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The Inertia Simulation System Based on Hydrostatic Secondary Control

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ABSTRACT

In the study on the braking system, the inertia simulator is necessary, which is generally realized by inertia plate. Its advantage is simple and accurate, whereas the disadvantage is the larger volume and difficult to be adjusted. This paper presents a novel scheme, which is realized by hydrostatic secondary control circuit. The inertia can be increased and decreased by electro-hydraulic servo control through momentum feedback, in which a dual variable servo pump is adopted, with the velocity and torque feedback loops applied. In the beginning, it is set as speed control mode until it reaches the braking speed. Meanwhile, it turns to the sate of inertia simulator, which is the torque control mode, so as to keep the inertia as set value.

The function of inertia simulation system based on hydrostatic secondary control is to simulate the momentum, which is realized by momentum feedback control, and it can be calculated through accelerator and desired inertia. The variable pump is driven by constant pressure network, and the variable swashplate is controlled through servo valve. The torque feedback and speed feedback guarantee the control performance requirements. Since there are some problems of nonlinearity, instability, strength friction, etc. a hybrid fuzzy control method are adopted to get higher dynamic control precise and steady characteristics. It is concluded that the scheme and control method is available and validity.

KEYWORDS

Inertia Simulator; Hydrostatic Secondary Control

NOMENCLATURE

J^* : simulated inertia;

θ_L : angle of load;

K_D : radian displacement coefficient;

K_P : system pressure;

J_m : secondary unit inertia;

J_L : inertia of load;

K_F : torque sensor coefficient;

B_m : secondary unit damping constant;

G_m : torque sensor elastic ratio;

$\dot{\varphi}$: Swash speed;

T : torque;

θ_m : angle of secondary unit

INTRODUCTION

By now, Antiskid Brake System (ABS) has been widely used in aeronautics, automobile and other fields. During the research and development, it is necessary to implement the braking tests in order to get optimal performance and designation parameters [5].

The inertia simulation device is needed in the test, which is used to simulate the real mass of the aircraft or automobile so as to obtain the inertia of tested system [4]. Conventionally, equivalent inertia plate is adopted, which is simple and accurate while the volume is large. So it is difficult to adjust the inertia smoothly in any direction according to the actual requirement.

Using hydrostatic secondary control circuit, the inertia can be increased and decreased smoothly by electro-hydraulic servo control through momentum feedback, in which a dual variable servo pump is adopted, with the velocity and torque feedback loops applied. In the beginning, it is set as speed control mode until it reaches the braking speed. Meanwhile, it turns to the sate of inertia simulator, which is the torque control mode, so as to keep the inertia as set value.

Secondary control is defined as the regulation of secondary component in constant pressure network. In the application, the system pressure is not always absolutely constant, considering the dynamic characteristics of oil source, pressure storage device and the disturbance of other factors to oil source. Hydrostatic secondary control system can work in four quadrants, that is, it can work in pump condition as well as motor condition. The energy losing is little and it can be recycled, besides, it is not sensitive to load variation.

Domestically or aboard, closed loop speed regulation is usually carried out by secondary control, and this is the speed control mode of inertia simulation. Now, some torque servo system based on this theory appears, such as load simulator[1，2], and its maximal advantage is no extraneous torque, which means that it is not sensitive to load variation. Therefore, during braking test, there is little disturbance to output torque for braking pressure change.

SYSTEM ANALYSIS

The function of inertia simulation system based on hydrostatic secondary control is to simulate the momentum, which is realized by momentum feedback control, and it can be calculated through accelerator and desired inertia. The inertia simulation system is shown in Fig.1. Secondary control inertia simulation a kind of electro-hydraulic torque servo control system, in which the output torque is adjusted by the regulation of the swashplate angle in constant pressure network. In Fig.1, the inertia plate is used to simulate the road surface, and driven by secondary component output shaft. The two systems interfere with each other.

