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Research on Rotating Rack Control System of Proton Therapy Instrument

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***Abstract*—Proton therapy instrument is a radiotherapy equipment for cancer. Its rotating frame is large in volume and more than 100 tons in mass. This paper proposes a dual drive device control system to meet the functions of acceleration, emergency braking and other functions of the rotating frame within a specified angle. The double drive of the rotating frame needs to establish the optimal synchronization scheme. The three synchronous methods of master command, master-slave and virtual spindle control are compared and compared. Simulation models of three synchronous control methods of the motor are established in MATLAB. The advantages and disadvantages of the three control methods are verified by simulation, and the virtual Spindle control is the conclusion of the best synchronization scheme.**

Keywords—component; Double-drive rotating frame; Motor synchronous control; Virtual spindle

I. INTRODUCTION

The rotating rack of the proton therapy instrument is a super heavy rotating device. It is required to realize the command control accuracy of the upper computer to be less than or equal to 0.01 °, the rotation positioning accuracy to be 0.01 ° error range, and the speed of the control rack to be output at 0.01-1.2rpm. Controlled with speed, there is no target such as accumulated error. If its rotation accuracy is low and the execution of control instructions cannot be timely feedbacked and processed, the proton beam will hit important nerves and important organs, causing serious medical accidents.

In order to achieve extremely high rotation accuracy, synchronization, stability and anti-interference ability, the electronic synchronization method is researched, and the master-slave mode is improved. The control mode of the virtual spindle method is adopted to maintain strict control between multiple axes. The speed characteristics fit well with the kinematics of the rotating frame.

The scheme of the virtual main shaft is based on the master-slave mode, and the driving torque of the driven shaft is fed back to the main shaft to realize the coupling between the master and slave shafts. The parameters of the virtual spindle method can be freely set in the program, and the synchronization control performance is improved by adjusting the parameter values. Add a torque coupling module between the master and slave axes, calculate the virtual torque according to the movement parameter deviation (such as the speed deviation) of each axis, and then feed back the virtual torque to the spindle channel to achieve the parameter coupling between the master and slave axes, and the virtual axis method Compared with other coupling algorithms, it is easy to implement, so it is more suitable for synchronous control between multi-axis movements. Moreover, the virtual spindle is set in the controller, which can avoid various interferences. Its operating state belongs to the ideal environment. It can be achieved by controlling the ideal spindle. Control the slave axis.

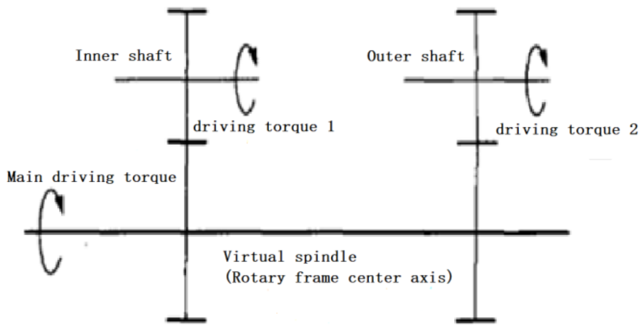

Fig. 1. Virtual spindle-type structure

In order to establish the synchronization scheme of the dual-drive device of the rotating rack, in the Simulink toolbox of Matlab, simulation models of the master order, master-slave, and virtual spindle were established, and the parameters of each synchronization method were compared to prove the practicality of the virtual spindle synchronization control.

II. MASTER SYNCHRONOUS SIMULATION

The main reference synchronization is parallel synchronization, which corresponds to the gantry axis mode in 840Dsl. In this solution, the input of the controller comes from the same speed reference signal, while the gantry axis is the same position signal. There is position coupling but no speed coupling. Each motion axis works independently in its own circuit. Do not interfere with each other.

Establish the main simulation model through simulink, as shown in Figure 2, the simulation settings are as follows:

(1) At time 0, the motor starts at a given speed of 4000r / min without load;

(2) Motor 1 and motor 2 add load disturbance of 30Nm at 0.2s and 0.3s respectively;

(3) When the system is 0.4s, the speed is adjusted to 4500r / min.

