Study and Simulation Analysis for Dual-Drive Control Strategy of the Firefighting and Rescue Equipment

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Abstract. The dual-drive synchronous control strategies are researched in the paper, in order to Solve the control problem of the firefighting and rescue equipment. Through analysis and comparison the control strategy of deviation coupling synchronous with the control strategy of the EVLS synchronous，the corresponding control system model of multi-motor synchronous motion is built, and the simulation calculation is carried out in Simulink of MATLAB software. The simulation results show that deviation coupling control strategy have better follow-up performance and synchronization performance than others, and this strategy is more suitable for the driving system in Firefighting and Rescue Equipment.

Introduction

Firefighting and Rescue Equipment is the new equipment that placed in external wall of building body, which can quickly lifting and using for firefighting rescue. It consists of main equipment and the cage, which of all needs drive system. When the main equipment operates and the cage works, the two drive systems are usually independent of each other. In order to achieve the purpose of saving power, to reduce the occupied space and reduce its own weight, the two drive systems are combined as the dual-drive system, that is, when the main equipment moving up and down with the cage together, the dual-drive system works synchronous. Otherwise, when the main equipment stopped, but the cage works alone, the dual- drive device is isolated, then, one group of drivers will drive the cage for high-speed movement through adjustable speed and FM. When the main equipment work with the cage together, it is necessary to maintain the speed of two motors synchronous and consistent. In this paper, the control strategy of the dual drive system was studied. After analysis and comparison of the two systems of deviation coupling synchronous control strategy and the EVLS synchronous control strategy, the two control models are established. Through simulation analysis, one of the synchronous control modes with better performances on track ability, synchronization and stability is selected to apply to the Firefighting and Rescue Equipment. It has important significance for studying the efficient and stable operation of dual-drive control system of the similar of equipment.

Analysis of Multi-Motor Synchronous Control Strategy

The synchronous control strategies of multi-motor include the following， such as Deviation Coupling synchronous control strategy, the EVLS synchronous control strategy, parallel synchronous control strategy, the master-slave synchronous control strategy and synchronous control strategy with a compensator,[1-2]each of which has different characteristics, and suitable for different occasions. At present, many scholars have studied the synchronous control strategy of multi-motor,

and many of them thought Deviation Coupling synchronous control strategy and the EVLS synchronous control strategy have better control performance. [3-4]In this paper, these two synchronous control was studied, compared and simulation analyzed to select the better control strategy which more applicable to Firefighting and Rescue Equipment.

Deviation Coupling synchronous control strategy. Deviation Coupling synchronization control strategy is based on cross coupled control strategy, the main improvement is dynamic allocation speed compensation signal of each motor according to the working state between the motors. [5][6]Figure 1 shows a structure of Deviation Coupling control system of the motor, it mainly consists of three parts: MUX, DEMUX and Relative Speed Block.

The MUX module of Deviation Coupling synchronous control strategy is setting the input speed and feedback speed of two motor gathered into a three-way wide single signal; the corresponding DEMUX module of each motor is setting the composite three-way wide single signal separation of basic elements, and then transferred to each motor. The main part of the Deviation Coupling control is the speed feedback module, the compensation signal for each motor is provided by it. The principle of the speed feedback module as follows, output rotation speed in the reference of the motor with speed feedback of other motor respectively do difference in the feedback module, then added as the speed compensation signal of the reference motor. Since the structure coupled together each motor of the system, forming a closed loop structure, so when any one motor disturbed, other motor can adjust the speed of real-time and accurate, so as to achieve higher speed synchronization performance. The gain K_{ir}（r=1, 2）of speed feedback module value about moment of inertia of motor, which i represents the motor number. The gain K_{ir}（r=1, 2）can compensate difference of inertia between the motor, and will not increase the overshoot of the system, thus avoiding jitter of output torque. Value of K_{ir} (r=1, 2) can be calculated by the relation of moment of inertia between the motor and other motors，the calculation relationship as shown in formula (1)：

$$K_{ir} = \frac{J_r}{J_i} \quad (r=1, 2)$$ （1）

Where, J_i is the moment of inertia of the motor I, and J_r is the moment of inertia of the other motor related to the motor I.

