Design Applications of Synchronized Controller for Micro Precision Servo Press Machine

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***Abstract*—The paper focus on the synchronous servo motors controller to minimize the synchronous errors. The motion command is transmitted simultaneously for two motors in the micro-precision servo press. Based on an available process model, the feedback control makes the system stable; the feed-forward control reduces tracking error due to friction, identified model of the linear motor drive system and PI control tracks errors that occur while the press is processing. The results of this research show that the relationships between the position of the slider and the angular velocity of the motor can predict the required position of the slider. The speed of the output torque creates the conditions for real-time response. The angular position of the motor is determined by the controller and can be tracked by the predefined speed control.**

***Index Terms*—feedback control, feed-forward control, PI control, synchronous, position control**

I. Introduction

Although the press machines appeared long time ago on the market, servo technology has only recently been able to establish itself in the field of high pressing machines. The appearance of servo presses has enhanced the possibility of press production techniques with high pressing forces. Mainly Japan [1] and Germany [2] use mechanical servo technology to press matel. The structure of press machine includes two or four servo motors with ball screws. A hybrid servo press with PC–based control system was proposed by [3] and [4]. This study is intent to use a servo press with two servo motors. The basic reasons for using servo systems in order to open loop systems include the need to improve transient response times, reduce the steady state errors, and reduce the sensitivity to load parameters. The typical commands in rotary motion control for speed of motors includes position, velocity, acceleration and torque. For linear motion, force is used instead of torque. The part of servo control that directly deals with this is often referred to the feed-forward control. Therefore, in this preliminary study, we designed a feed-forward control, which predicts the needed internal commands for zero following error. Moreover, disturbances can be anything from torque disturbances on the motor shaft to incorrect motor parameter estimations used in the feed-forward control.

II. Dynamic Model of Servo Press Machine

A. Fundamental of Servo Press Motion Control

The basic components of a typical servo motion system are shown in the Fig. 1. Disturbances can be anything from torque disturbances on the motor shaft to incorrect motor parameter estimations used in the feed-forward control, as proposed by [5]. The familiar PI (Proportional Integral) is used to solve these types of problems. In contrast, the feed-forward control predicts the needed internal commands for zero following error; disturbance rejection control reacts to unknown disturbances and modeling errors. Complete servo control systems combine both these types of servo control to provide the best overall performance.

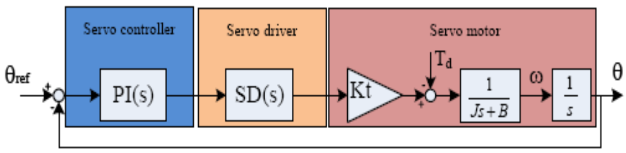

Figure 1. The PI controller diagram.

The combination of the feed-forward plus feedback control can be measured disturbance before it affects the process output was proposed by [6].

A PI controller has a form in s-domain in (1)

$$PI(s) = (K_P + K_T \frac{1}{s})E(s) \tag{1}$$

where: e(t) is the error between the command speed and the output speed.

$$e(s) = \omega_{ref}(s) + \omega(s) \tag{2}$$

The feed-forward plus feedback control block diagram is shown as in Fig. 2.

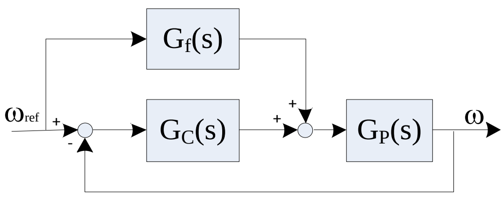

Figure 2. The feed-forward plus feedback speed control loop.

Manuscript received July 1, 2013; revised September 6, 2013.

doi: 10.12720/ijoee.2.1.62-66

where,

$G_p(s)$ – transfer function of plant.

$G_c(s)$ – feedback control law.

$G_f(s)$ – feed-forward transfer function.

In order to achieve near zero following or tracking errors, the feed-forward control is often employed by the equation which can be found as follows. We define:

$G_p(s)$ is the transfer function of plant

$$G_P(s) = H(s) \tag{3}$$

$G_c(s)$ is the feedback controller (PI controller)

$$G_C(t) = K_P e(t) + K_T \int_0^{\tau} e(\tau)\, d\tau$$

$$= 0.0521e(t) + 89.3635 \int_0^{\tau} e(\tau)\, d\tau \tag{4}$$

$G_f(s)$ is the feed-forward transfer function.