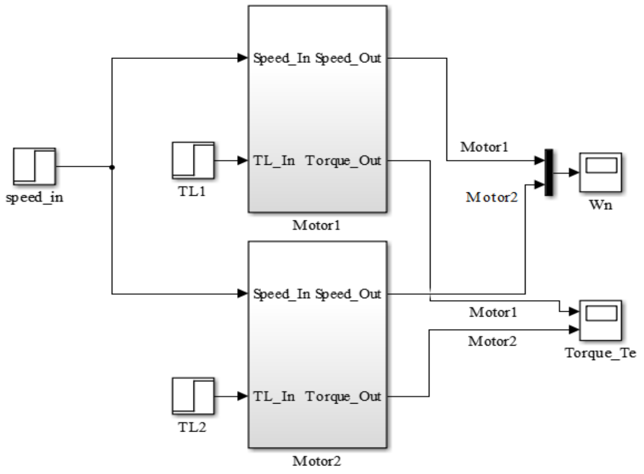

Fig. 2. Simulation model of master reference mode

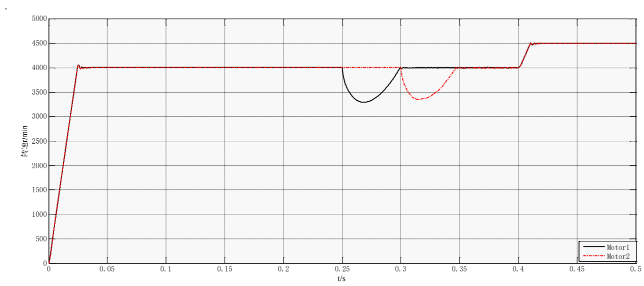

Fig. 3. Speed of motor 1 and motor 2

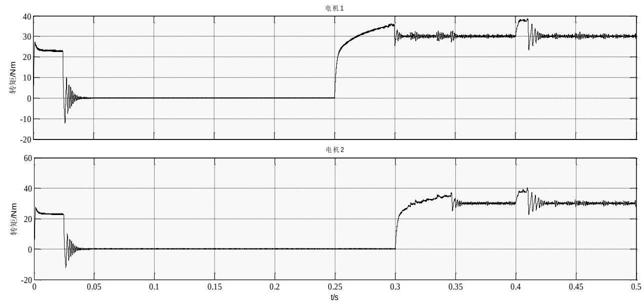

Fig. 4. Torque of motors 1 and 2

As can be seen from Figures 3 and 4, there is no correlation between the two motors, and the speed and torque output are independent of each other and there is no coupling. There is an overshoot of up to 80r / min during startup. When it is between 0.2s and 0.3s, one of the motors 1 and 2 will not be affected after the disturbance, and there is no synchronization relationship between the motors. After the system runs stably, if both motors move at the same time when the same disturbance or speed regulation occurs at the same time, and the speed error is 0, it means that the master order has high requirements for the control and working environment of a single motor. However, in a rotating rack, the ideal working environment does not exist, so this method is not the optimal rack control solution.

III. MASTER-SLAVE SYNCHRONOUS SIMULATION

For the master-slave type, a simulation model is established in simulink to verify the synchronization performance of the dual-drive device. As shown in Figure 5, the simulation conditions are set as follows to obtain the master-slave speed in Figure 6 and the synchronization error in Figure 7:

(1) At time 0, the motor starts at a given speed of 4000r / min without load;

(2) When motor 1 is at 0.2s, add 30Nm load disturbance;

(3) When the system is 0.4s, the speed is adjusted to 4500r / min.

