A Study on Tracking Control for Networked Multi-Motor Systems

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Abstract: In recent years, a lot of industrial equipments have serial communication channel such as FieldBus (CAN, Profibus, etc.) or Ethernet that provides real time communication between industrial equipments. Theses applications include gantry crane, robot, chip mounter, etc.. In this paper, we discuss the synchronization technique for networked multi-motor systems where controllers (commercial servo amps) are distributed and interconnected by CAN (Controller Area Networks). We first describe the equivalent model for the individual servo-amp and motor using the frequency response. We design the H∞ controller for motion synchronization. Finally, the synchronization technique using the equivalent model and the H∞ controller is verified by the simulation and the experiment.

Keywords: H∞ controller , networked multi-motor systems, CAN(Controller-Area-Network), synchronization technique

1. INTRODUCTION

It is general to use the industrial network such as Ethernet or FieldBus instead of the traditional peer-to-peer connection in order to exchange control signals and various sensors' data in the distributed control systems. The networked control scheme reduces complexity of wiring structure and increases the system flexibility and the efficiency of system maintenance. Recently, these systems are called networked control systems. From industrial network point of view, there are various protocols in FieldBus and the choice of the suitable protocol depends on the application area and the system requirements. For example, FIP or Profibus is applied to communication between production cells. On the other hand, in case of device level communication of inside production cell or multi-motor control, CAN can be adopted. Although CAN was developed for vehicle network, it is adopted to the factory automation area because of its low price, multiple sources, high performance and already widespread acceptance.

In this paper, we propose synchronization algorithm for the dual motors and implement the CAN networked synchronization scheme that is suitable for multi-motor operating system in Gantry crane or rolling process [1]. Our interest is limited to the only two servo-amps with CAN network for the convenience of implementation. The synchronization algorithm is designed by H-infinite control method with the equivalent model of servo-amp and motor that is simplified as PID controller and DC motor respectively by considering input-output frequency characteristics.

The proposed scheme is implemented using CAN network and verified experimentally.

2. SYSTEM MODELING

2.1 CAN protocol

CAN has CSMA/CD+AMP(Carrier Sense Multiple Access/Collision Detection + Arbitration on Message Priority) protocol. This protocol is same as an IEEE 802.3 CSMA/CD protocol and supports physical layer and data link layer of ISO/OSI 7 layers. To describe CAN protocol briefly, any node which has a message to transmit can transmit message when the bus state is idle. If several nodes simultaneously try to transmit, the highest priority node occupies bus without any delay time according to the identifier delimiter(ID) which is assigned to the messages or nodes. This method is called NBA(Non-deductive Bitwise Arbitration). Lower priority node can get the right of bus usage and retransmit the message when the bus is in idle state. Maximum transmission speed of CAN is 1Mbps in the specification 2.0A(B)[2] but we raise the transmission speed up to 2Mbps and there is no problem in our experiment.

2.2 Servo-amp modeling

In this paper, the servo-amp system is simplified by considering input(speed command)-output(speed) frequency characteristics, and the resulted equivalent model includes PID controller and dc motor, which is shown in Fig.1.

The state equations of equivalent model in the servo-amp system can be defined as follows[3]:

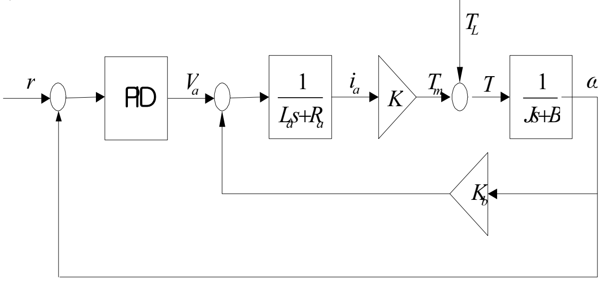

Fig. 1. Equivalent model of servo-amp

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix}=\begin{bmatrix}-\alpha & -\beta & -\gamma\\ 1 & 0 & 0\\ 0 & 1 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix}+\begin{bmatrix}1\\ 0\\ 0\end{bmatrix}u \tag{1}$$