For speed control loop, the transfer function is given in (5).

$$\frac{\omega(s)}{\omega_{ref}} = G(s) = \frac{G_C(s)G_P(s) + G_f(s)G_P(s)}{1 + G_C(s)G_P(s)} \tag{5}$$

Desired transfer function G(s) is 1, the equation is given

$$G_f(s) = \frac{1}{G_P(s)} \tag{6}$$

With this system, the plant transfer function $G_p(s)$ is,

$$G_P(s) = \frac{K_T}{Js+B} = G_o(s)$$

$$= \frac{2.6022e006}{s^2 + 937.5s + 5.8810e005} \tag{7}$$

$$G_f(s) = \frac{1}{K_T}s + \frac{B}{K_T}$$

$$= \frac{(s^2 + 937.5s + 5.8810e005)}{2.6022e006} \tag{8}$$

$$G_f(s) = (3.8432e-007) * s^2 + (3.6030e-004) * s + 0.2260 \tag{9}$$

We can omit the s^2 term because its coefficient is very small that compare to another part.

$$G_f(s) \approx (3.6030e-004) * s + 0.2260 \tag{10}$$

B. Discrete Time Design

With natural frequency, $w_n = 377\, rad/s$. Apply the sampling theorem, we should choose the sampling frequency:

$$w_s = (5 \div 10) * w_n = (5 \div 10) * 377 \rightarrow T_s = \frac{2\pi}{w_s}$$

Choose $T_s = 0.002\, second$.

The plant model in the z – domain is given in (11), with sampling time, $T_s = 2ms$.

$$P(z) = \frac{4.421z + 0.003527}{z} \tag{11}$$

We need to design a *PI* controller to meet the following design specifications: settling time should be minimal and the closed loop system should follow unit step reference signal without steady – state error.

A discrete *PI* controller is given in equation (12)

$$C(z) = K_p + K_i \frac{T_s z}{z-1} \tag{12}$$

PI parameters for speed control loop: $K_p = 2.5051e-4, K_i = 8.2858e-3$.

$$C(z) = 0.00026708 * \frac{z-0.938}{z-1} \tag{13}$$

In order to achieve a high performance tracking position error, a discrete PI controller is designed for position control loop. The control block diagram is shown in Fig. 3. PI parameters for position control loop $K_p = 5.6857, K_i = 0.6143$.

$$C(z) = 5.6857 + 0.0012 * \frac{z}{z-1} \tag{14}$$

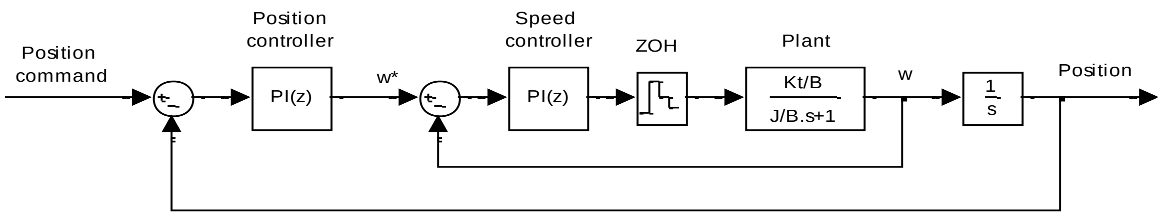

Figure 3. The proposed schematic control.

C. Design of Synchronous Controller

This study already designed controllers for one motor. Now, in our application, we need two servo motors to drive only one shaft. For the transducer, we use a timing belt with a transmission ratio of 1.

The algorithm is simple, as shown in Fig. 4, which can get the error between two motors and add it to the feedback loop. The speed error is defined by (15).

$$e_s(t) = \omega_1(t) - \omega_2(t) \tag{15}$$

Assume the command speed is shown in Fig. 5 and the torque disturbance adds on motor 1 and motor 2 are shown in Fig. 6.

All the motor parameters are given in Table I. We use Matlab/Simulink to simulate our system. The current (voltage) and torque of the motors are limited. So, we need to limit them. Now, we can see the performance of the synchronous control algorithm, and the synchronous speed errors are shown in Fig.7. Thus, the results show that the errors are very small in (16),

$$Max\left(abs\left(e_s(t)\right)\right) \approx 0.01, rad/s \qquad (16)$$

The maximum (peak) error occurs when the command speed changes very fast or the acceleration is very rapid. The better the motion profile we design, the better response behavior the system will be high.

