Multi-motor Synchronization Techniques

Vismay Chauhan, Prof. V.P. Patel

***Abstract*— Multi-motor systems has vast application industrial environment. Applications can be found in offset printing, paper machines, textiles industries and robotics also. Multi-motor techniques are required where synchronization speed during acceleration, deceleration and changes in load requires speed and angle synchronization between at least two axes. Several synchronization techniques have been developed in order to fulfill those necessities. Here the Master-Slave, Cross Coupling Technique, Bi-axial cross coupled control method, and the Relative Coupling Strategy are briefly described.**

***Index Terms*— motion control, DSP motion control, distributed motion control, Bi-axial control, Synchronous Control. Multi motor motion control system.**

I. Introduction

Development of micro-processers has brought significant changes in motion control technology. The development of high-speed digital signal processors (DSP) paves the way to software servo for motor control. High-speed DSP controller with processing higher speed initiates the age of digital motor and motion control.

Digital PWM control of the power converters and digital current regulation of the motor drives enable the feasibility of developing universal motor drives using software control technique. Successful application of digital motor drives needs computer interface with higher transmission rate and high-level motion and motor control protocols. [9]

Motion control are an essential part of modern machinery. A challenging problem is that the motion of multiple axis or motor must be controlled in synchronous manner [10]. For example, in conventional mobile robot controllers each drive loop receives no information about the other and any disturbance occurs in one loop carries on as before. This lack of co-ordination causes an error in resultant path [17]

Several cross-coupling controllers have been developed to improve the synchronization performance of the multi axis motion. Koren and Lo [14], and Srinivasan and Kulkami [15] implement fixed cross coupled controllers to reduce the contour error of two motion axes in machine tool control. A cross-coupling motion controller was proposed in reference [12] for mobile robots to adjust path accuracy by compensating the orientation error in reference [11] theory and applications of the robust cross-coupled control design is presented to reduce the contour errors of multiple axes. A cross-coupling generalized predictive control with reference models is also presented in reference [8], which can effectively handle various processes of multiple motion axes by compensating the tracking error However, the principal shortcoming of existing control techniques is their inability to explicitly incorporate plant model uncertainty to provide satisfactory synchronization performance.

Vismay Chauhan, Instrumentation & control, GTU/ LDCE/ Ahmedabad, Gujrat, India.

Prof.V.P.Patel, Instrumentation & control, GTU/ LDCE/ Ahmedabad, Gujrat, India .

The main improvements associated with the Multi-motor strategy are listed to follow [5].

- An inherent capacity to maintain synchronization between drive axes during transient time and under load disturbances.
- Fast response to load changes and start-up and shutdown conditions.
- A significant increment in the tighter machine stiffness (synchronization between components) than a mechanical shaft offers.
- A non-dissipative coupling shaft damping.
- A possible extension technique in cams, cam followers, transmission, differentials, gearboxes, clutches and brakes.

This paper is organized as follows. Section-II give brief introduction about synchronization technique. Section–III give procedure to tune controller of individual loop. Section -IV describe steps for an overall tuning procedure.

II. Procedure for Paper Submission

A. Master-Slave

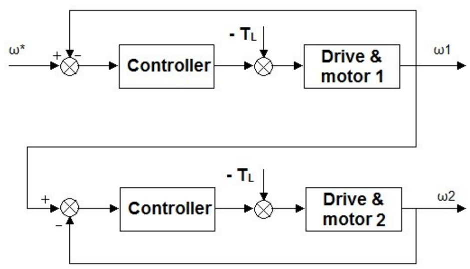

Figure 1. Structure of Master-Slave

Master-slave configuration for a two motor system is shown in Fig. 1. The output speed of the master serves as the speed reference for the slaves; main idea here is that load disturbances applied to the master will be reflected and followed by the slaves, but disturbances in any the slaves

ISSN: 2278 – 7798

will not be throw back to the master, nor any other slave. This configuration is recommended in industrial applications when synchronization in speed or position is not a main, because during load impacts, synchronization between axes cannot be guaranteed [4].

B. Cross-coupling Technique

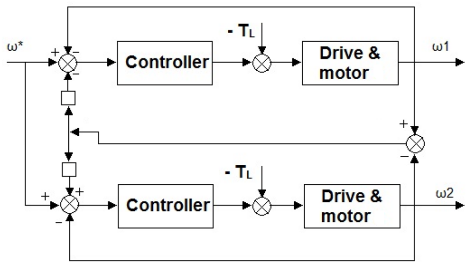

Figure 2. Structure of cross couple technique

This technique was initially proposed by Koren for manufacturing systems [18] and extended by Tomizuka et all. [13], a diagram is shown in Fig. 2. An additional feedback signal produced by the relative difference in speed or angle between two systems is the main difference of this structure compared with the first one. This arrangement allows reflecting any load variations presented in both systems by using the additional signal as a "relative" tracking signal via weighted gains, a good degree of synchronization is obtain-ed.