$$y=\begin{bmatrix}\delta & \varepsilon & \gamma\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} \tag{2}$$

where

$$\alpha=\frac{JR+BL+KK_d}{JL},\ \beta=\frac{BR+KK_p+K^2}{JL},\gamma=\frac{KK_i}{JL}$$

$$\delta=\frac{KK_d}{JL},\varepsilon=\frac{KK_p}{JL}$$

J=the moment of inertia, R=rotor resistance
L=rotor inductance
K=counter electro-motive force constant(torque constant)
Ki, Kd, Kp=PID controller gain, B=friction coefficient

3. CONTROLLER DESIGN

3.1 H^{∞} controller First part

In this paper, the synchronization control for two servo-amp is achieved by using H-infinite control technique to make system robust. Fig.2 shows overall system block diagram. Transfer function can be defined as equation (3).

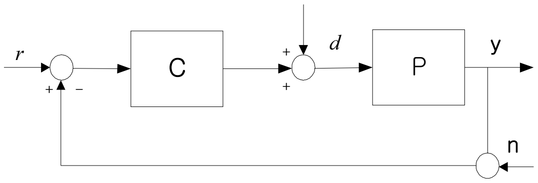

Fig. 2 Overall system block diagram

$$y=\frac{PC}{1+PC}r+\frac{P}{1+PC}d-\frac{PC}{1+PC}n$$

$$=T\cdot r+P\cdot S\cdot d-T\cdot n \qquad (3)$$

A premise condition which plant P must be stable and minimum phase is required to satisfy robust performance when H-infinite controller is designed with the aid of loop-shaping[4]. In our system, this condition is satisfied.

The robust performance problem is to design a proper controller C so that the feedback system for the nominal plant is internally stable and the inequality condition as equation (4) is satisfied. Thus the problem input data are P, W_1 and W_2; the problem is how to design the controller C achieving robust performance.

$$\left\|W_1S+W_2T\right\|_{\infty}<1 \qquad (4)$$

where, W_1, W_2 is weighting function.

Weighting function W_1 is used to adjust the magnitude of S in low frequency range and W_2 is used to adjust the magnitude of T in high frequency range. Weighting function W_1, W_2 can be chosen suitably according to the given plant P and the control requirements.

In a loop-shaping design, Bode plots are used. In this case, the Bode plot for $L(=PC)$ is obtained by plotting the graph of $|W_1|/(1-|W_2|)$ over the low frequency range where $|W_1|>1>|W_2|$ and the graph of $1-|W_1|/|W_2|$ over the high frequency range where $|W_1|<1<|W_2|$. From the Bode plot for L, we can design the controller $C(=L/P)$ which satisfies the condition of the equation (4).

3.2 Synchronization control

In this paper, the synchronization controller is designed with the H-infinite control method which is described in the previous section. The H-infinite controller for synchronization is located between the 2 servo-amps and the feedback signal is the output error as shown in Fig.3.

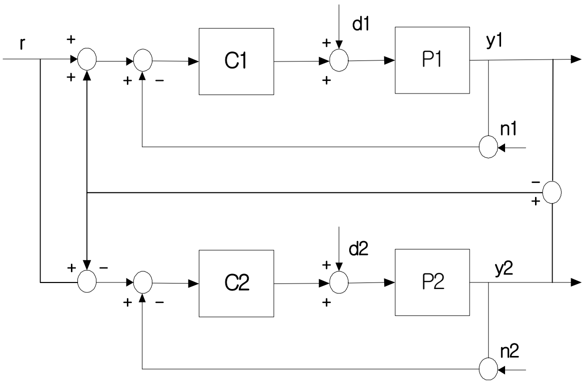

Fig. 3 Block diagram of synchronization control

4. SIMULATION

The digital simulation is carried out in order to verify the performance of the proposed controller. The parameters of servo system are shown in table 1.

