Synchronous Control for Two Motor Systems

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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 Cross Coupling Technique is briefly described.

Keywords: motion control, DSPmotioncontrol, 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 is 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 controller store duce the contour error of two motion axes in machine tool control. Across coupling motion controller was proposed in reference [12]for mobile robots to adjust path accuracy by compensating the orientation error in reference[11] the ory and application soft he robust cross coupled control design is presented to reduce the contour errors of multiplexes. Across-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.

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 gives Simulation procedure to tune controller of individual loop. Section -IV describe steps for a overall implementation procedure.

II. SYNCHRONIZATION TECHNIQUE

A. Cross Coupling Technique

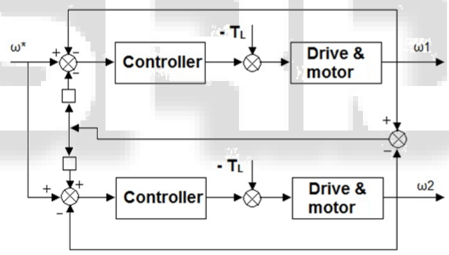

Fig. 1: Structure of cross couple technique

This arrangement allows reflecting any load variations presented in both systems by using the additional signalise "relative" tracking signal via weighted gains, a good degree of synchronization is obtained. Consider a cross coupled system below;

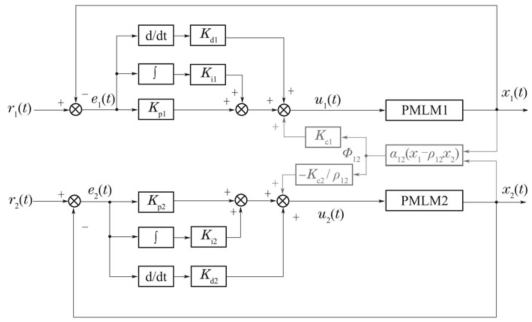

Fig. 2: Block Diagram of Cross coupling

Steps for tuning process [1]:

A typical PID controller for each motor could be easily developed for satisfactory tracking performance, as given by,

$$u_i(t) = K_{Pi}e_i(t) + K_{Ii}\int e_i(t)dt + K_{Di}\frac{d(e_i)}{dt} \quad ..(1)$$

Where $e_i = r_i - x_i$ is the tracking error of the motor deviated from a reference signal r_i, K_{Pi}, K_{Ii} and K_{Di} are the proportional, integral and derivative gains of the controller, respectively.

In a synchronous mode, both the tracking response and the synchronization motion for multiple motors are desired.

Also, in case that the motors are specified to follow different i.e., $r_i = r_j$ a scalar of $\rho_{ij} = r_i/r_j$ should be introduced to indicate the relationship between the motor i and the j th motor accurately. Then, the following synchronization error can be introduced;

$$\Phi_{ij}=\alpha_{ij}\,(x_i - \rho_{ij}x_j) \quad ..(2)$$

Where α_{ij} and ρ_{ij} are the coupling factor and the synchronization factor.

If the synchronization between the motors are not required, α_{ij} should be set as 0. Otherwise, $\alpha_{ij} = 1$, $\rho_{ij} = 1$ is meaningful for applications with the different tracking trajectories.

Then, the cross-coupling PID controllers;

$$u_i(t) = K_{Pi}e_i(t) + K_{Ii}\int e_i(t)dt + K_{Di}\frac{d(e_i)}{dt} + K_{Ci}\Phi_{ij}(t) \quad ..(3)$$

In practice, the control parameters can be tuned as follows:

- First, optimal parameters K_{Pi}, K_{Ii} and K_{Di} could be obtained through optimization method.
- Then, cross-coupling gain K_{Ci} is introduced to suppress the synchronization error. Turn the controller gain, K_{Ci}, up or down slowly and observe the synchronization error. When a value of K_{Ci} results in a mini- mum synchronization error, mark this critical value as K_{ui}, the ultimate gain.
- Obtain cross-couple gain as $K_{Ci} = K_{ui}$ / 2

III. CONTROLLER TUNING USING SIMULATION

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 modelling, simulating and analyzing dynamic, multi-domain systems. It allows accurate describing, simulating, evaluating and refining of a system's behaviour 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

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

Step 1 is realized using MATLAB® System Identification Toolbox which gives Practical model of system in no time. Using pseudorandom Binary Test (PRBS) test signals and with the help of MATLAB System Identification Toolbox the system is identified as

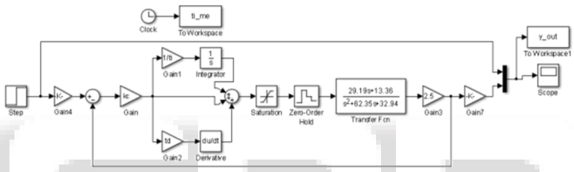

Fig. 3: PI controller for single Motor system

$G(s) = \frac{29.19*s+13.36}{s^2+62.35*s+32.94}$. This transfer function fits to estimation data by 91.29%

Step 2 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) see figure [3].