TABLE I. PARAMETERS OF SERVO MPOTOR

Model: ECMA Series	F118
Rated output power (kW)	7.5
Rated torque (N-m)	47.74
Maximum torque (N-m)	119.36
Rated speed (rpm)	1500
Maximum speed (r/min)	3000
Rated current (A)	47.5
Maximum current (A)	118.8
Power rating (kW/s) (without brake)	159.7
Rotor moment of inertia($\times 10^{-4}$kg.m^2) (without brake)	142.7
Mechanical time constant (ms) (without brake)	0.63
Torque constant-K_T (N-m/A)	1.01
Voltage constant-K_E (mV/(r/min))	35.5
Armature resistance- R_a (Ohm)	0.015
Armature inductance - L_a (mH)	0.04

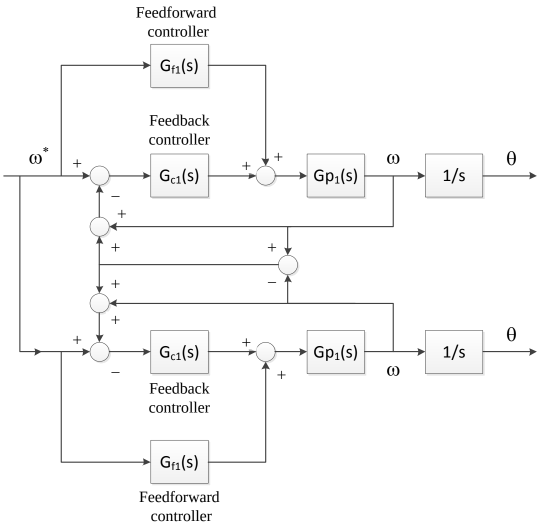

Figure 4. The scheme control of two servomotors.

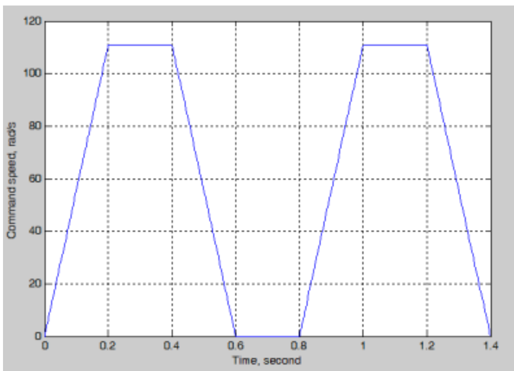

Figure 5. A command speed.

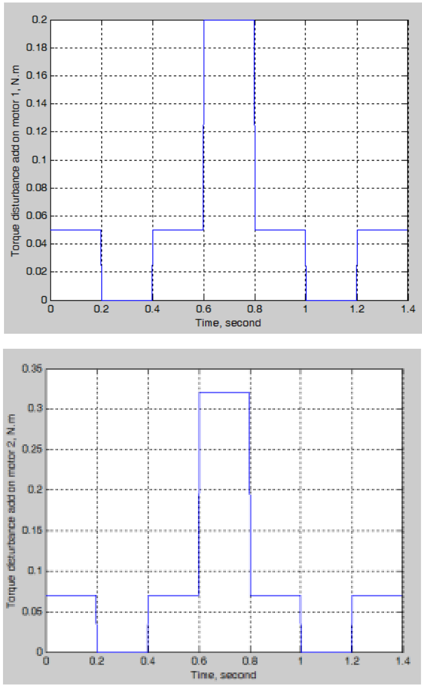

Figure 6. The torque disturbance model adds on motor 1 and 2.

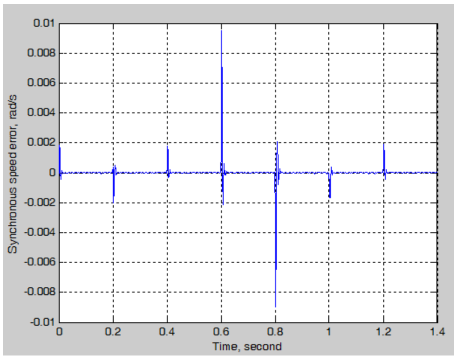

Figure 7. The synchronous speed errors.

As shown in the block diagram of the system, there is no position controller loop. In other words, no position feedback loop or we do not need a position sensor. But, we observe the synchronous position errors are shown in Fig. 8. The results show that the errors are very small,

$$Max\left(abs\left(e_{ps}(t)\right)\right) \approx 4e-5 \qquad (17)$$

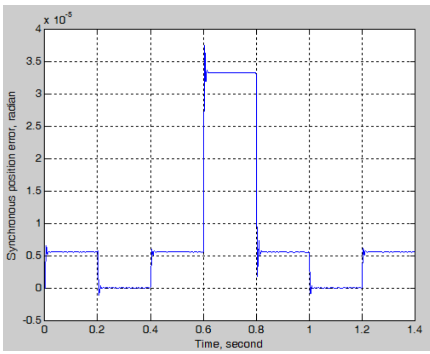

Figure 8. The synchronous position errors.

III. EXPERIMENTAL RESULTS

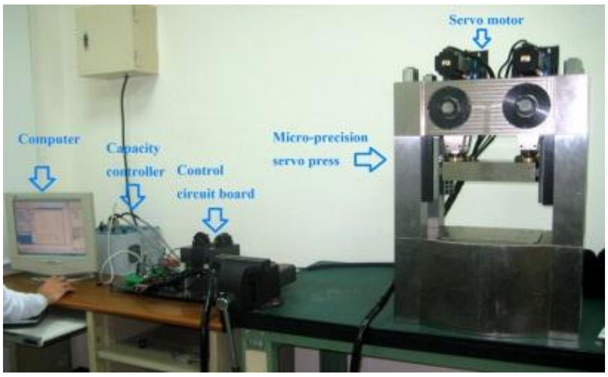

Figure 9. Servo press machine system.

