SYNCHRONOUS MOTION CONTROL OF DUAL-DRIVE GANTRY STAGE SYSTEM WITH SLMPM

I. Vargha, M.Žalman, T.Mudráková

Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Institute of Control and Automation

1 Introduction

Dual-drive gantry stage systems are commonly used in many industrial processes, where high-dynamic and/or high-precision Cartesian movements are required (e.g. printed circuit board assembly, precision metrology or plasma/laser/water-jet cutting machines). Linear dual-drive gantry stage system is based on two motors mounted on parallel rails in the x direction, which simultaneously move a beam. The studied industrial dual-drive gantry stage system developed by Microstep spol. s r. o. (Slovakia) is equipped with synchronous linear motor with permanent magnets (SLMPM).

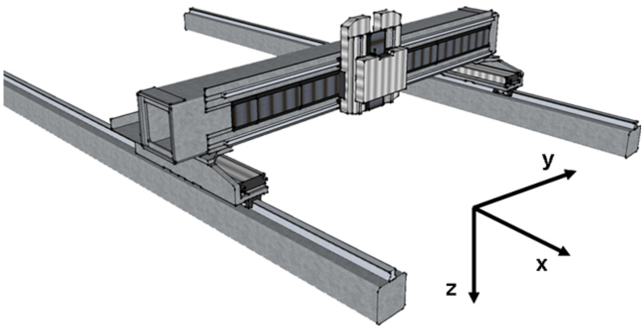


Figure 1: Dual-drive gantry stage system

The demands on the dual-drive gantry stage application are constantly raised. The high requirements for velocity, high precision and performance are becoming obvious nowadays. The classical rotational dual-drive gantry stage more and often deals with technical and construction limitation.

In linear dual-drive gantry stage systems the high dynamical and high-precision movement place very high demands on mechanical construction.

The speed of the system is limited with induced vibrations which increase settling time.

The mechanical structure of the system has to undergo many overloads due to the synchronous error between the two linear encoders. The potential energy stored during the movement of the system is dissipated when the system stops and consequently leads to the mechanical vibration of the system.

That is why we try to figure out how to minimize the synchronous error during the movement.

In this paper we present the gantry stage control with disturbance observer based on detailed physical model of the system.

The main idea is to use the detailed physical model of the system to minimize the synchronous error during the movement.

First of all, the parameters of the dual-drive gantry stage are experimentally identified. A model with one elastic element is carried out. Finally, the control structure with disturbance observer is compared with the industrially supplied gantry stage control structure.

2 Physical modeling of the gantry stage system

The present objective is to establish a control- oriented model of the linear dual drive gantry stage system, based on its physical mechanical and dynamical parameters.

Based on the knowledge that we have from the work of (J. Gomand, et al., 2008), we model the joints between the beam and the cart with the motor as the elastic elements Fig.2.

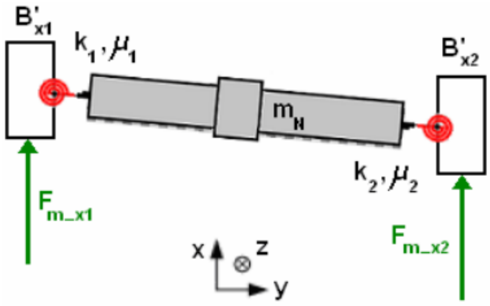


Figure 2: Dual-drive gantry stage model with elastic elements on both sides

The elastic element on one side of the beam, model a very small rotational degree of freedom which is created by imperfection of the rails and freedom of the ball line. The elastic element on the other side of the beam allow slip and thermal expansion of the beam. The beam it self is thus considered as a rigid body element.

This kind of model contain to many $\left(m_{vx\_1}, m_{vx\_2}, m_N, k_1, k_2, \mu_1, \mu_2, B^I_{x1}, B^I_{x2}\right)$ parameters for experimental identification.

If we consider that both joints of the dual drive gantry stage model are subjected to the same angle than we can model them by a single equivalent spring with stiffness k and damping ratio μ Further more we can not assume that the weight distribution of the beam is constant, this condition is generally impossible to reach because of the load variation induced by the position of the moving head along the beam.

This leads us to physical dynamical model of gantry stage system presented in Fig.3.

