Simulation of Hydraulic Suspension System of Electric Tractor Based on Matlab-AMESim

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Abstract: For electric tractor engine power output characteristic, a load sensitive hydraulic suspension system in front of the valve is designed. In order to meet the operation requirements of different soil conditions when the electric tractor is plowing, and to improve the dynamic response characteristics of the system and the uniformity of tillage depth, a fuzzy PID based resistance-position combined adjustment tillage depth control strategy is designed. The hydraulic system simulation model is established based on AMESim, and the fuzzy PID controller model is established using Matlab. Through the joint simulation of AMESim and Matlab, the control performance of hydraulic suspension system of electric tractor with different resistance-position comprehensive proportional coefficients is analyzed. The simulation results show that the control strategy of tillage depth based on fuzzy PID is more responsive and anti-interference strong ability, the resistance-position combined adjustment has higher adaptability to different soil changes and operation methods than a single resistance adjustment or position adjustment.

1. Introduction
As the energy crisis continues to intensify and the emission requirements of non-road vehicles increase, domestic and international research on electric tractor technology has been increased. The tractor suspension system is used to pull machinery for agricultural operations, and control the lifting of agricultural machinery. Its control performance has a greater impact on the operating efficiency and traction efficiency of the whole machine [1]. The research of electric tractor hydraulic suspension control technology can improve the traction efficiency and endurance of the whole machine, which plays an important role in the development and application of electric tractors.

At present, the research on electric tractor technology mainly focuses on the whole machine structure, power system and energy system [2, 3], and there is little research on electric tractor suspension system [4]. The electric suspension system of the electric tractor realizes the lifting of agricultural machinery through the forward and reverse rotation of the motor. A separate electric motor is required to provide power for the suspension system, resulting in a waste of effective power; the
working conditions of the electric tractor are complex, the electric suspension device has poor impact resistance, large wear and high failure rate [5]. The hydraulic suspension system has the characteristics of flexible layout, strong overload capacity and high efficiency, which is more suitable for the needs of electric tractor suspension system.

In summary, according to the power output characteristics of the electric tractor, this paper designs a hydraulic suspension control system for the working characteristics of electric tractors, and a resistance-position combined adjustment strategy based on a fuzzy PID control is designed. Through AMESim and Matlab joint simulation, the performance of the electric tractor hydraulic suspension control system is verified.

2. Hydraulic suspension control system of the electric tractor

2.1 Principle of hydraulic suspension system
Traditional tractor transmission systems usually have multiple gears to ensure that the whole machine can often work in high efficiency area. Different from traditional tractors, the drive motor of electric tractors has the characteristics of constant torque in low speed area and constant power in high speed area. Its characteristics are quite different from those of traditional tractors. According to the power output characteristics of the electric tractor, the hydraulic suspension system for lifting agricultural implements is designed. It can be seen from the figure 1, when the electric tractor is working, the drive motor can output different stable speeds. When the inclination angle of the load sensitive pump is within the adjustable range, the output flow of the load sensitive pump is only related to the opening of the main control valve spool. When the displacement of the load sensitive pump reaches the limit value, the pump output flow will increase with the increase of the motor speed. The load sensing hydraulic system of electric tractors has the advantages of simple control, high efficiency, and low power loss.

![Figure 1 Principle of electric tractor hydraulic system](image)

1. Variable pump 2. Control piston 3. Pressure shut-off valve 4. Load sensing valve 5. Pressure compensator 6. Electro-hydraulic reversing valve 7. Shuttle valve 8. Hydraulic cylinder

2.2 Adjustment method of tillage depth
The hydraulic suspension system is used to adjust the soil depth of agricultural machinery according to the different working environment. An important indicator of tillage quality is the uniformity of tillage depth. The hydraulic suspension system usually adopts resistance adjustment or position adjustment to ensure the farming quality. The position adjustment can maintain a uniform tillage depth or height from the ground when the ground is flat, when the ground is uneven, the farm implements can not be as high as the ground, and the stability of traction load and the uniformity of the tillage depth of the whole machine are poor. With resistance adjustment, when the working depth mainly changes due to
the undulation of the ground, the stability of the traction load of the whole machine and the uniformity of the tillage depth are better; when there is a big difference in soil solidity, it can only ensure the fluctuation of the traction load of the whole machine, which has a great influence on the uniformity of tillage depth. Resistance-position combined adjustment sets a ratio of resistance adjustment and position adjustment to participate in system control, which makes its working characteristics of resistance adjustment and position adjustment have better control effect under various soil tillage conditions [6].