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:

$$\text{IAE} = \int_0^\infty |\, e(t)|dt \qquad (4)$$

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.

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

x = fminsearch(fun,x0)
Where,
fun = script which calculates the cost function or Performance index
x0 = initial guess of P-I-D parameter in vector form
x = returns a vector which is optimize P-I-D term value Which minimize IAE.

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

Result obtained with sampling time = 0.01 sec, *Kp* = 0.4998, *Ti* = 0.0524   x0 = [0.5 0.5] Using this controller setting the system response is;

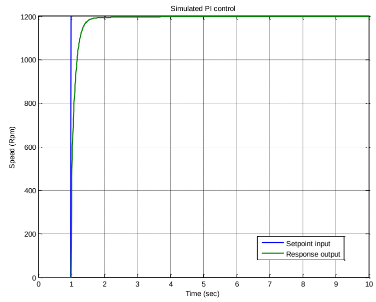

Fig. 4: Simulation result for PI controller

Coupling such two systems with described technique;

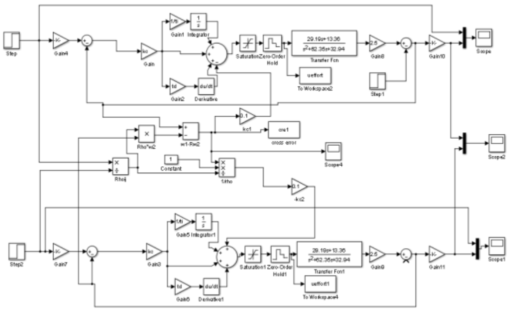

Fig. 5: Cross coupling of two DC motor

Here in figure Two DC motor system is shown. The overall system posses two DC motors with their PID controller and coupling mechanism. The PID controller is tuned as P-I controller with *Kp* = 0.4998, *Ti* = 0.0524 and coupling gain *Kc* = 0.1. Using this tuning parameter obtained output of the synchronous strategy as below;

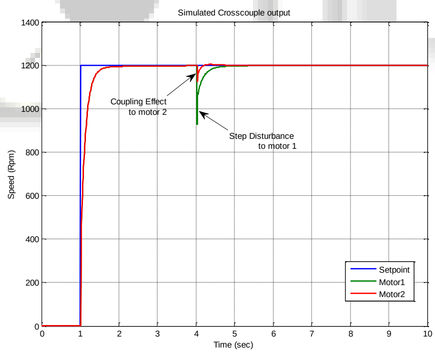

Fig. 6: Coupled System Output

Near view of disturbance at motor-1 is applied at t=4 sec which is also rejected as shown below;

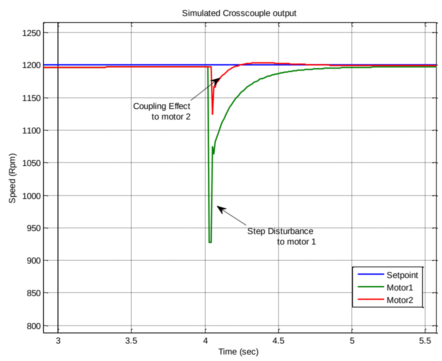

Fig. 7: Disturbance rejection or system under load change

Simulation result demonstrate that how efficiently this technique synchronize two system.

IV. METHODOLOGY AND IMPLEMENTATION

For practical testing and verification following hardware has been used;

Benix DC motor trainer kit is a standalone trainer kit used for velocity control tutorial at laboratory level. This kit is consisting of following individual parts in one complete unit;

- DC motor
- Power Supply Unit
- Buffer and Power amplifier unit
- Optical Encoder Unit
- Frequency to Voltage Control unit

Technical Specification of each unit:

A. DC motor:

Maximum speed: 1500 Rpm
Maximum input Voltage: 10 vdc
Maximum input Current: 0.9Amp

B. Power Supply Unit:

12 Vdc and 1Amp current

C. Buffer and Power amplifier unit

D. Optical Encoder Unit:

This unit is made up of slotted disk which is mounted on back of the motor. This unit provides 12 pulses per revolution.

E. Frequency to Voltage Control unit

This unit is providing for speed Measurement. Pulses from optical encoder are fed to the Frequency to voltage (F-V) converter for measurement of speed in terms of DC voltage.
Range: 0 to 2 volt DC for 0 to 1500 Rpm
This whole practical work is carried out on Arduino Mega 2560. Which act as a controller? Using this open source embedded hardware and Simulink tool box from MATLAB implementing the Simulink model file of Single loop PI control;

1) Single loop PI controller:

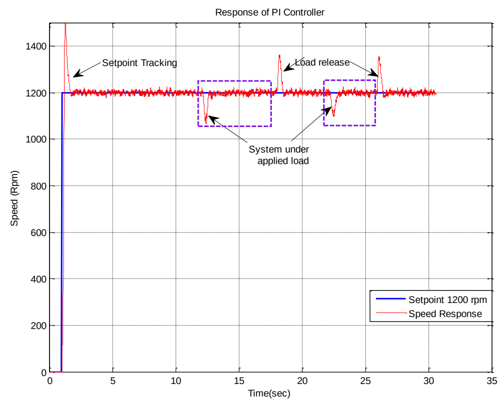

Fig. 8: Actual response of PI controller implemented on Arduino

Here Figure represents Actual PI controller response implemented over Arduino with sampling time = 0.01 sec, *Kp* = 0.4998, *Ti* = 0.0524.