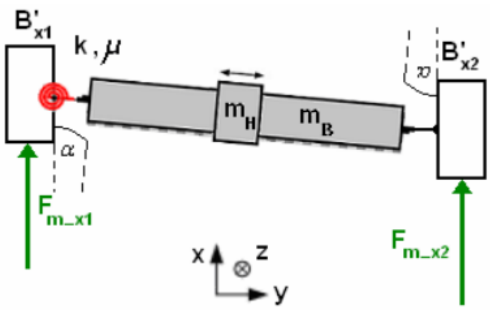


Figure 3: Dual-drive gantry stage model with one elastic element with considering the weight of the head

The weight distribution of the beam on the real dual drive gantry stage system is still changing because the head of the machine is still moving. This change of the weight causes that the moment of inertia of the beam and also the distribution of the breaking force still change.

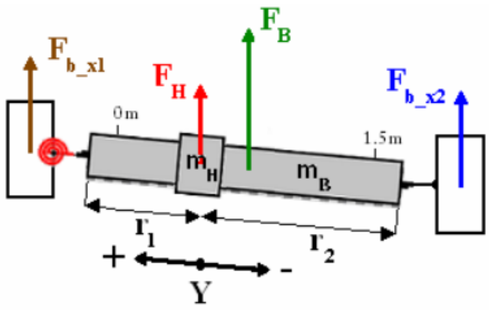


Figure 4: Distribution of the breaking force and initial point of the y-axis of the dual-drive gantry stage model

If we want to include this weight distribution change of the beam into our model, we need to specify the initial point of the y-axis in our coordinate system Fig.4. Applying the Newton's laws of motion to each equivalent mass of the gantry stage model, the system can be described by (1, 2, 3, 4, 5, 6).

$$F_{s\_x1} = \frac{m_B}{2}\left(\frac{a_{x1}+a_{x2}}{2}\right) + m_H\left(\frac{a_{x1}+a_{x2}}{2}\right)\left(\frac{d_{dz}+s_y}{d_B}\right) \quad (1)$$

$$F_{s\_x2} = \frac{m_B}{2}\left(\frac{a_{x1}+a_{x2}}{2}\right) + m_H\left(\frac{a_{x1}+a_{x2}}{2}\right)\left(\frac{d_B-(d_{dz}+s_y)}{d_B}\right) \quad (2)$$

$$J_C = J_B + J_{v\_x1} + J_{v\_x2} + J_H \quad (3)$$

$$\frac{v_i}{F_{m\_i} - F_{b\_i}} = \frac{1}{m_{v\_i}s - B_i^I} \quad i = x_1, x_2 \quad (4)$$

$$F_{b\_x1} = F_{s\_x1} + \frac{J_C}{L^2}(a_{x1} - a_{x2}) + \left(\frac{\mu}{L^2} + \frac{k}{L^2 s}\right)(v_{x1} - v_{x2}) \quad (5)$$

$$F_{b\_x2} = F_{s\_x2} + \frac{J_C}{L^2}(a_{x1} - a_{x2}) - \left(\frac{\mu}{L^2} + \frac{k}{L^2 s}\right)(v_{x1} - v_{x2}) \quad (6)$$

The experimental identification of the B^I_{x1}, B^I_{x2} model parameters has been carried out with both direct mechanical transfer functions given by relations (4).

The corresponding schematic representation of the model is given in Fig.5

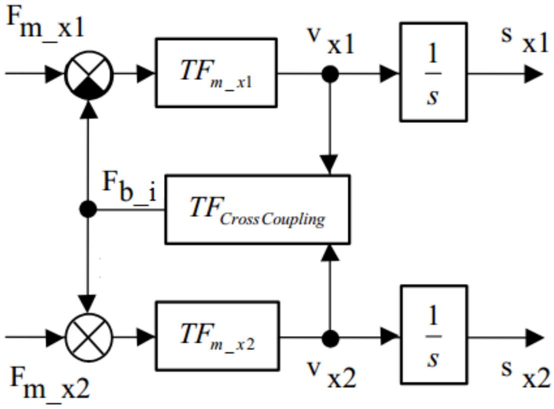


Figure 5: Schematic representation of dual drive gantry stage model

3 Control of dual drive gantry stage system

Classical industrially supplied control structure for the servo drive systems which are mounted into gantry stage system are based on P+PI cascade control structures. In my bachelor thesis we deal with discretization (P+PS) and designing of cascade control structures for synchronous linear motors with permanent magnets. The control structure for gantry stage system with two servo drive systems is consequently based on two independent SISO position cascade controllers P+PS with correction.

