is the wheel ground braking force, T_t is the wheel drive torque, F_z is the wheel and ground reaction force, μ is the road adhesion coefficient, ω is the wheel angular velocity, F_j is the jet force, V_j is the jet velocity, q_v is the mass flow, P_j is the jet pressure, A is the nozzle section area, P_a is an atmospheric pressure, T_j is the absolute temperature, k is the gas index, R is the gas moore constant.

PI Controller

The PI controller is a linear controller, according to the given value r(t) and the actual output values $\lambda(t)$ to form a control windage $e(t)$, then $e(t) = r(t) - \lambda(t)$. It sets slip rate S as the control

volume, S_0 as the expectation slip rate, then the control error is $e = s - s_0$. PI control rule can be expressed as given below.

$$u(t) = K_P e(t) + K_I \int e(t)dt \tag{7}$$

The proportion function of PI control is to make the response quickly of application system, rapidly reflect the error, and reduces the error. The proportion control can eliminate steady state error, cause oscillation aggravate in the system. The integral function is that the error is accumulated ceaselessly, eliminated with output control object. Therefore, if there is enough time, integral control will be able to eliminate completely the error. The integral rule is too strong to slow response, or to make system instability by increasing the overshoot. After the model is debugged, the parameters are K_P :950, K_I :0.05.

APD Simulation Tests

Simulation Model. Simulation model is established according to the mathematical theory of ASR ＆APD[9]. We adopt MATLAB/Simulink simulation software to establish simulation models of ASR and ASR＆APD. The simulation models include ground driving dynamics module, wheel drive module, slip rate calculation module, PI control module, drive torque adjustment module and air power drive module. Simulation model of ASR＆APD includes ASR simulation model and APD module. By changing the jet pressure of air storage reservoir, the air mass flow and the nozzle section area to control the jet force of compressed air.

   Simulation Tests of Starting Drive. In order to actualize APD to work steadily at the initial starting drive condition stage, APD control strategy is that APD starts to work after 0.6 select so that the air power driving keeps a steady status. The optimal slip rate is set to 20%, and the simulation test is over when starting drive speed is up to $7\,m/s$.

   Starting Drive Mode 1. ASR and ASR＆APD simulation test of vehicle starting drive will be experimented on wet concrete road. We can obtain curves of starting drive vehicle speed and driving wheel velocity as shown in Fig. 2 and Fig. 3, vehicle acceleration as shown in Fig. 4. slip ratio as shown in Fig 5. ASR drive distance and time are $3.388\,m$, $1.10\,s$, and ASR＆APD drive distance and time are $2.645\,m$, $0.956\,s$ in 1-mode. The slopes of vehicle speed and wheel velocity increases markedly when APD starts to drive. To set the starting drive speed, starting drive distance of ASR＆APD reduces $0.743\,m$ than ASR, curtailment rate is 21.93%. Drive time reduces $0.144\,s$, curtailment rate is 13.09%. The maximum value of vehicle acceleration is $10.57\,m/s^2$. The maximum value of slip ratio is 20.09%.
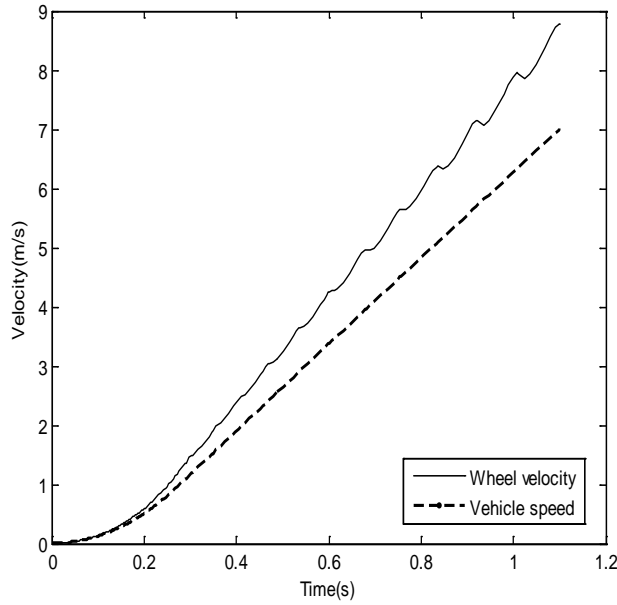
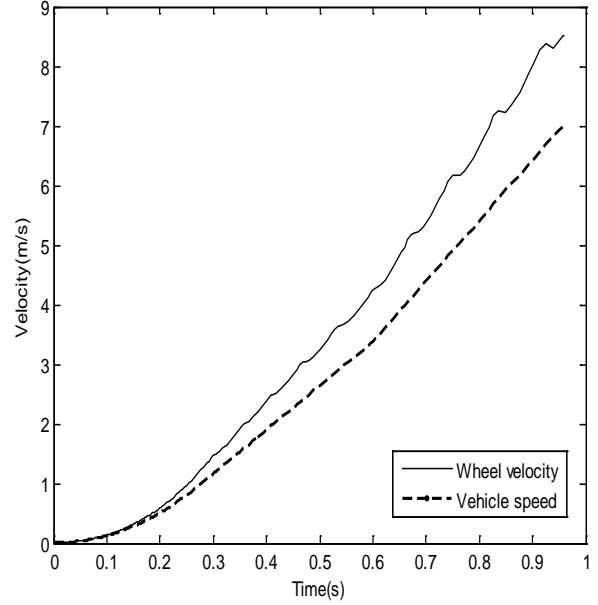Fig. 2 Vehicle speed and wheel velocity
of ASR in 1-mode