C. Bi-axial cross coupled technique

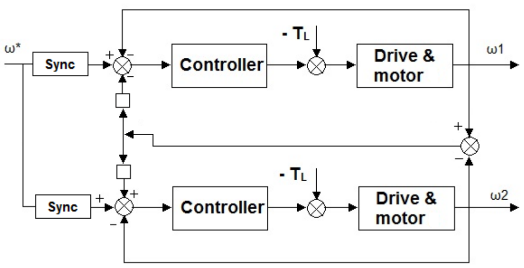

Figure 3. Structure of Bi-axial cross coupled technique

This method is originally presented in [7] and it is just applied for a two motor system. It can be observed by looking in Fig.3 and comparing it with Fig. 2, this method is just an extension of the cross coupling technique, where a master reference block "Sync" (synchronization) is added. Reference [7] discuses that both controllers act on the absolute and relative speed block, where such technique lets to achieve a good speed synchronization action. However reference [7] does not show a possible way to achieve an equal relative position control by using the same scheme, or a possible way to extend this technique for more than two motors.

D. Relative Coupling Strategy

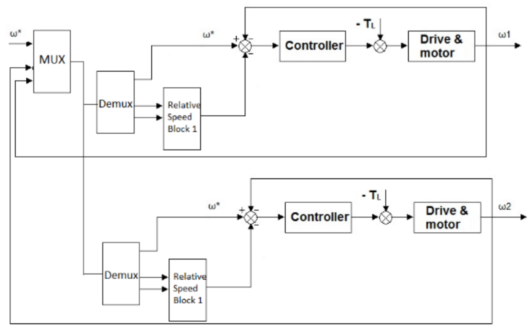

Figure 4. Structure of Relative Coupling Strategy

Fig. 4 show the Relative Coupling Strategy, which is developed in reference [5]. The main idea of this technique is based on the relative moment of inertia "seen" by each motor, which is integrated in the relative speed block. It states that the motor speed of each drive has a different "relative" speed impact reflected to each drive, where the main difference between drives is the moment of inertia "seen" by the motor under analysis. Based in that consideration, a general speed reflection from the overall system to each drive is added by using an additional "relative" error signal. This scheme can be extended for more than two motors, but a complex array is required due to each motor's speed signal must be considered an added in the relative speed block.

III. CONTROLLER TUNING

Advancement in control theory and computer programming paves an easy way for implementation of complex algorithm on embedded system.

On embedded platform by controlling the PWM output of controller we can easily control the power and angular velocity of motors. Over last 50 years there are so many techniques have been developed for controller design. Selections of techniques are constrained by controller's ability and supporting programming platform or vice versa.

Most common and favorite techniques are PID control, Model Predictive Control, Optimal control, Adaptive control, Artificial Intelligence control technique, Feedback and Feed forward technique. Combination of any one of this technique with synchronization technique described in section-II will give better result.

Though availability of advance control algorithm commonly engineers select PID control due to its simplicity easy implementation on every platform, less parameter handling and low computation burden on controller.

MATLAB Simulink is an interactive tool for modeling, simulating and analyzing dynamic, multi-domain systems. It allows accurate describing, simulating, evaluating and refining of a system's behavior through standard and customized block libraries. Simulink integrates seamlessly with MATLAB, providing an immediate access to an extensive range of analysis and design tools.

One of these tools is the MATLAB Optimization Toolbox which provides tools for general and large-scale optimization. The toolbox includes algorithms for solving many types of optimization problems, including unconstrained nonlinear minimization.

A. Tuning PID controller using IAE performance index using MATLAB Simulation

1. Develop the process model and control algorithm in Simulink and Matlab
2. Create Matlab m-file to calculate Performance index (cost function).
3. Use function of Matlab optimization toolbox to minimize the IAE criteria.

Step 1 is realized opening a new Simulink window and drag-and-drop all necessary blocks to simulate the process in Simulink. Some global variables must be defined (in this case, the controller parameters).

In step 2, a MATLAB m-file is defined to calculate the IAE index (the objective function).The IAE performance index is mathematically given by:

$$\mathbf{IAE} = \int_0^{\infty} |\, e(t) \,|\, dt \quad \mathbf{(1)}$$

where t is the time and e(t) is the difference between set point and controlled variable. The objective of optimal tuning is to reduce the rotational speed error between reference and output.

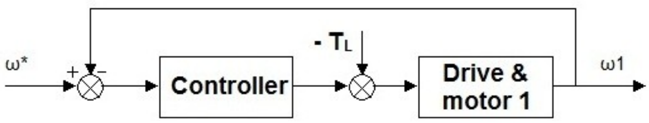

Figure 5. Single Loop tuning Structure

In step 3, a function of MATLAB Optimization Toolbox is called to calculate the minimum of the objective function defined in step 2.

Model developed in Simulink is executed and the IAE performance index is calculated using the multiple-application Simpson's 1/3 rule [3].