The EVLS Synchronous Control Strategy. The EVLS synchronous control strategy was presented by Professor Lorenz and Meyer in the late 1990s. This kind of control strategy as template to mechanical line shaft, and the formation of it modeled on the physical properties. First of all, total shaft receives external instruction, and after the spindle controller treatment obtains driving instructions from sub units, all sub units get synchronous operation by obtaining processing instructions, the benefit of this strategy is that a sub unit is processed from receiving instructions. So the tracking performance is better. And the structure is shown in Figure 2.
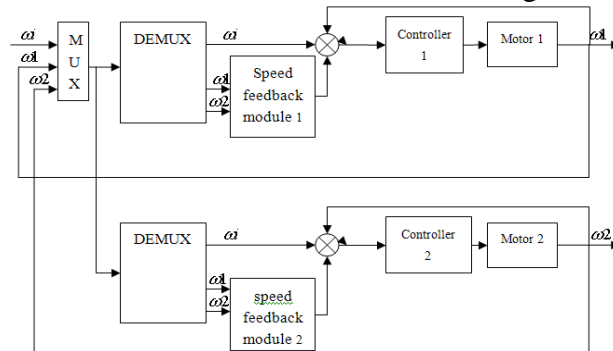

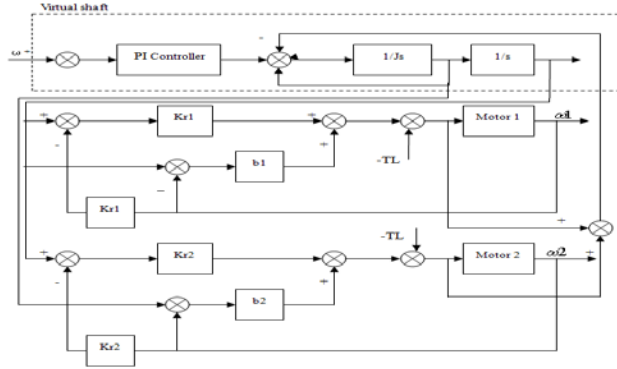Fig 1. Structure of Deviation Coupling synchronous control strategy

Fig2. Structure of the EVLS synchronous control strategy

Virtual spindle works the same as the real axis. Since each moving axis is connected with the main shaft, who provides driving torque, loading forces of moving axes, equivalent to the driving torques, are delivered as feedback to the spindle by synchronizing mechanical devices:

$$T - \sum T_i = J_m \ddot{\theta}_m \qquad (2)$$

Among them, T_i is torque feedback by every moving shaft. T is input torque, J_m is inertia of the virtual axis . Torque input of the virtual axis is virtual and calculated based on speed, position and other parameters. Assuming the virtual line axis is a flexible shaft, the input reference speed is ω_r, the actual shaft speed is ω_m, so the driving torque generated is:

$$T = K_m(\omega_r - \omega_m) \qquad (3)$$

By the same token, feedback torque of each moving axis can also be calculated. Due to the existence of the connection devices between the moving axis and the spindle, influences of elasticity, damping should also be taken into consideration to obtain the calculation formula of feedback torque shown below :

$$T_i = b_r(\omega_r - \omega_m) + k_r(\theta_i - \theta_m) + k_{ir}\int(\theta_i - \theta_m)dt \qquad (4)$$

The ω_i is rotating speed of each axis, the θ_i is motion displacement of each axis, T_i is the feedback torque of each axis.

Simulation Analysis Based on MATLAB Model

In order to compare the following performance with synchronous performance of the EVLS synchronous control model and relative coupling synchronous control model, the corresponding simulation model is established in Simulink of MATLAB software. The set speed is 700rad/min to simulate and analyze of the multi motor synchronous control system in no-load start and   load sharp change conditions.

First of all, establish a simulation model of single motor, the structure diagram is shown in Figure 4, its working principle is: after inputting the motor with voltage through module of the armature circuit inductance reciprocal and integral module Integrator, the output the armature current becomes i, which later goes through module Gain1 and module of reciprocal of moment of inertia and integral module Integrator 1 to gain the final output angular velocity ω. The differential equation of single motor is:

$$LJ\frac{d^2w}{dt^2} + RJ\frac{dw}{dt} + K_tK_ew = K_tU - L\frac{dT_l}{dt} - RT_l \qquad (5)$$

Applying equation (5) with the Laplace transform to get the transfer function of the motor helps to create a complete motor mathematical simulation model, whose set module parameters are shown in Table 1. Figure 3 is motion simulation model established by a mathematical equation of a single motor .
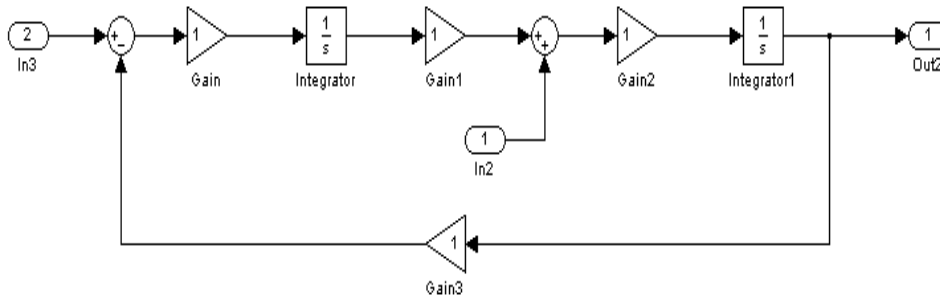
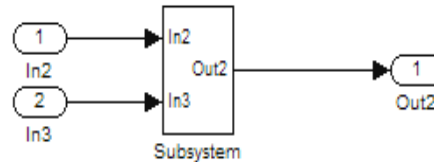Fig3.   Motion simulation model of Single motor

