Advances in Engineering Research, volume 119
2nd International Conference on Automatic Control and Information Engineering (ICACIE 2017)

Control Strategy and Simulation of Vehicle Leveling for Heavy Transporter Plane

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Abstract—Heavy transporter plane is the carrier for segmented hull in modern shipbuilding. Its positioning accuracy directly affects the installation accuracy of hull, therefore it is necessary for the heavy transporter plane to improve the accuracy of leveling control by hydraulic automation. The leveling strategy of coplanar type is proposed for adjusting the heavy transporter plane and avoiding the virtual leg with four-point positioning. Furthermore, AMESim and Matlab/Simulink are used to establish the simulation model of rising-leveling system for improving the hydraulic suspension of the heavy transporter plane. Considering the nonlinear and time-varying properties in hydraulic suspension system, the control strategy with dual-mode fuzzy controller is employed to converge the systemic leveling error promptly and improve the positioning accuracy and dynamic performances of the hydraulic suspension. The simulation results show that control strategy with dual-mode fuzzy controller performs a higher positioning accuracy and anti-load interference with a shorter adjusting time. The control strategy can meet the practical requirement with a precision 2.0mm for leveling positioning when the segmented ship is docked.

Keyword—Heavy transporter plane; Hydraulic suspension system; vehicle leveling positioning; dual-mode fuzzy control; Systemic simulation

I. INTRODUCTION

Modern shipbuilding is a process of subsection manufacture and general combination. The positioning accuracy of heavy transporter plane mainly determined by the performances of its hydraulic leveling system directly affects the installation accuracy of hull in the process of ship blocks merging. At present, the main researches are focused on the performances of single leg hydraulic suspension loop [1-4], while further researches on the performances of the hydraulic leveling system for platform lorry are still not sufficient. It is necessary to investigate the automatic hydraulic leveling control of heavy transporter plane with the increasing demand for the performances of leveling positioning accuracy. In this paper, the research on the automatic precise hydraulic leveling control of heavy transporter plane are conducted based on the improvement of heavy transporter plane WTW175B developed in a special vehicle Co., Ltd.

II. LEVELING CONTROL STRATEGY FOR PLATFORM LORRY

Due to unevenness resulting from uneven load distribution, road conditions like turning and braking during the process of ship blocks merging, it is necessary to analyze the suspension hydraulic system and adopt appropriate control strategy to improve the levelness of heavy transporter plane. Because of the limited space, leveling analysis is carried out for the failure of bearing platform caused by uneven load distribution when the platform lorry stops moving horizontally in this paper.

According to the number of fulcrums, the leveling of heavy transporter plane can be divided into three classes[5]: three-point, four-point and six-point. Among these leveling methods, the four-point leveling is studied in this paper. In the model of four-point leveling, the suspension system of platform lorry consists of four groups of suspension fulcrums, i.e. A, B, C and D, to realize the four-point support. The tilt sensor is installed on each suspension fulcrum to detect the height of each fulcrum in real-time, and the deviation of the suspension height will be controlled and adjusted by the electro-hydraulic leveling system when it is beyond the allowable range. This control method based on position deviation has three strategies [6]: 1) "chasing" leveling with the highest point fixed, 2) "chasing" leveling with the lowest point fixed, and 3) leveling with the center point fixed. The common defect of these three leveling strategy is that "virtual leg" appears at one of the fulcrums because the fulcrums perhaps are not on the same plane when each fulcrum rises or falls alone during the leveling process. For the avoidance of "virtual leg", the four points must be guaranteed on the same geometric plane. According to this, a "coplanar" rising-leveling method [7] is proposed and its leveling principle is shown in Fig.1. The height deviation of each suspension fulcrum from the highest point is calculated based on the detection value of the angle sensor. These deviation values are employed to control and drive hydraulic cylinders to a given height to make all the fulcrums at the same height. Beside, each fulcrum should be on the same plane during the process of leveling.

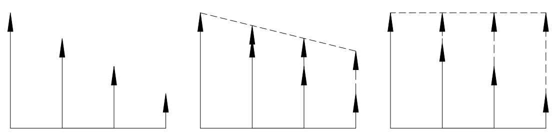

Fig. 1. Schematic diagram of the "coplanar" rising-leveling

In order to solve the mutual coupling among the four fulcrums of hydraulic cylinder, the four suspension fulcrums are regarded as four subsystems, each of which is a proportional valve controlled closed-loop position control system whose outputs are positions and forces while the output positions and forces of other subsystems are the interferences.