IV. Methodology

1. Obtain the system model of the motor system.
   A. This can be obtain either by pen and paper using mathematical modeling technique of motor by considering physical parameter of motor given in data sheet or specification manual prepared by the manufacturer.
   B. Another option is to use MATLAB® System Identification Toolbox which gives Practical model of system in no time.
2. Controller design and tuning. This can be perform in two steps;
   A. First design individual controller for motor of each axis. For example if we choose controller type as PID controller and tuning method as Optimal PID tuning. Tune it for individual axis.
   B. Next for synchronization and error reduction choose any method from Section-II; for example Bi-axial Cross Couple Technique.
3. Tune controller parameter again if necessary.
4. Simulate this using Simulation software; for example MATLAB® Simulink.
5. For experiment setup choose proper hardware platform which is able to work at hi speed and capable of implementing complex algorithm in fair way.

V. Conclusion

Master-Slave configuration is the simplest topology but it is inherent lack of stiffness results in an appropriate technique for multi-motor synchronization. Cross coupling offers good speed synchronization and it can be easily implemented, but it haves a limited performance where a relative angle is a main. Relative coupling offers the best performance but the highest complexity, as well.

References

[1] Y. Xiao, Y. Pang, X. Ge and J. Sun, "Synchronous control for high-accuracy biaxial motion systems," *Journal of Control Theory and Applications,* vol. 11, no. 2, pp. 294-298, 2013.

[2] J. Ren, C.-W. Li and D.-Z. Zhao, "CAN-based synchronized motion control for induction motors," *International Journal of Automation and Computing,* vol. 6, no. 1, pp. 55-61, 2009.

[3] F. G. Martins, "Tuning PID Controllers using the ITAE Criterion*," *International Journal of Engineering Education,* vol. 21, no. 5, pp. 867-873, 2005.

[4] F. J. Perez-Pinal, C. Nunez, R. Alvarez and I. Cervantes, "Comparison of multi-motor synchronization techniques," in *Industrial Electronics Society, 2004. IECON 2004. 30th Annual Conference of IEEE*, 2004.

[5] F. Perez-Pinal, G. Calderon and I. Araujo-Vargas, "Relative coupling strategy," in *Electric Machines and Drives Conference, 2003. IEMDC'03. IEEE International*, 2003.

[6] Y. Xiao and K. Zhu, "Cross-coupling generalized predictive control for motion systems," in *Control, Automation, Robotics and Vision, 2002. ICARCV 2002. 7th International Conference on*, 2002.

[7] G. Turl, M. Sumner and G. Asher, "A synchronised multi-motor control system using sensorless induction motor drives," in *Power Electronics, Machines and Drives, 2002. International Conference on (Conf. Publ. No. 487)*, 2002.

[8] K. Y. Zhu and B. P. Chen, "Cross-coupling design of generalized predictive control with reference models," *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering,* vol.

ISSN: 2278 – 7798

215, no. 4, pp. 375-384, 2001.

[9] S.-Y. Lin, C.-Y. Ho and Y.-Y. Tzou, "Distributed motion control using real-time network communication techniques," in *Power Electronics and Motion Control Conference, 2000. Proceedings. IPEMC 2000. The Third International*, 2000.

[10] G. T.-C. Chiu and M. Tomizuka, "Coordinated Position Control of Multi-Axis Mechanical Systems," *Journal of Dynamic Systems, Measurement, and Control,* vol. 120, no. 3, pp. 389-393, sep 1998.

[11] S.-S. Yeh and P.-L. Hsu, "Theory and applications of the robust cross-coupled control design," in *American Control Conference, 1997. Proceedings of the 1997*, 1997.

[12] L. Feng, Y. Koren and J. Borenstein, "Cross-coupling motion controller for mobile robots," *Control Systems, IEEE,* vol. 13, no. 6, pp. 35-43, 1993.

[13] M. Tomizuka, T. Kamano, J.-S. Hu and T.-C. Chiu, "Synchronization of Two Motion Control Axes Under Adaptive Feedforward Control," *Journal of Dynamic Systems, Measurement, and Control,* vol. 114, no. 2, pp. 196-203, #jun# 1992.

[14] Y. Koren and C.-C. Lo, "Variable-Gain Cross-Coupling Controller for Contouring," *CIRP Annals Manufacturing Technology ,* vol. 40, no. 1, pp. 371-374, 1991.

[15] K. Srinivasan and P. K. Kulkarni, "Cross-Coupled Control of Biaxial Feed Drive Servomechanisms," *Journal of Dynamic Systems, Measurement, and Control,* vol. 112, no. 2, pp. 225-232, jun 1990.

[16] R. Lorenz and P. Schmidt, "Synchronized motion control for process automation," in *Industry Applications Society Annual Meeting, 1989., Conference Record of the 1989 IEEE*, 1989.

[17] J. Borenstein and Y. Koren, "Motion Control Analysis of a Mobile Robot," *Journal of Dynamic Systems, Measurement, and Control,* vol. 109, no. 2, pp. 73-78, jun 1987.

[18] Y. Koren, "Cross-Coupled Biaxial Computer Control for Manufacturing Systems," *Journal of Dynamic Systems, Measurement, and Control,* vol. 102, no. 4, pp. 265-272, dec 1980.