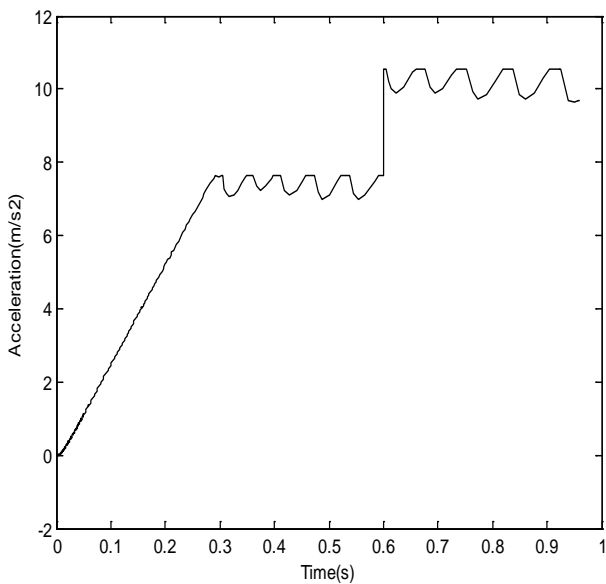Fig. 3 Vehicle speed and wheel velocity
of ASR＆APD in 1-mode

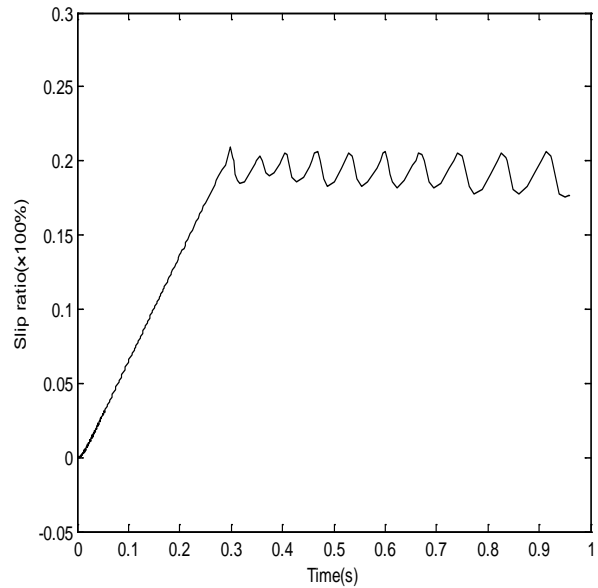Fig. 4 Vehicle acceleration of ASR＆APD in 1-mode   Fig. 5 Slip ratio of ASR＆APD in 1-mode

Starting Drive Mode 2. ASR and ASR＆APD simulation test of vehicle starting drive will be experimented on ice and snow road. We can obtain curves of starting drive vehicle speed and driving wheel velocity as shown in Fig. 6, and Fig. 7, vehicle acceleration as shown in Fig. 8. slip ratio as shown in Fig. 9. ASR drive distance and time are $33.11\,m$, $8.87\,s$, and ASR＆APD drive distance and time are $6.74\,m$, $2.307\,s$ in 2-mode. The effect of ASR＆APD working is more remarkable, and the slopes of vehicle speed and wheel velocity increases obviously. Starting drive distance of ASR＆APD reduces $26.37\,m$ than ASR, curtailment rate is 79.64%. Drive time reduces 6.563s, curtailment rate is 73.99%. The maximum mutation value of vehicle acceleration is $4.308\,m/s^2$. The maximum value of slip ratio is 23.56%. It explains that the jet force drive is effective to enhance vehicle speed. Curtailment rates of drive distance and time are more bigger so that starting drive effect is more obvious. This is mainly because that ASR engine output torque is