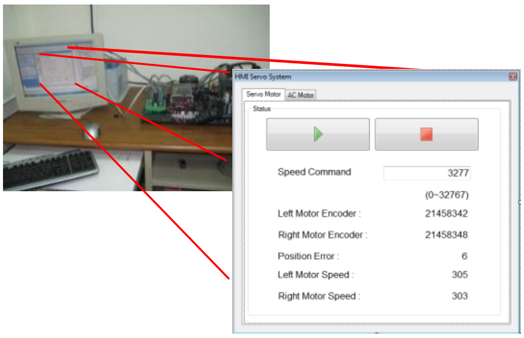

Figure 10. The experimental drive system configurations.

The servo press system is tested by applying model of the block diagram of the synchronous controller as shown in Fig. 4, with different motion profiles. Initially, test signals like step input and ramp function are designed by this study. While applying these test signals, the crank only included in the model calculations, and other links have not took into consideration. The system is simplified and treated as a crank driven with a servo motor. Later, the designed motion profiles are implemented with the inclusion of all links in the mechanism and simulation results are obtained. The input for the simulation consists of the required motion profile, the slider-crank mechanism parameters, the servo motor data and the initial conditions for the integration.

The system architecture of the experimental set-up is shown in Fig. 9. After we type the speed command from the keyboard, and click to the start button, two AC servo motors will start, they drive the press machine system in Fig. 10. The AC motor is only used when we need to adjust the press machine's table. We have to focus on two AC servo motors. The label that shows a = (0 - 32767) pulses/sec = (0 – 10) Voltages = (0 - 3000) rpm, it is the range of the speed command.

Two slider crank mechanisms are driven by two servo motors via two timing belts, with the gear reduction ratio is 1: 24. The punching speed, 40 stroke per minute was undertested which corresponds to 500rpm rotation speed of the servo motor. The synchronous position error between two motors is shown in Fig. 11. The maximum error is 0:0041radian.

The output speed compares with nominal output speed then error between two motor are change into degree, as show in Fig. 12 and Fig. 13. It only is around (-3^0C ÷ 3^0C).

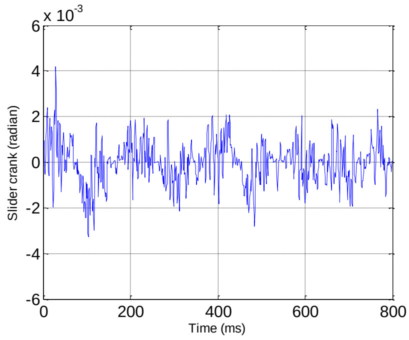

Figure 11. The synchronized position errors between two sliders.

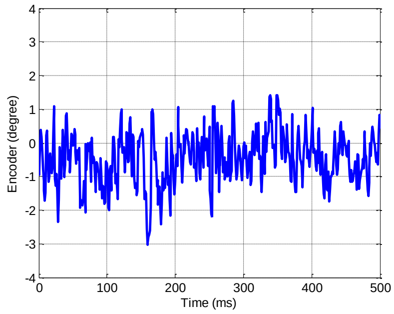

Figure 12. The position errors between motor 1and motor 2 with Scmd=25rmp.

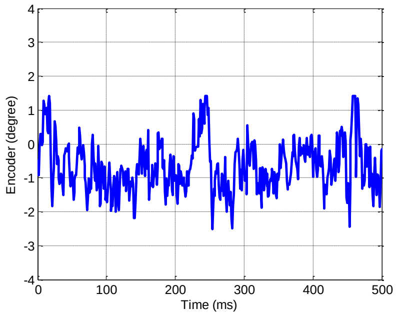

Figure 13. The position errors between motor 1and motor 2 with Scmd=35rmp.

IV. CONCLUSIONS

Micro-precision servo press technology applies for the micro products with high speed, which can lead to increase the productions and organizational profits. This study proposes a simple control system that consists of the feedback controller, the feed-forward and the synchronous controller. The feedback controller is used to regulate variables in the control systems design, which has time varying disturbances, and or operating parameters. The feed-forward controller is used to reduce the tracking error. And the synchronous controller is employed to eliminate the motion error between two motors. This control system can make two sliders move at the same position and the servo press is stable under a wide range of operating speed.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support and enlightening comments the Metal Industries Research & Development Center (MIRDC) and Foxnum Technology Company in Taiwan.

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