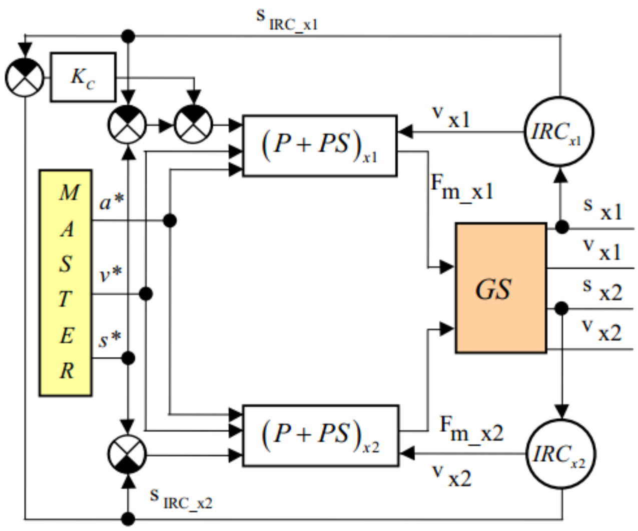


Figure 6: Schematic representation of P+PS cascade control structure with correction

This control structure does not take into account the mechanical coupling between the two servo drive systems and leads to induced vibration when the system stop.

If we want to reduce the mechanical coupling between the axis of the gantry stage we need to know the cross coupling forces of the system.

Luenberger observer

Luenberger observer is an observer of position, speed and acceleration. Its main function is to numerically evaluate the speed (first derivation of the position) and acceleration (second derivation of the position) from known course of position.

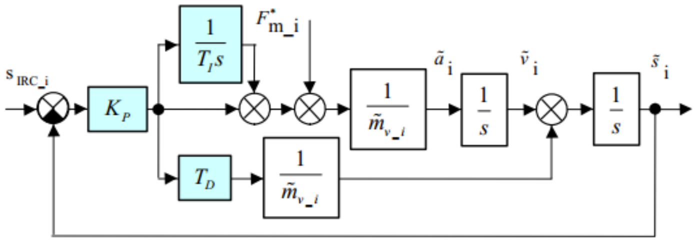


Figure 7: Schematic representation of Luenberger observer

Based on the known courses of position, speed and acceleration we create a special correction block which main function is to calculate the observed breaking force of each axis of the gantry stage system.

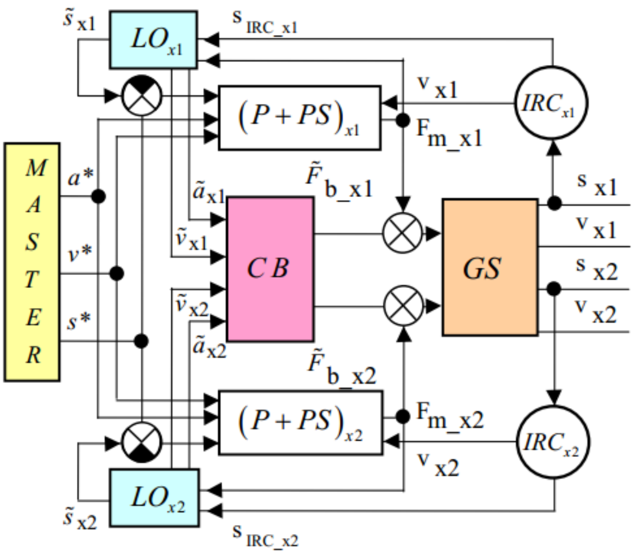
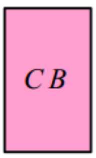


Figure 8: Schematic representation of P+PS cascade control structure with Luenberger observers

Dual-drive gantry stage model with one elastic element with considering the weight of the head Fig.5



Compensation block of the dual-drive gantry stage model with one elastic element with considering the weight of the head Fig. 8