III. Leveling Simulation Model for the Whole Vehicle Based on the "Coplanar" Rising-Leveling

A. *Leveling control principle and its mathematical model*

Three-point suspension support is adopted in the previous hydraulic leveling system of the heavy transporter plane WTW175B with poor positioning accuracy and stability. Aiming at the disadvantages of three-point support, four-point support is proposed with each fulcrum installed a proportional valve controlled closed-loop position control system, whose schematic diagram is shown in Fig.2. The attitude signals measured by tilt sensors are transmitted to the control system. Then, the difference between each fulcrum height and the reference suspension height, namely the height deviation of each fulcrum, is obtained. When the deviation excesses the allowable value, the piston cylinder will be driven to output a displacement to realize the control and adjustment of tilting posture.

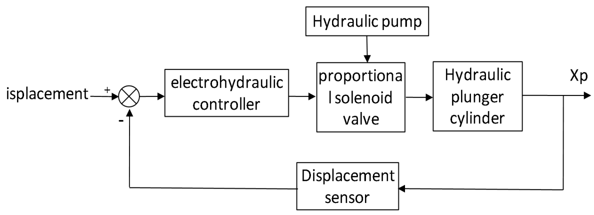

Fig. 2. Schematic diagram of leveling control

Transfer function for each main component [8]:

In engineering, the transfer function of electro-hydraulic proportional valve is generally represented by the two-order oscillation section.

$$G(s)=\frac{Xv(s)}{I(s)}=\frac{K_{sv}}{\frac{s^2}{\omega_{sv}^2}+\frac{2\zeta_{sv}}{\omega_{sv}}s+1} \tag{1}$$

Where K_{sv} ($m^3/s\cdot A$), ω_{sv} and ζ_{sv} are the flow gain, natural frequency and damping ratio of proportional valve respectively.

The flow continuity equation of hydraulic piston cylinder is

$$Q_L=A_P\frac{dx_P}{dt}+C_{ep}p_L+\frac{V}{\beta_e}\cdot\frac{dp_L}{dt} \tag{2}$$

The flow of slide valve in electro-hydraulic proportional valve is

$$Q_L=C_dWx_V\sqrt{\frac{2(p_S-p_L)}{\rho}}=C_dx_vW\sqrt{\frac{2\Delta p}{\rho}} \tag{3}$$

The equilibrium equation of piston cylinder is

$$A_pp_L=m_t\frac{d^2x_p}{dt^2}+B_P\frac{dx_p}{dt}+Kx_p+F_L \tag{4}$$

The Laplace transforms of equation (2), (3) and (4) respectively are

$$Q_L=A_P\cdot s\cdot X_P+C_{ep}P_L+\frac{V}{\beta_e}\cdot s\cdot P_L \tag{5}$$

$$Q_L=C_dX_VW\sqrt{\frac{2\Delta p}{\rho}} \tag{6}$$

$$A_pP_L=m_t\cdot s\cdot X_P+B_P\cdot s\cdot X_P+KX_P+F_L \tag{7}$$

From equations (5), (6) and (7), the transfer function of proportional valve is obtained with the input being the spool displacement X_v and load F_L and the output being the piston displacement X_p.

$$x_P=\frac{\frac{C_dW}{A_p}\sqrt{\frac{2\Delta p}{\rho}}x_v-\frac{1}{A_p^2}(C_{ep}+\frac{sV}{\beta_P})F_L}{\frac{s^3}{\omega_h^2}+\frac{2\zeta_h}{\omega_h}s^2+(1+\frac{K}{K_h})s+\frac{C_{ep}K}{A_p^2}} \tag{8}$$

Where, ω_{sv} is the hydraulic natural frequency with $\omega_h=\sqrt{\frac{\beta_PA_p^2}{m_tV}}$, ζ_h is the hydraulic damping ratio with $\varsigma_h=\frac{C_{ep}}{2A_p}\sqrt{\frac{\beta_em_t}{V}}$, and K_h is the hydraulic spring stiffness with $K_h=\frac{\beta_PA_p^2}{V}+\frac{B_P}{8A_P}\sqrt{\frac{V_t}{\beta_em_t}}$.