Table 1 Servo system parameters

R[Ω]	1
L[H]	0.1
J[$kg.cm^2/\sec$]	0.0098
B[$kg.cm^2/\sec$]	0.2
K[$kg.cm^2/A$](V/rad)	0.1
Kp, ki, kd	100, 100, 10

The closed loop transfer function of servo-amp shown in Fig. 1 can be defined as follows using Table 1 and equation (2):

$$\frac{w_o}{w_i}=\frac{\delta S^2+\varepsilon S+\gamma}{S^3+\alpha S^2+\beta S+\gamma} \qquad (5)$$

In order to design H-infinite controller, we regards the servo-amp as the P so that the controller C can be defined by the loopshaping of L that satisfies the equation (4). The weighting functions W_1, W_2 which can satisfy the control performance are selected as the equation (6) and (7) respectively. Then, the Bode diagrams can be plotted for L, W_2 and $|W_1S+W_2T|$ as shown in Fig.4.

$$W_1=\frac{10}{2S^2+2S+1} \qquad (6)$$

$$W_2=\frac{S+1}{0.2S+20} \qquad (7)$$

Through these procedures, the transfer function of H-infinite controller that expresses the controller C can be defined as follows:

$$H^{\infty}=\frac{0.49S^4+15.8S^3+169.5S^2+655S+200}{0.1S^4+1.2S^3+3.1S^2+3S+1} \qquad (8)$$

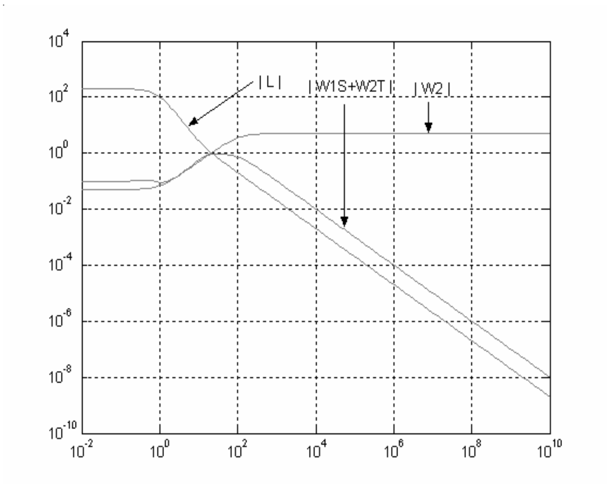

Fig. 4 Bode plots of $|L|,|W_2|,|W_1S+W_2T|$

The performance of the proposed synchronization control method is simulated with Matlab. Simulink model of synchronization control is as shown in Fig.5.

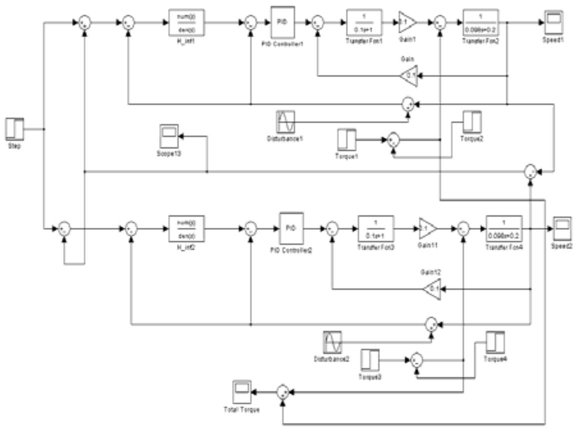

Fig. 5 Block diagram of synchronization control system

Simulated results are shown from Fig.6 to Fig.11.