In order to work on the state of torque and velocity feedback, the torque sensor and velocity sensor are amounted on the pump output shaft with a connected small inertia plate against braking disc, which is of mid value of the inertial simulated. Output torque and swashplate angle are fed to control computer by A/D, and the control computer controls the servo valve and actuator by given control law, so as to control the torque. In the testing system, the computer still to gather the velocities of inertia plate and tyre wheel simultaneously in order to simulate the ABS under real condition. Pressure sensor is mounted for the sake of the variation observation of system pressure. Oil system's constant pressure must be regarded to guarantee the dynamic performance of system, so the fixed quantity pump and overflow valve system of wide frequency is adopted.

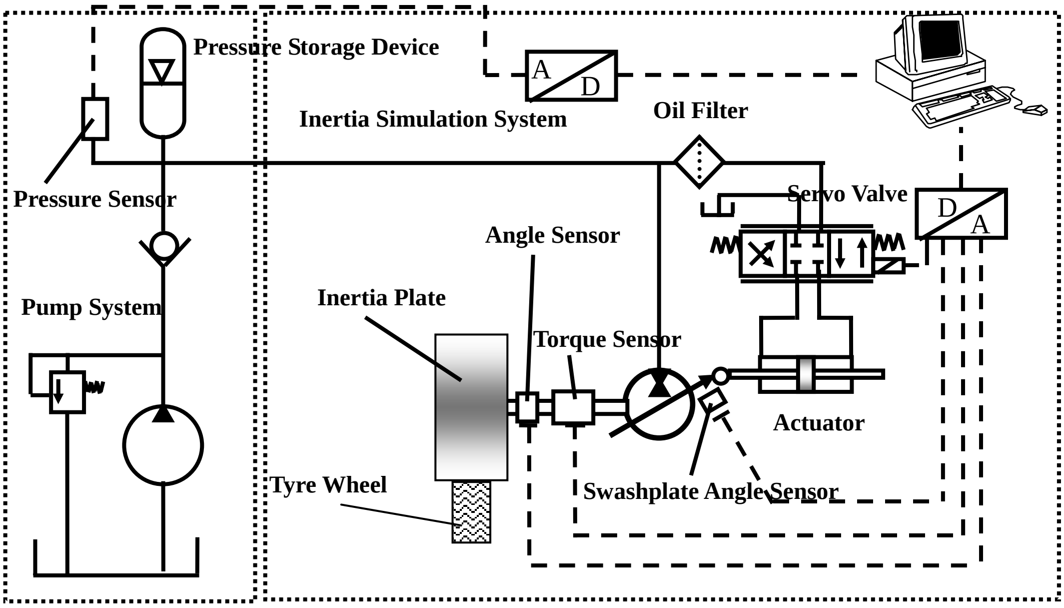

Fig.1. Diagram of Inertia Simulation System Based on Secondary Control

CONTROLLER DESIGNATION

The inertia simulator based on secondary control is not a complicated multi-variables coupling system, but there are certain nonlinearity and time varying characteristics in it. For instance, inertia simulation based acceleration signal of system presence delay，causing fluctuation of inertia torque，influencing system dynamic performance；the servo valve flux is the nonlinear function of oil pressure, load pressure and the valve core displacement, and it has a great effect on forward magnification coefficient of servo system; Furthermore, with the increasing simulation time, the oil temperature variation induces the transformations of viscidity and elasticity, and this represents the time varying characteristic of system. Under this circumstance, the precise mathematical model is difficult to be obtained.

Fuzzy controller can't study by itself and eliminate the steady state error, but its implementation is very convenient for its simpleness, also it can improve the system robust effectively.

The integral control can be introduced in the controller in order to improve the steady state performance, which can eliminate the steady state error, but the dynamic response is slow, so integration [3] of PID controller and Fuzzy controller constitutes Fuzzy-PID compound controller to improve the steady state performance of Fuzzy controller, which is shown in Fig.2.

In the big error range, it adopts fuzzy control, and in small error range uses PID control. The conversion between two controls is automatically carried out by command programmed in advance. The conversion method includes direct switch, straight line switch and exponential switch, etc.