smaller to gain ground small driving force on low adhesion coefficient surface, APD output jet driving force is relatively large so that the vehicle acceleration increases quickly.
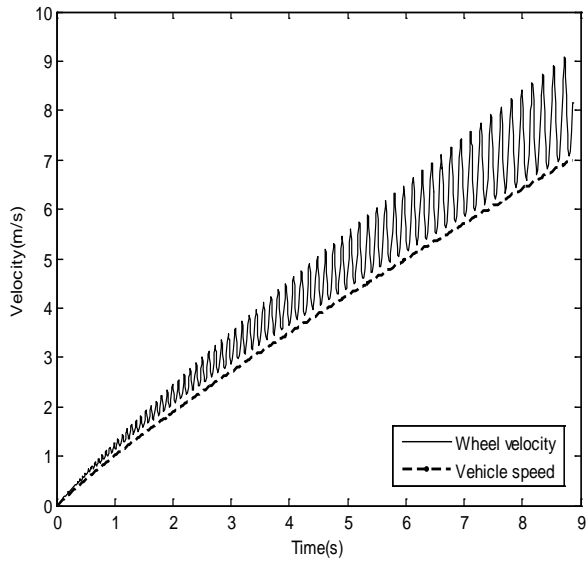
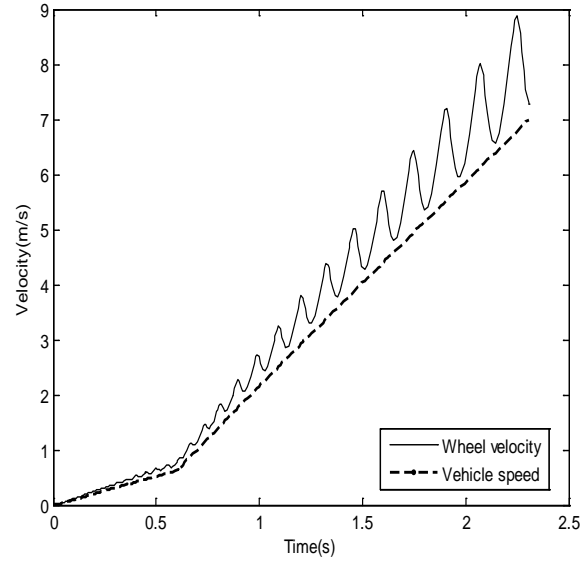

Fig. 6 Vehicle speed and wheel velocity of ASR in 2-mode

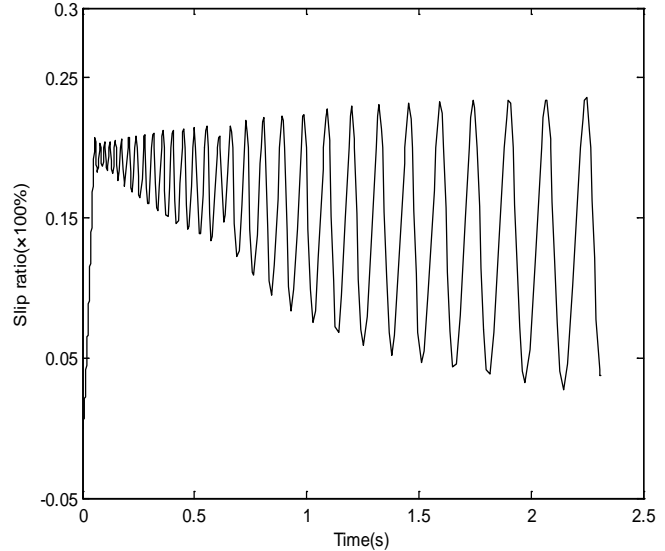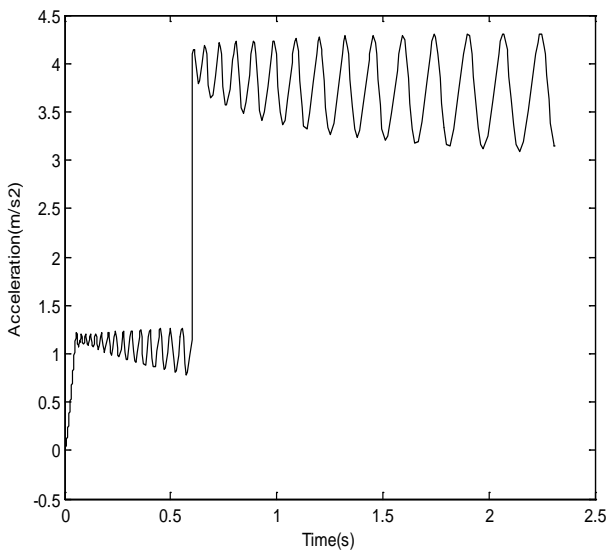Fig. 7 Vehicle speed and wheel velocity of ASR＆APD in 2-mode

Fig. 8 Vehicle acceleration of ASR＆APD in 2-mode

Fig. 9 Slip ratio of ASR＆APD in 2-mode

Conclusions

We established the APD starting drive dynamics model, researched the curve change of vehicle speed and driving wheel velocity within the APD work process. Comparison of simulation data, curtailment rate of starting drive distance with ASR＆APD is at 21%~79%, curtailment rate of starting drive time with ASR＆APD is at 13%~73% than ASR. It show that APD working effect is more obvious on low adhesion coefficient surface by simulation tests result. APD can improve efficiency of vehicle starting drive.

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