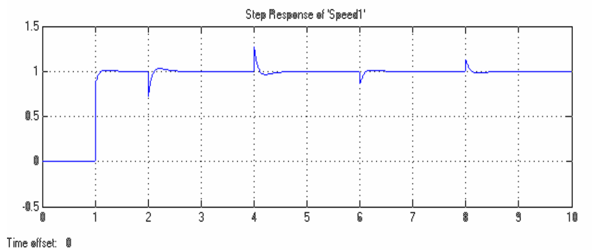

Fig. 6 Motor 1 speed response (step input)

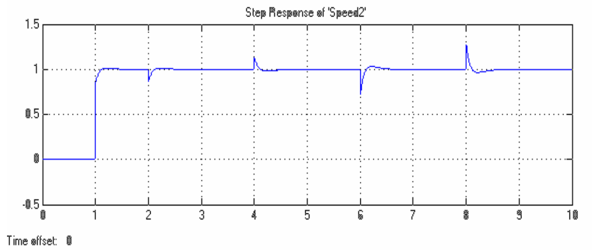

Fig. 7 Motor 2 speed response (step input)

Speed responses are shown in Fig. 6 and 7 for each servo motor when the load is applied like Fig. 11 after starting with step speed input. In Fig. 11, 25% rated torque is applied to motor 1 from 2 to 4 second after starting and the same torque is applied to motor2 from 6 to 8 second in order to test the performance of synchronization controller. In case of sinusoidal speed references, speed responses are shown in Fig. 8 and 9 for each servo motor when the load is applied like Fig. 11, and the speed error between the motors is presented in Fig. 10.

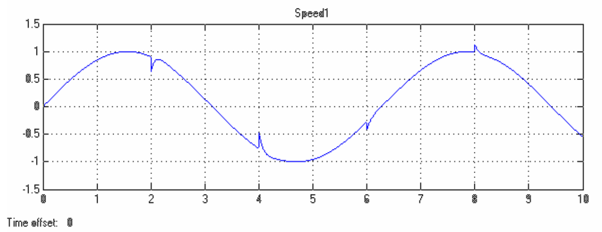

Fig. 8 Motor 1 speed response (sine wave input)

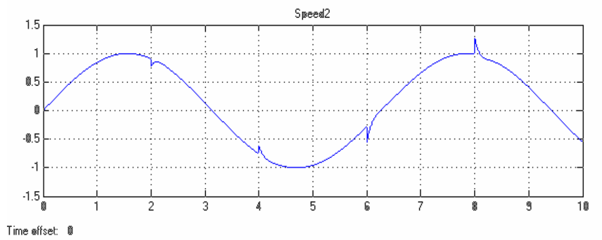

Fig. 9. Motor 2 speed response (sine wave input)

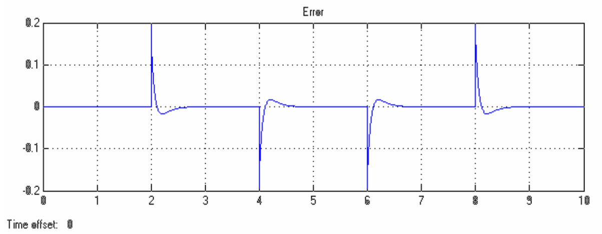

Fig. 10 Speed error

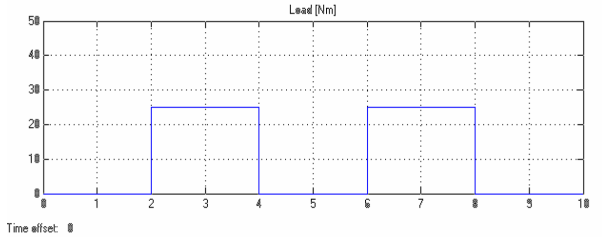

Fig. 11 Applied load

5. EXPERIMENTS

The experimental equipment of the synchronization control system is shown in Fig.12. As is shown in Fig. 12, the synchronization scheme is implemented with the real time network, CAN. The specifications used in the experiment are given in table 2. Fig. 13 shows the data signals of control input and speed information on the CAN network. Fig. 14 shows the motor speed responses of servo-amp 1,2 when the speed commands of 2900rpm are applied abruptly to each servo-amp. The waveforms of speed responses are obtained using the VECTOR's CANALYZER. When the sinusoidal speed commands of 0.25Hz is applied, the resulted speeds are given Fig. 15. From these results, two speed waveforms almost coincide with each other, and we can find the synchronization controller using CAN network is well operated.