Fig4. The packaged simulation module of Single motor

To reduce the number of modules in Simulink simulation and use the visual privilege of simulation, it is   required to group simulation system with the same functional modules, then each group will be encapsulated as a sub module so to simplify the problem, i.e. single motor model can be encapsulated as a sub module. Figure 4 shows a single motor simulation module packaged.

The simulation analysis using EVLS synchronous control strategy. According to the control model of EVLS synchronous control mode, establish the simulation block diagram as shown in Figure 5, in which the input data includes: motor speed, parameters of each processing module. The outputs are the actual speeds of motors. Based on
the actual situation and current conditions of firefighting and rescue equipments, the module parameters are set in Table 1.

TABLE I.   THE TEST PARAMETERS OF SIMULATION

| *Parameters*	*Numerica*	*Explanation of parameters*
Ke	0.1	Motor voltage coefficient
Kt	0.005	Motor torque coefficient
R	0.2Ω	The circuit resistance of motor
Ktr	0.1759N m/rad	The elastic coefficient of transmission mechanism
Kg	0.05Nm/（rad/Sec	The coefficient of friction drive mechanism of the equivalent
J	0.02N/m^2	Unit of the motor and load inertia
Ri	12.5	The current integral link
Rp	100	Current loop proportional link
Ka	0.01	The angular acceleration feedback gain coefficient
L	0.01	The motor inductance
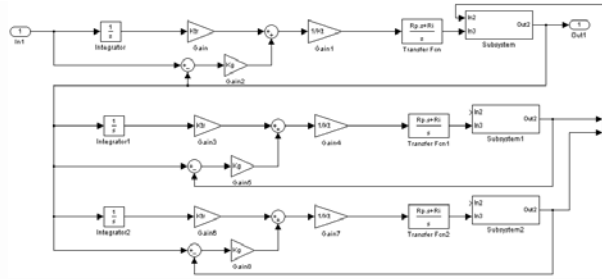
Fig5. Simulation block diagram of the EVLS synchronous control system

As shown in the simulation block Figure 5, to start with, input the set speed into the input port In1. After signal processing of integral module Integrator, gain module Gain, gain module Gain1 and Transfer Function Module, the input signals are transited into motors, which work according to the processed signals of electronic virtual spindle. The output speed practical motor speed.

No-load starting. Under the Simulink environment in the MATLAB software, the simulation time is 0.4s, the set speed is 700rad/min. As shown Figure 6 is the speed simulation curve of the EVLS synchronous control system with no-load starting.
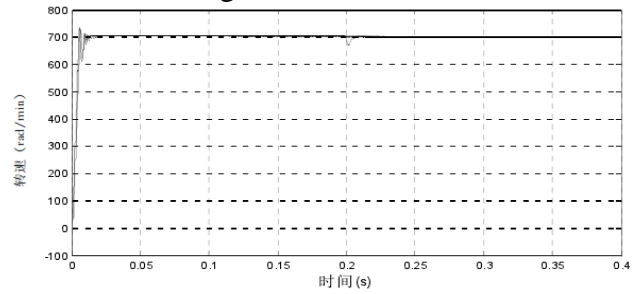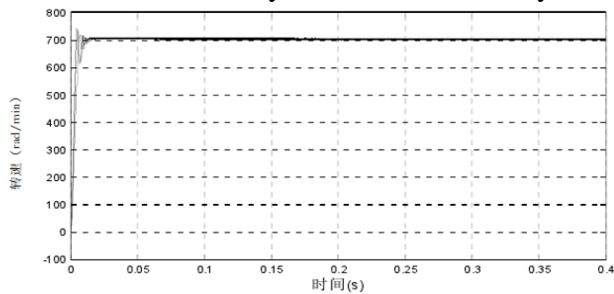

Fig6. Speed simulation curve of the EVLS synchronous control system   Fig7. Speed simulation curve of the EVLS synchronous control system

Sharp Load Change. Under the Simulink environment in the MATLAB software, the simulation time is 0.4s. Apply load disturbance of 10KN·m to the motor 1 at 0.2s to simulate EVLS synchronous control system. The speed simulation curve of EVLS with sharp load change is shown in Figure 7.