The system transfer function block diagram is obtained from equation (1) and (8) and it is shown in Fig.3.

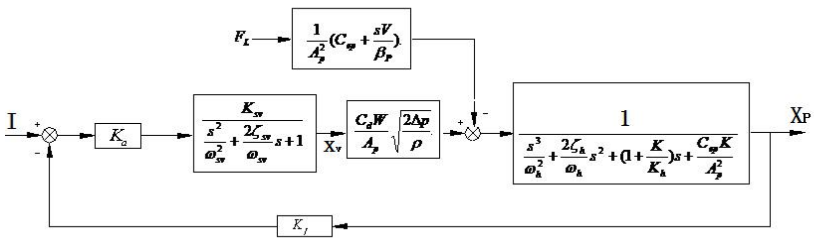

Fig. 3. Block diagram for the system transfer function

B. *Design of dual-mode fuzzy controller*

The dual-mode fuzzy controller is employed due to the nonlinearity and time-varying in hydraulic leveling system [9].

Considering the fact that leveling quickly is expected when the height deviation of fulcrum is large while pinpoint is required when the deviation is small, fuzzy controller is designed to be the dual-mode fuzzy controller, which is the combination of the coarse-tuning fuzzy controller and the fine-tuning fuzzy controller. The coarse-tuning fuzzy controller operates to achieve rapid leveling when the height deviation of fulcrum is larger than 10 mm. Conversely, the fine-tuning fuzzy controller works to achieve the pinpoint.

The inputs of the fuzzy controller are the height deviation of fulcrum e and the deviation rate ec and the output u is the input current of proportional multi-way valve. For the coarse-tuning fuzzy controller, the basic domains of e, ec and u are ±[10,500]mm, [-16.4,+16.4] mm/s and ±[5,20]mA, respectively. For the fine-tuning fuzzy controller, the basic domains of e, ec and u are ±[0,10]mm, [-10,+10] mm/s and ±[0,10]mA. The membership functions of all the three variables, e, ec and u, are triangular.

The leveling simulation model of the “double-fuzzy model” control is designed by Matlab/Simulink, shown in Fig.4. The simulation results show that the positioning accuracy of single leg is able to reach 1.76mm, the deviation rate is R=0.35% and the positioning time is reduced to about 35 seconds.

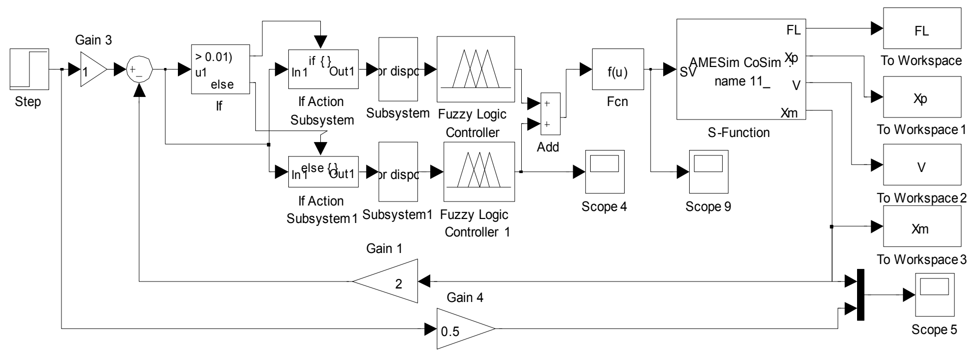

Fig. 4. Leveling simulation model of the dual-mode fuzzy controller

C. Leveling simulation model for the whole vehicle

The co-simulation model of mechanical system and hydraulic system for the whole vehicle is established based on "coplanar type" leveling strategy, shown in Fig.5. In the model, the input current of proportional multi-way valve at the suspension fulcrums A, B, C and D is taken as the control object, and the output displacements of the hydraulic cylinder at A, B, C and D are taken as the feedback signal. As shown in Fig.6, the model of co-simulation controller is established in Simulink. In order to simplify the modeling, the dual-mode fuzzy controller of the single leg is packaged, and its icon is the same with that of fuzzy controller.