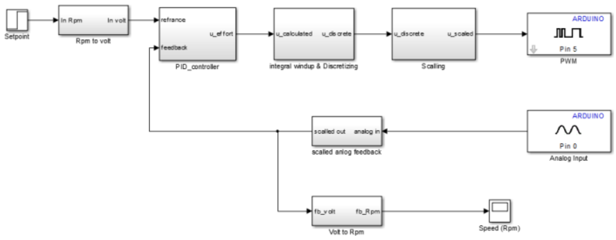

Fig. 9: Simulink model running on Arduino

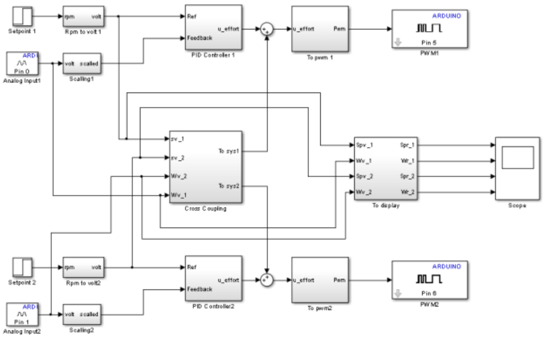

Fig. 10: Simulink model for cross couple system

2) Response of Cross coupled system:

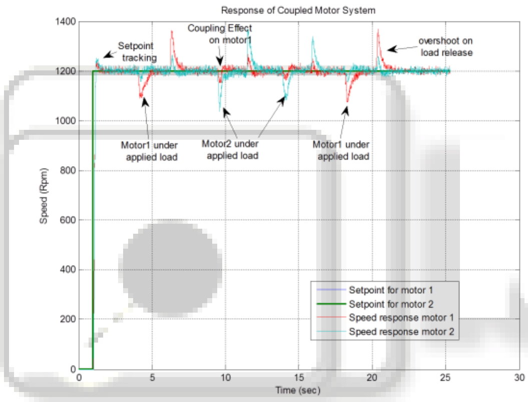

Fig. 11: Coupled system for set point of 1200 rpm

This Figure represents actual response of cross couple system. The PID controller is tuned as P-I controller with *Kp* = 0.4998, *Ti* = 0.0524 and coupling gain *Kc* = 1. this graph shows all the conditions like set point tracking, disturbance rejection.

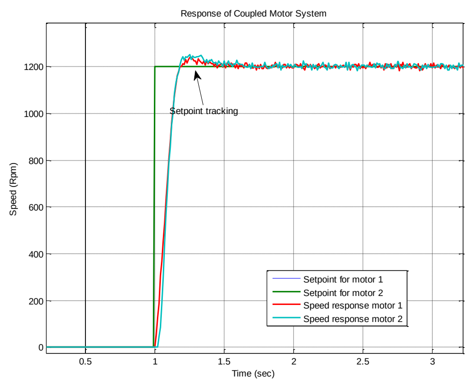

Fig. 12: near view of coupled system for set point of 1200 rpm

Here in figure set point tracking characteristic of actual cross couple system has been shown. This represents this technique give satisfactory result on practical system also.

3) Cross coupled System with Different Setpoint:

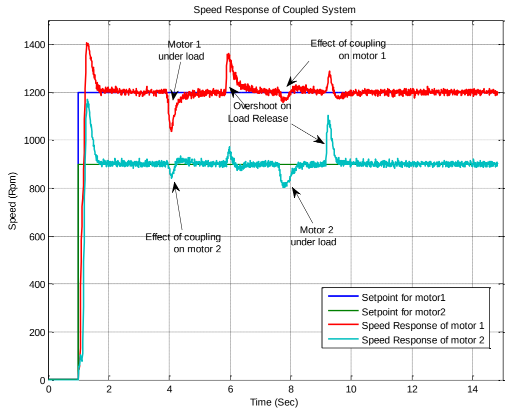

Fig. 13: Coupled system for different set point of 1200 & 900rpm

Here in figure set point tracking characteristic of actual cross couple system has been shown. This case represents the situation though both motors are running on different set point synchronization doesn't break.

V. CONCLUSION

Cross coupling offers good speed synchronization and it can be easily implemented, but it have a limited performance where a relative angle is to b maintain.

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