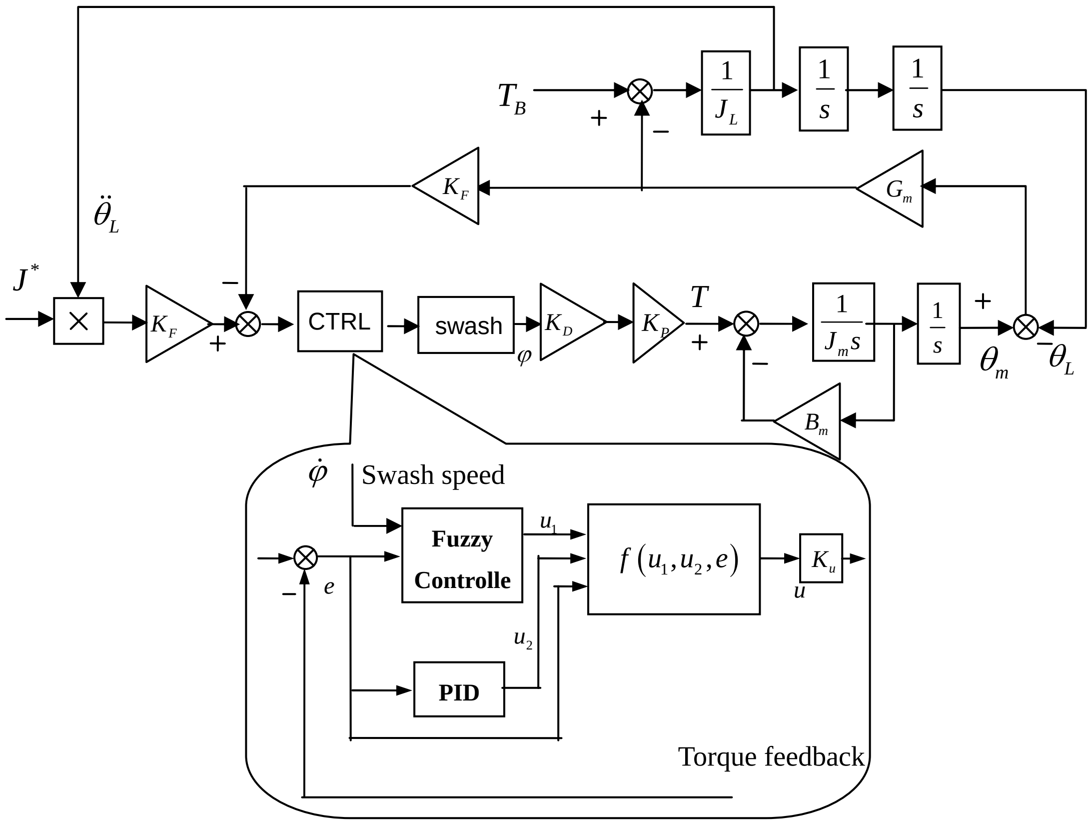

Fig.2. Diagram of Fuzzy PID Controller

In Fig.2 $f(u_1, u_2, e)$ is transition function of Fuzzy control and PID control. According to current error, to determine the controlled output u , u is a certain integration of u_1 and u_2 . According to the three conversion methods mentioned above, f can be calculated as follows.

$$u = \begin{cases} u_1 & |e| > \alpha \\ u_2 & |e| \le \alpha \end{cases} \tag{1}$$

Namely, if absolute value of error is less than a certain set value, the system uses the PID controller output, otherwise, uses the Fuzzy controller output. In the formula, $\alpha > 0$ is the threshold.

$$u = \begin{cases} u_1 & |e| > \frac{e_{\max}}{k_e} \\ u_1 \frac{k_e |e|}{e_{\max}} + u_2 \left(1 - \frac{k_e |e|}{e_{\max}}\right) & |e| < \frac{e_{\max}}{k_e} \end{cases} \tag{2}$$

Namely, if absolute value of error is larger than a certain set value, the system uses the Fuzzy controller output, otherwise, uses the linear integration of the two controllers as the ultimate output. In the output, the proportions of each controller is determined by coefficient k_e, where, $e_{max} > 0$ is conversion threshold.

$$u = u_1\left(1 - \exp\left(-\alpha|e|\right)\right) + u_2 \exp\left(-\alpha|e|\right) \tag{3}$$

This method doesn't need to set threshold. It uses exponential relation to integrate from zero to infinite. The change speed along the exponential curve is determined by α. α is the larger, change is the steeper.