4 Simulation comparisons

Position of the head of the beam $s_y = 0{,}75\,m$

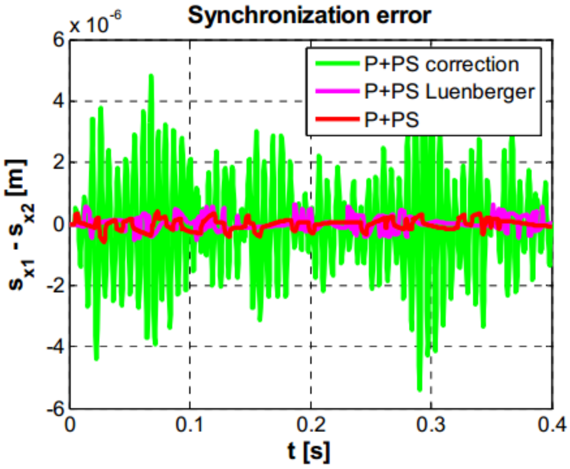


Figure 9: Comparison of the measure of synchronization error control structure of the dual drive gantry stage model

Position of the head of the beam $s_y = 0\,m$

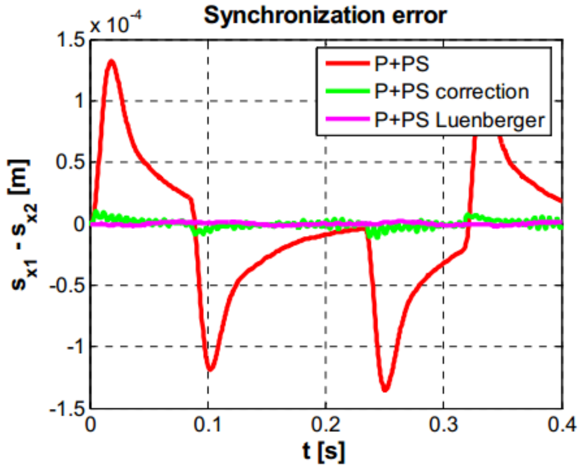


Figure 10: Comparison of the measure of synchronization error control structure of the dual drive gantry stage model

Position of the head of the beam $s_y = 1{,}5\,m$

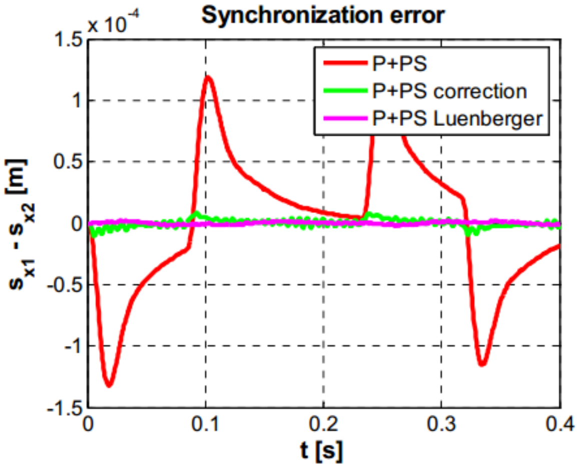


Figure 11: Comparison of the measure of synchronization error control structure of the dual drive gantry stage model

5 Conclusion

This paper presents a P+PS cascade control structure with Luenberger observers based on a control-oriented model of the linear dual drive gantry stage system.

The dual-drive gantry stage model with one elastic element with considering the weight of the head is used to deduce the compensation block for the gantry stage cascade control structure with Luenberger observer.

Finally, based on simulation comparison of the control structures of the dual drive gantry stage model we may state that P+PS cascade control structure with correction is from the view of connection simplicity and applicability in practice one of the best possible control option of the dual drive gantry stage model. Disadvantage of this control method is failure to maintain measure of synchronization error at controlling of symmetrical dual drive gantry stage model (Fig.8) at the same level as offered by classical industrially supplied P+PS cascade control structures.

The P+PS cascade control structures with Luenberger disturbance observers can preserve the level of synchronization error and offer higher precision in positioning at controlling of symmetrical dual drive gantry stage system, but this control structures are much more complex for experimental identification.

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Ing. Imrich Vargha

imrich.vargha@stuba.sk

prof. Ing. Milan Žalman, PhD.

milan.zalman@stuba.sk

Ing. Tatiana Mudráková, PhD.

tatiana.mudrakova@stuba.sk