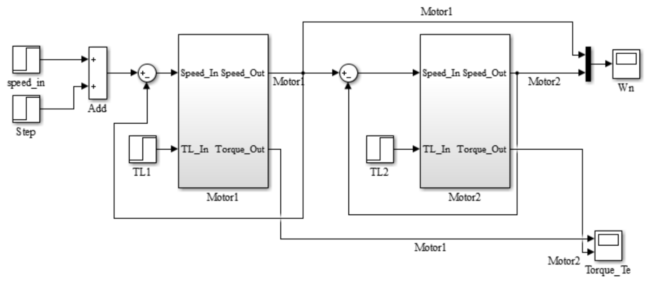

Fig. 5. Simulation model in master-slave mode

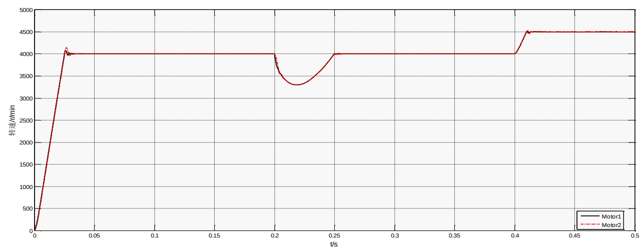

Fig. 6. Comparison of master and slave speeds

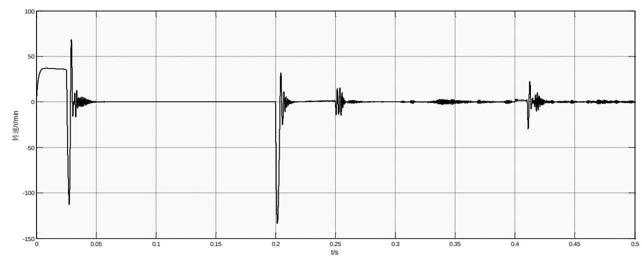

Fig. 7. Master-slave synchronization error

It can be seen from Figure 6 that the load is added to the spindle motor at 0.2s. The speed of the slave motor follows the spindle synchronization performance is good. The speed of the dual motors is increased to 4500r / min. After running for 0.02s, the motor 1 can quickly reach the given value. , And the steady-state error is small, and the motor 2 has a significant fluctuation phenomenon, and it has a large steady-state error.

It can be seen from Fig. 7 that there is a relatively large speed error during the start-up, the recovery after the load disturbance, and the speed change process. Among them, the maximum synchronization error during load interference has reached 133r / min. To eliminate some interference signals on the channel or to prevent the set value from fluctuating too much.

IV. SIMULATION OF VIRTUAL SPINDLE METHOD

In the virtual spindle system, the slave axis follows the master axis in a certain proportion, but there is no direct relationship between the virtual spindle and the motor. There is a large difference between the spindle speed and the rotation angle and the actual rotation speed and rotation angle after transmission through the driving device Value, the speed difference of each axis can be adjusted by its own PI controller (the driving torque calculation formula is similar to the PI algorithm formula, which is replaced by the PI controller here). The simulation established in Simulink is shown in Figure 8, and the simulation is set to as follows:

(1) At 0, give the virtual spindle speed 1r / min to start without load;

(2) At 0.2s, add 30Nm load disturbance to motor 1;

(3) When the system is 0.4s, the spindle speed is adjusted to 1.2r / min.

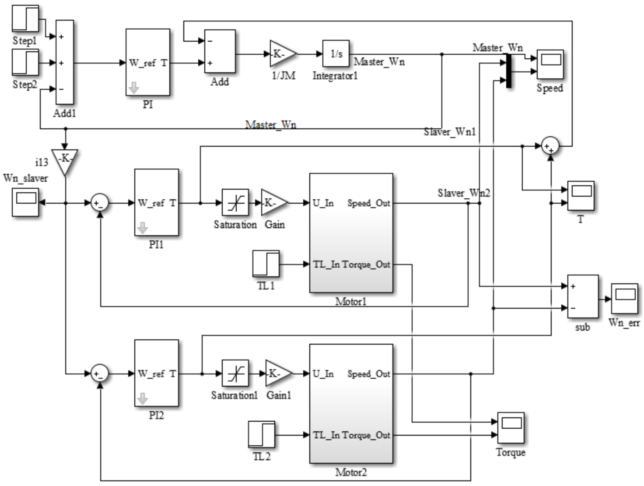

Fig. 8. Virtual spindle synchronous simulation

The master and slave shaft speed simulation waveforms are shown in Figure 9. Figure 10 shows the following error of the speed following the slave shaft;