As shown in figure 2, the displacement signal detected by the displacement sensor is converted into a tillage signal \( H_1 \), and the resistance signal detected by the resistance sensor is transformed into a tillage signal \( H_2 \). The tillage signals \( H_1 \) and \( H_2 \) are integrated proportions. The coefficient is weighted and used as a feedback signal of tillage depth. The feedback of the tillage depth signal is compared with the target tillage depth signal to obtain an error signal. The error signal is processed by the controller as the input signal of the electro-hydraulic proportional reversing valve. The signal size controls the spool opening of the electro-hydraulic proportional reversing valve. By adjusting the output flow of the hydraulic system, the tillage depth or working height of agricultural machinery can be controlled.

![Figure 2 Structure principle of resistance-position combined adjustment control system](image)

3. Design of fuzzy PID controller

According to the tillage depth control principle of the hydraulic suspension system of electric tractor, there is a certain hysteresis loss in the system at the initial and commutation time; the electro-hydraulic proportional directional valve has certain dead zone characteristics, which leads to certain non-linearity and hysteresis of the system. The change of soil specific resistance and tillage depth are non-linearity and time-varying in the process of tillage. It is difficult to achieve the ideal control effect of the system by using traditional PID control strategies. Aiming at the problems of traditional PID control effect and poor adaptability, a control method combining traditional PID control algorithm and fuzzy algorithm was adopted. Fuzzy control rules are established through control experience, and PID control parameters are adjusted in real time by using fuzzy principle. The fuzzy PID control algorithm makes full use of the simple structure, high control performance and strong adaptability of traditional PID control algorithm. It can be applied to the working conditions of electric tractors, and optimally control the tillage depth of the hydraulic suspension system.

3.1 Fuzzification and deblurring

The control system compares the feedback tillage depth signal with the target tillage depth signal to obtain the tillage depth error \( e \), which is differentiated to obtain the tillage depth error change rate \( ec \), and takes the tillage depth error \( e \) and the tillage depth error change rate \( ec \) as the the fuzzy PID controller input. and the output quantities \( \Delta K_P \), \( \Delta K_I \) and \( \Delta K_D \) are the parameter corrections of the PID controller. The basic domain of the input error \( e \) of the fuzzy PID controller for tillage depth is [-300, 300], the basic domain of the variation rate of the tillage error \( ec \) is [-100, 100], and their discrete domain are [-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6], the quantization factors are \( K_e=0.02 \), \( K_{ec}=0.06 \). The basic domain of fuzzy PID controller output \( \Delta K_P \) is [-300, 300], the basic domain of \( \Delta K_I \) is [-3, 3], the
basic domain of $\Delta K_D$ is $[-3, 3]$, and the three discrete domains are $\{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$, the scale factors are $U_p=50, U_I=0.5, U_D=0.5$. Considering the simplicity of operation, the triangular membership function is selected, as shown in Figure 3.

![Figure 3 Membership function of input and output](image)

3.2 Formulate fuzzy control rules
According to the change of tillage depth error $e$ and tillage depth error change rate $ec$, the three parameters of proportional coefficient $K_P$, integral coefficient $K_I$ and differential coefficient $K_D$ are adjusted in real time, so that the system has better dynamic or static output characteristics. If the tilling depth error $e$ is large, no matter how large the tilling depth error change rate $ec$ is, in order to speed up the response speed of the hydraulic suspension control system while avoiding the differential integral saturation, a larger $K_P$ value, a smaller $K_D$ value and a $K_I$ value should be used, usually $K_I=0$ to avoid large overshoot in the hydraulic suspension control system; if the tillage depth error $e$ and the tillage depth error change rate $ec$ are moderate, you can choose to take a smaller $K_P$ value, a moderate $K_D$ value and a moderate $K_I$ value. To ensure the response speed of the control system; if the tillage depth error $e$ is small, a larger $K_P$ value and $K_I$ value should be selected to ensure good stability of the control system. When $ec$ is larger, choose a smaller $K_D$ value. When it is smaller, choose a larger $K_D$ value to ensure the system has a strong anti-interference ability. Figure 4 shows the membership of the input and output in the fuzzy controller.