SIMULATION ANALSIS

Brake sharply

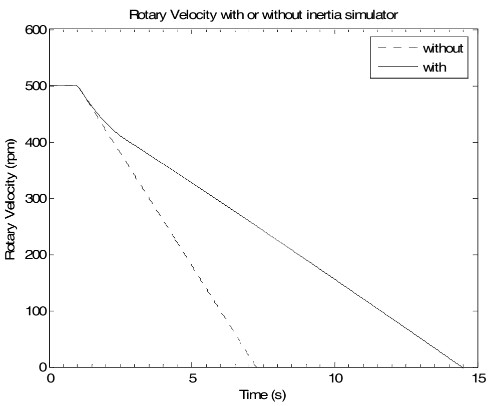

Fig 3. Velocity with or without inertia simulator

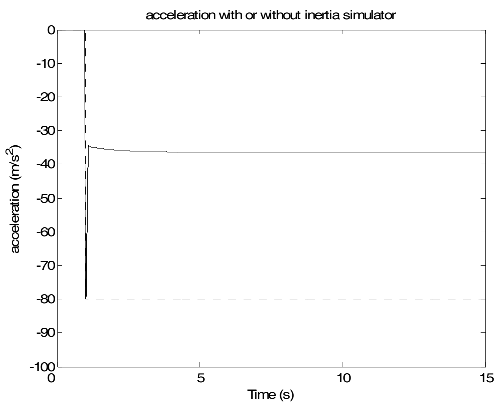

Fig 4. Acceleration with or without inertia simulator

Using the method mentioned above, some simulations are done. Firstly, the inertia plate is initialized to a velocity of 500rpm. After 1 second, change the braking torque to 100Nm directly like a step. While the inertia simulator is used, the total inertia is greater than the one which inertia simulator is not used. So the simulator suppresses the deceleration by reduce acceleration to a small constant of about 37Nm quickly. See figure 3 and figure 4.

In this case, the actual inertia changes sharply to the expected value with a little over shoot, so does the torque control performance, which the actual torque reaches the expected one. See figure 5 and figure 6.

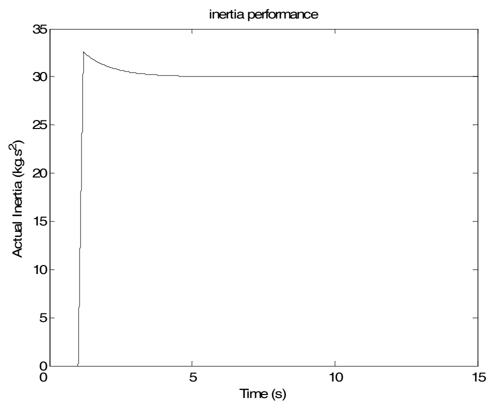

Fig 5. The actual inertia

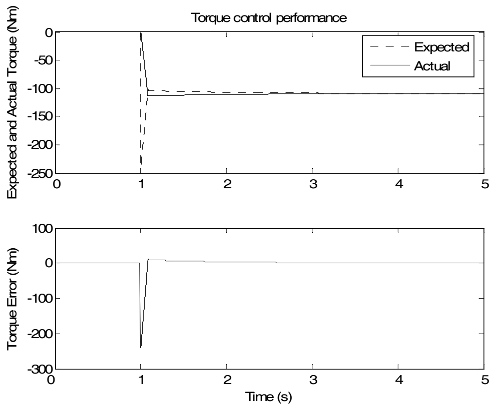

Fig 6. Torque tracing

Brake gradually

Here, the inertia plate is initialized to a velocity of 500rpm. After 1 second, change the braking torque by adding 10Nm per second. While the inertia simulator is used, the total inertia is greater than the one which inertia simulator is not used. So the simulator suppresses the deceleration by reduce acceleration compared to the one without inertia simulator. See figure 7 and figure 8.

