doi: 10.21495/71-0-407

25th International Conference
ENGINEERING MECHANICS 2019
Svratka, Czech Republic, 13 – 16 May 2019

MOTION SYNCHRONIZATION FOR ELECTRO-HYDRAULIC SERVO-DRIVES

P.Wos[*], R. Dindorf[**]

Keywords: *This article presents a control algorithm that solves the problem of motion synchronization for a system of three electro-hydraulic drives. The designed control system takes into account not only position errors for individual drive axes, but also synchronization errors with neighboring axes. The synchronization function for the control system, which takes into account the positioning errors of individual drive axes was specified. Experimental results on a 3-cylinder system were presented to verify the effectiveness of the proposed approach.*

Keywords: electro-hydraulic, servo drive, synchronization error

1. Introduction

The problem of synchronization of many linear hydraulic cylinders occurs with the use of hydraulic drives with high load. In these machines, the synchronous movement of hydraulic cylinders under load is very important (Sun, H. and Chiu, 2002). This issue is most visible in hydraulic handling and crane devices with many actuators. Due to the uneven loading and the differences in the design of the individual hydraulic drive systems, there are differences in the accuracy of their positioning (Ishizaki et al., 2013), (Sun, Dong, 2003). The problem of traffic synchronization occurs when several hydraulic cylinders loaded with forces or moments of various character and value, fed from one source, are to simultaneously work. Without the introduction of appropriate synchronizing elements, the simultaneous advancing of the cylinder rods at the same speed is impossible, because the separation of the liquid flowing from the power source depends on the difference in load of the hydraulic pistons. There are many approaches to solve the problem of synchronization of many hydraulic cylinders (Sun, D. et al., 2006). The simplest approach is to design a flow divider circuit that will maintain the same cylinder speed by maintaining the same flow rate for the cylinders. The efficiency of the synchronization depends on the efficiency of the flow distributor, as well as the compressibility of the working fluid and the consistency of the hydraulic components (Liu et al., 2014). Another solution is the mechanical connection of hydraulic cylinders by means of cabling or other switching construction. The disadvantage of mechanical synchronization is the weight and complexity of the system, as well as the limitation of the device's operating range. Compared to purely hydraulic and mechanical solutions, electro-hydraulic synchronization is a flexible alternative. In the EH system, synchronization control strategies can be designed to deal with uneven loads as well as uncertainties and external disturbances associated with the hydraulic system (LU et al., 2017). In classical control systems, the positioning errors of one of the drive axes are corrected only for itself, while the other axes perform their previous operation. Lack of knowledge about positioning errors of individual axes results in unacceptable contour errors (synchronization) of the end effector of the manipulator (Mengfei et al., 2015), (Yao et al., 2018). Controlling the operation of hydraulic systems is perceived as a relatively easy task. However, it is completely different when it is necessary to control the operation of the actuators in the entire range of motion (Wos and Dindorf, 2016).

[*] PhD Piotr Wos, Faculty of Mechatronics and Machine Design, Kielce University of Technology, Kielce, 25-314, Poland, wos@tu.kielce.pl

[**] Prof. Ryszard Dindorf, Faculty of Mechatronics and Machine Design, Kielce University of Technology, Kielce, 25-314, Poland, dindorf@tu.kielce.pl

2. The design electro-hydraulic servo control

In order to evaluate the effectiveness of the proposed synchronous tracking controller, experiments were carried out on a Hydraulic Manipulation Platform (HMP), as shown in Figure 1. The HMP consists of a moving platform (1) connected to a fixed base with several arms (2). The arms are mounted with rotary joints (5). The position of the platform (1) is dependent on the position of the arms. Each arm incorporates an electro-hydraulic servo drive, controlled by a proportional valve (3), which is able to generate power of up to 20 kN for each axis (Wos and Dindorf, 2015).