It can be seen from the above that, under control of the EVLS control mode, the time needed to reach steady state is 0.18s in no-load start-up situation. When load changes sharply, the minimum speed is 672r/min and the maximum amplitude of fluctuation is 28.

The simulation analysis using deviation coupling synchronous control strategy

According to the control model of deviation coupling synchronous control mode, establish the simulation block diagram shown in Figure 8, in which the input data and processing module parameters are the same with the previous step, the set module parameters are shown in Table 1. Its working principle is: Input the set speed into the input port In1, and after signal processing of integral module Integrator, gain module Gain, gain module Gain1 and Transfer Function Module, the processed input signals are transited into rotating motors. Through feedback and the processing of speed feedback regulation module, compensation signals are dynamically distributed among motors according their working conditions.
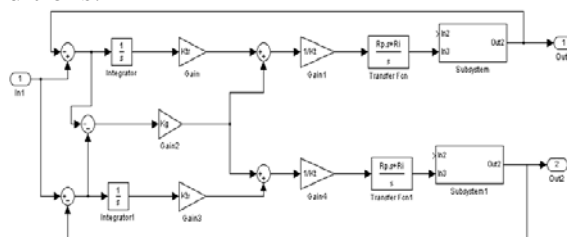

Fig8. Simulation block diagram of Deviation Coupling synchronous control system

No-load starting. Under the Simulink environment in the MATLAB software，the simulation time is 0.4s, the set speed is 700rad/min. As shown Figure 9 is speed simulation curve of the relative coupling synchronous control system at sharp load changes.
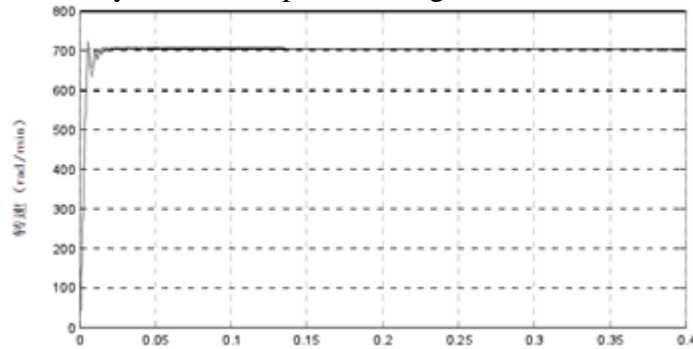

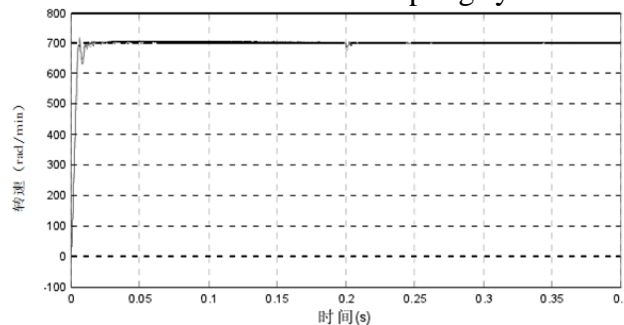Fig9. Speed simulation curve of Deviation Coupling synchronous control system

Fig10. Speed simulation curve of Deviation Coupling synchronous control system

Sharp Load Change. Under the Simulink environment in the MATLAB software, the simulation time is 0.4s, apply load disturbance of 10KN·m to the motor 1 to simulate the deviation coupling synchronous control system with sharp load changes, which is shown Fig10.

It can be seen from the above that, under control of the deviation coupling control mode, the time needed to reach steady state is 0.13s in the no-load start-up situation. When load changes sharply, the minimum speed is 683r/min and the maximum amplitude of fluctuation is 17.

The analysis of simulation results

According to the simulation analysis of the EVLS synchronous control strategy and deviation coupling synchronous control strategy, conclusions are drawn as follows:

(1) In the no-load starting process, the time needed to reach steady state is 0.18s in the EVLS synchronous control strategy, while the time is 0.13s in the deviation coupling synchronous control strategy. Deviation coupling synchronization control method holds a previlege of 28% shorter time to reach steady state comparing with that of EVLS synchronous control strategy.

(2) In the process of sharp load change situations, the maximum amplitude of fluctuation is 28 in the EVLS synchronous control strategy, while the maximum amplitude is 17 in the deviation coupling synchronization control strategy. The maximum amplitude in the deviation coupling synchronization control method is reduced by 39% comparing with EVLS synchronous control strategy.

In summary, from the comparison of the two known synchronous control strategy, no-load start time is shorter in deviation coupling synchronization control strategy, and the load fluctuation amplitude is smaller in the sharp load change process. So deviation coupling synchronization control has the competitive advantage to meet following performance, synchronous performance and stability performance required in fire fighting equipment.

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