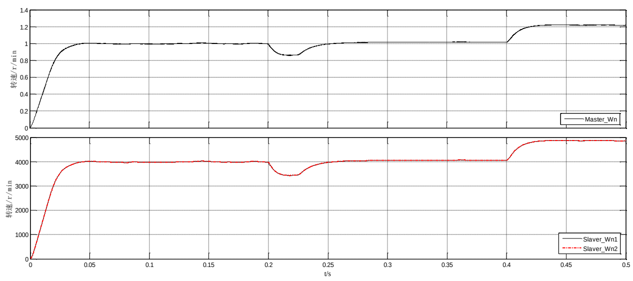

Fig. 9. Speed of master and slave shafts

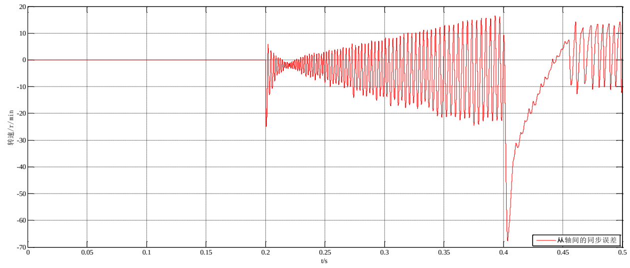

Fig. 10. Virtual internal shaft speed tracking error

It can be seen from Fig. 9 that motors 1 and 2 follow the virtual spindle speed and change in a certain proportion, but the number of couplings of motor 2 is less than that of motor 1, so there is less oscillation. The torque added by the spindle to the internal shaft feedback, when the load is disturbed, the overall speed of the system decreases less, and the synchronization performance of the internal shaft is greatly improved. Only when load disturbance is added to the motor 1 and the speed is adjusted, the synchronization error increases to about -15 r / min and -45 r / min. The oscillation after 0.4s speed stabilization is smaller than the 0.2s load disturbance. This is because the rotation speed is different, which results in more couplings of the rotation speed. After the speed is stabilized at 1.22r / min, the speed adjustment error is 0.167%. It can be seen from FIG. 10 that the synchronization error is 0 during the no-load operation phase, which has excellent synchronization performance, but the error is relatively large during interference or speed adjustment.

Because the speed of the slave axis is affected by the actual speed of the virtual spindle, the rotation angle error is caused by the integral of the rotation speed, and the acceleration speed cannot reach the set speed instantly, resulting in a large difference between the rotation angle between the rack and the motor during the acceleration phase. The system itself adjusts the difference, and a large overshoot will occur, which must be avoided in the actual control of the rotating rack; therefore, in the debugging stage, the speed control is used during the startup of the rack, and it enters the uniform speed operation. Add a compensation value to the position loop to eliminate the cumulative error and static error during the acceleration phase, and use the ramp function generator to make the acceleration and deceleration process achieve smooth speed control. This method can effectively use the maximum torque of the motor, achieve faster system response, and control the movement of the rack stably and smoothly.

V. CONCLUSION

Through the simulation analysis of the master command, master-slave, and virtual spindle methods, the synchronization accuracy comparisons are performed at the start, load disturbance, and speed adjustment stages, respectively, and the simulation results in Table 1 are obtained:

TABLE I. COMPARISON OF SIMULATION DATA OF DIFFERENT STRATEGIES

Contrast parameter	Response time (s)	Starting speed error (r/min)	Load disturbance following error (r/min)	Disturbance recovery time (s)	Speed following error (r/min)
Master-order	<0.05	0	Do not affect each other	0.05	Do not affect each other
Master-slave	<0.05	68.44 ~ -112.6	31.87 ~ -133.7	0.07	22.54 ~ -29.1
Virtual spindle	<0.05	0	16.5 ~ -25.2	0.05	15 ~ -68.8

From the above data, it can be concluded that: firstly, the master-command type is too dependent on the control accuracy and working environment of a single motor, so it is not considered; the accuracy of the master-slave synchronization error depends on the performance of the master motor and the fast tracking speed of the slave motor. This solution meets the basic requirements of the synchronization of the dual drive device of the rotating frame, but there are high following errors and steady state errors, and the overshoot is too large; the virtual spindle synchronization control strategy, the virtual spindle not only responds fast, but also synchronizes And the steady-state error is much smaller than the uncoupled master-slave.

For the virtual axis method, the structure of this method uses the coupling of speed and torque, and does not limit the number of motors. The speed of each motor unit can be synchronized through the feedback adjustment of the virtual spindle, and the synchronization accuracy and steady-state performance depend on the parameters of the virtual spindle. Selection, compared with the other two methods, the error oscillation is smaller, the synchronization performance is better, and it is more suitable for occasions with many interferences. To sum up, the virtual axis method is very suitable for the rotary treatment control of the rotating frame.

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REFERENCES

[1] Qin Zhong.Research on Open CNC System Based on Motion Control Card in Circuit Board Engraving Machine[J]. Machine Tool & Hydraulics,2009,37(6):45

[2] Jongen Y,Kleevn W,et al.Design studies of the compat superconducting cyclotron for hadron therapy[R].IBA,Chemin du Cyclotron 3,Belgiun,2006.

[3] Siemens.SINUMERIK 840Dsl/828D Basic Functions[M].SiemensAG,2018

[4] Siemens.SINUMERIK 840Dsl Concise Commissioning Manual[M].Siemens-AG,2018.

[5] B. T. Zhang, Y. Pi. Robust fractional order proportion-plus-differential controller based on fuzzy inference for permanent magnet synchronous motor[J]. Control Theory&Applications, IET, 2012, 6(6): 829-837.

[6] Antoni.Arias,Carlos.Ortega,Jordi.Zaragoza,JordiEspina,JosepPou. Hybrid sensorless permanet magnet synchronous machine four guadrant drive based on direct matrix converters[J]. Electrical Power and Energy Systems.2013(45):78-86.