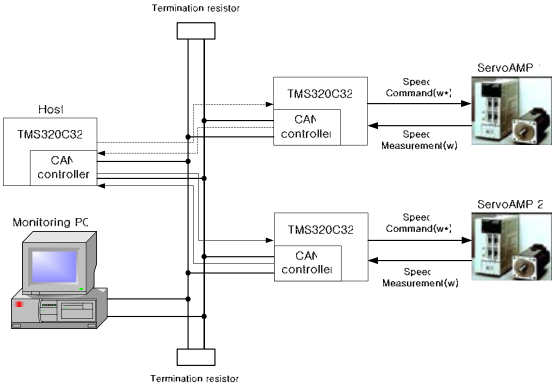

Fig.12 Networked synchronization system

Table 2 Data of the control system

CAN Spec.	2.0B
Data rates	1Mbps
Control input	4 Bytes
Speed information	2 Bytes
Control period	10mS

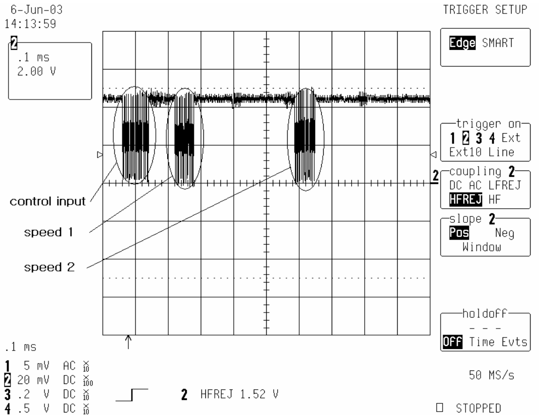

Fig. 13 Control input and speed information on CAN network

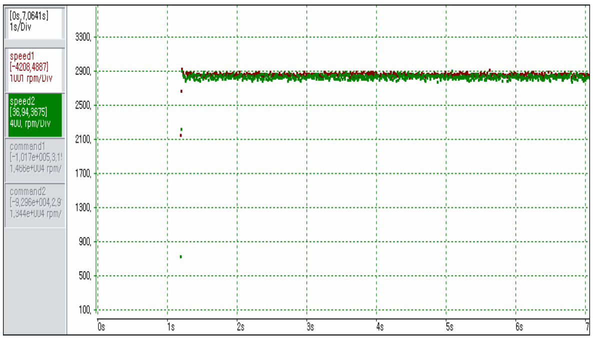

Fig. 14 Motor 1,2 speed for speed command of 2900rpm

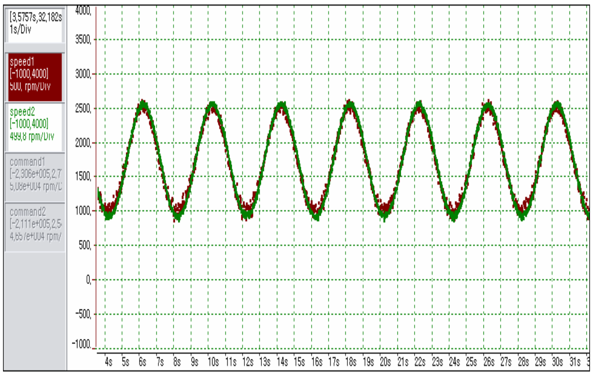

Fig. 15 Motor 1, 2 speed for 0.25Hz sine wave input speed

6. CONCLUSION

In this paper, we implement synchronization algorithm that can be adopted to the two servo-amp which are operated dependently each other. The synchronization scheme is implemented easily with the aid of CAN network which is one of various Fieldbus. Approximation model for the each servo-amp is obtained by frequency responses related to the input(speed command) and output(speed) of the servo-amp. H-infinite controller for the synchronization control is designed by the loop-shaping design method. The simulated results using Matlab verify that the synchronization controller implemented by H-infinite controller has higher robustness and good dynamic responses. It is proved experimentally that the proposed control scheme is useful for the synchronization of two servo-amps linked with CAN network. Further study will be done for field applications.

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