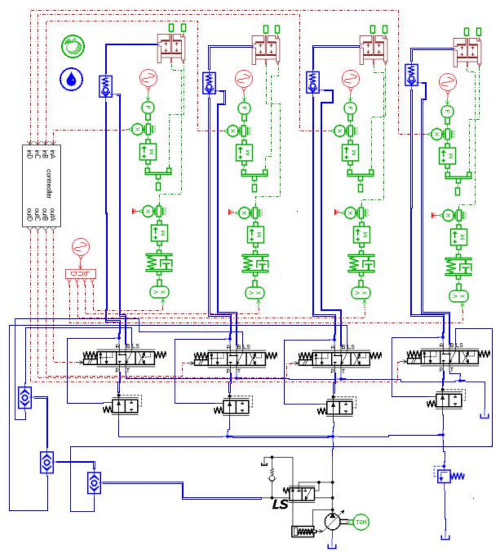

Fig. 5. AMESim model for the rising-leveling of whole vehicle

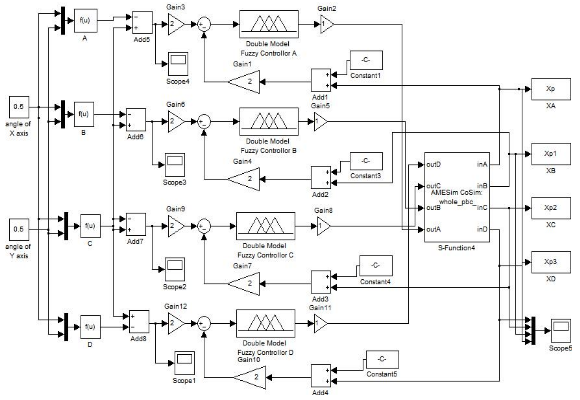

Fig. 6. Simulink model for the rising-leveling of whole vehicle

IV. Simulation and Analysis of the Rising-Leveling System for the Whole Vehicle

Taking the dip 0.5° both in X and Y direction detected by the level meter in the initial state as the condition to operate the simulation, the output displacements of the hydraulic cylinder at the suspension fulcrums A, B, C and D are shown in Fig.7. From the simulation analysis, it is clear that the time of the leveling process for the whole system is about 22.7s. The output displacements at A, B, C and D are h_A=0.1591m, h_B=0.1214m, h_C=0.0001m and h_D=0.0392m, respectively. Their errors are Δh_A=1.3mm, Δh_B=1.0mm, Δh_C=0. 1mm and Δh_D=1.7mm compared with the theoretical output displacements H_A=0.1578 m, H_B=0.1204m, H_C=0.0000m and H_D=0.0357m. Therefore, it can meet the actual requirements of the positioning accuracy 2.0mm for platform when the segmented ship is docked.

To test the capability of the system rejection load disturbance, it set amplitude 80KN, frequency 0.01Hz, each of the phase angle difference of 30°sinusoidal interference forces in each suspension fulcrum. The result of run and simulation again show that each suspension fulcrum output displacement curve of the hydraulic cylinder under the influence of interference are basically the same with output displacement of the no load interference. When the vehicles adjust the balance, load changes affect the leveling accuracy that is negligible, achieved the actual use of the flatbed truck requirements.

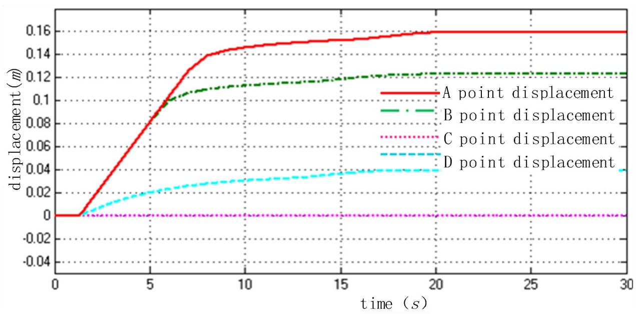

Fig. 7. Output displacements of the hydraulic cylinder at suspension fulcrums A, B, C and D

V. Conclusions

In this paper, taking the heavy transporter plane as an example, the dual-mode fuzzy controller is adopted to establish the simulation model of rising-leveling system for the whole vehicle with AMESim and Matlab/Simulink based on the "coplanar type" leveling strategy. The results show that the system has the advantages of high positioning accuracy, short adjustment time and high anti-load interference, which can meet the actual requirements of the positioning accuracy 2.0mm for the platform when the segmented ship is docked.

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