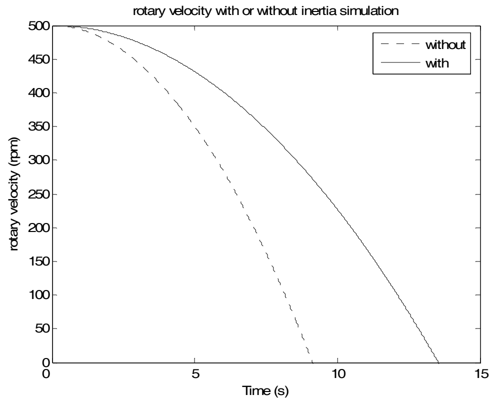

Fig 7 velocity with or without inertia simulator

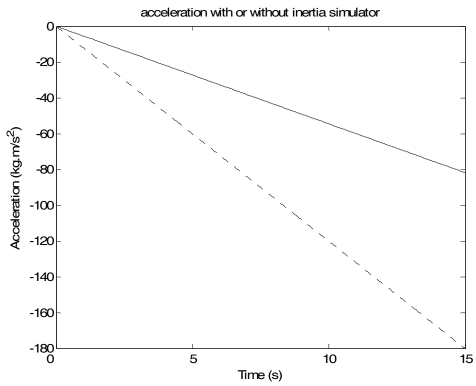

Fig 8. acceleration with or without inertia simulator

In this case, the actual inertia changes sharply to the expected value with no over shoot. And the actual torque traces the expected one well. See figure 9 and figure 10.

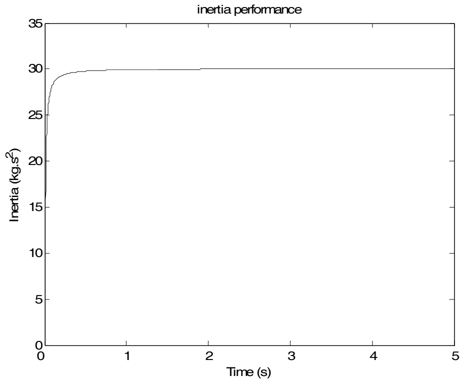

Fig 9 actual inertia

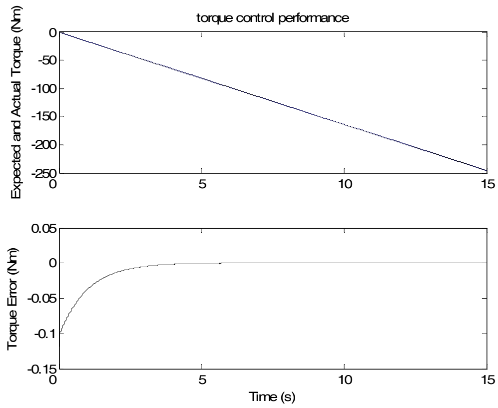

Fig 10. torque control performance

CONCLUSION

For the complex structure, nonlinear and mathematical model complexity of inertia simulation system based on secondary control, this paper presents a fuzzy control scheme, its structure is simple and performance is fine. The scheme characteristics are as follows.

The torque error and its change are two inputs of fuzzy control. The swashplate speed is the third input, and its membership function is specially designed to eliminate the influence of static friction torque and to minimize the time of zero speed;

Using pressure signal to carry out feed-forward compensation, according to the pressure change to adjust the system output gain so as to compensate the torque fluctuation;

Integrating Fuzzy Controller and PID Controller organically, and using exponential conversion method to regulate the ultimate output proportion of two controllers.

The experiment results show that the control effect of fuzzy controller is fine, the system exceedance is small, and the response is rapid. It is also indicated that is necessary to introduce Fuzzy-PID control to eliminate steady error and minish dead area, and also necessary to introduce pressure variable gain to restrain the influence of pressure fluctuation.

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