![AKP Surface observer](image)

![AKI Surface observer](image)
4. Joint simulation analysis of hydraulic suspension system of electric tractor

4.1 Build a simulation model
The hydraulic suspension system of the electric tractor adopts AMESim and Matlab, a SimuCosim interface module is established in AMESim, in which the input and output quantities and names are defined for system compilation. Select the AME2SLCosim interface module in the Matlab model library, define the compiled file of the hydraulic system in AMESim as this module, and send the signal to the hydraulic system to control the speed and stroke of the hydraulic cylinder piston through this module.

As shown in figure 5 and figure 6, the mass block M represents the weight of the entire suspension unit of the electric tractor. The displacement sensor is used to detect the displacement of the hydraulic cylinder piston. There is a linear relationship between tillage depth and displacement of hydraulic cylinder piston, so the tillage depth of agricultural machinery is detected by displacement sensor. There is a linear relationship between the resistance of farm implements and the tillage depth, and the resistance sensor is used for detecting the resistance converted by the resistance signal converter. The displacement signal detected by the hydraulic cylinder is transformed into tillage depth $H_1$ through the functional relationship, and the resistance signal of the agricultural implement detected by the resistance sensor is transformed into tillage depth $H_2$ through the functional relationship, a is the proportional coefficient involved in the comprehensive proportional control, $(1-a)$ is the proportional coefficient involved in the comprehensive proportional control, the tillage depth signal $H=aH_1+(1-a)H_2$, and the comprehensive proportional coefficient a is represented by K. The damper represents the resistance change during the movement of the suspension unit.
4.2 Performance analysis of joint simulation

In order to verify the control characteristics of resistance-position combined adjustment of the hydraulic suspension system of an electric tractor, a random signal and a step signal are added to the system. The random signal simulates the change of the soil specific resistance during the operation of the hydraulic suspension system, as shown in Figure 7; the step signal is used, which represents the working condition where the specific resistance of the working soil of the machine changes exponentially or is blocked by obstacles, as shown in Figure 8. The target tillage depth is set at 30cm, and the comprehensive scale coefficients k of different resistances were 0, 0.2, 0.4, 0.6, 0.8 and 1, respectively, and the tillage depth curves and resistance curves under different comprehensive scale coefficients were obtained.

It can be seen from figures 9 and 10 that after adding the step interference signal, when a=0, the control signal is completely the resistance control signal at this time, and the interference resistance has a greater impact on the change of tillage depth, but has almost no effect on the change of traction resistance. At this time, the traction load stability of the electric tractor is good, but the uniformity of the tillage depth is poor. When a=0.2, position control and resistance control are involved in the control signal at this time, and the influence of interference signal on the change of tillage depth is reduced, while the influence on the change of traction resistance is increased. With the increase of the comprehensive proportional coefficient, the proportion of position adjustment increases gradually, the influence of interference signals on the change of tillage depth decreases gradually, and the influence on the change of traction resistance increases gradually. When a=1, the control signal is a complete position control signal, and the interference signal has little effect on the change of tillage depth, but has a great influence on the change of the traction resistance. At this time, the traction load of the electric tractor is large and the traction efficiency is low.
The advantage of resistance-position combined adjustment is that the comprehensive proportional coefficient can be selected according to the difference of the actual farming environment, that is, the proportion of position adjustment and resistance adjustment involved in the resistance-position combined adjustment can be adjusted, so as to obtain better tillage depth uniformity and stable traction load of the whole machine. In operating conditions such as shallow tillage or large differences in soil firmness, the control of tillage depth should be mainly based on position adjustment, and the selection of the resistance position comprehensive coefficient should tend to 1; Under operating conditions such as deep tillage or uneven terrain, the control of tillage depth should be based on resistance adjustment, and the selection of resistance position comprehensive coefficient should tend to 0. Compared with single position adjustment or resistance adjustment, the resistance-position combined adjustment has higher adaptability to different soil changes and operation methods, which enables electric tractors to obtain higher farming quality and traction efficiency in the actual farming process.

5. Conclusion
According to the operating characteristics of electric tractors, the hydraulic suspension control system of the load sensitive pump is designed, and the tillage depth control method for comprehensive adjustment of resistance position is analyzed. The farming control strategy of hydraulic suspension system based on fuzzy PID control is designed, the hydraulic suspension system model and fuzzy PID controller model are established, and the simulation is carried out by using the joint simulation model of AMESim and Matlab. The results show that the hydraulic suspension control system of electric tractor can make the whole machine have higher farming quality and traction efficiency in different soil environments, and can effectively improve the working efficiency and working time of the electric tractor. It meets the operation requirements of electric tractors and lays a theoretical foundation for the study of hydraulic suspension control systems of electric tractors.
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