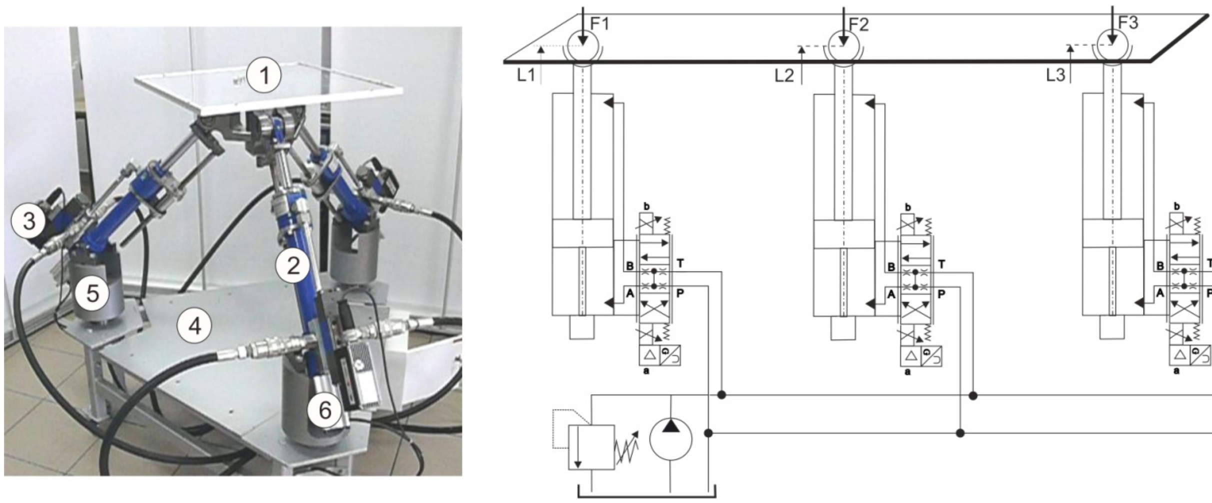

Fig. 1: The hydraulic manipulation platform [HMP] prototype: 1 – platform, 2 – hydraulic cylinder, 3 – proportional control valve, 4 – base, 5 – joint connecting the actuator with the base, 6 – position sensor

The HMP control system directly controls servo-drive mounted in the joints. The HMP trajectory is performed by minimising the difference of the current and predetermined position of the individual joint. Signals from actuator sensors are processed through real-time software. In the measurement system of hydraulic cylinders DAC and ADC converters of PCI–DAS1602/16 and PCI-DDA08/12 type were used. Piston displacement L_i of the hydraulic servo-cylinder was conducted by position transducers (6) (Dindorf and Wos, 2014)(Wos and Dindorf, 2015).

3. Control strategy

The control strategy is to stabilize the position tracking of each hydraulic axis during its synchronization with the movements of other axes, so that the differential position errors between the axes converge to zero.

Trajectory tracking error of *i*-th actuator is:

$$e_i(t) = L_i^d(t) - L_i(t) \tag{1}$$

Synchronization function described by demand (7):

$$\frac{L_1(t)}{L_1^d(t)} = \frac{L_2(t)}{L_2^d(t)} = \frac{L_3(t)}{L_3^d(t)}, \tag{2}$$

where L_i is the actual length and L_i^d is the desired length of the *i*-th actuator.
Thus, the synchronization errors were defined as:

$$\begin{cases} \varepsilon_1(t) = e_1(t) - e_2(t) \\ \varepsilon_2(t) = e_2(t) - e_3(t) \\ \varepsilon_3(t) = e_3(t) - e_1(t) \end{cases} \tag{3}$$

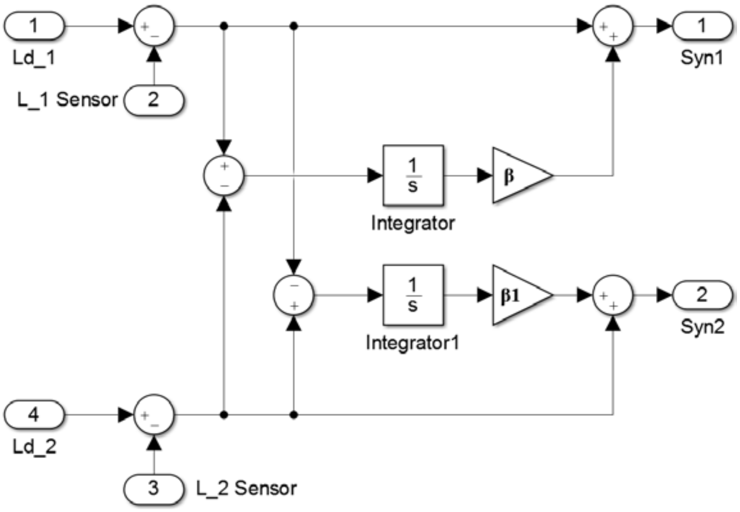

Fig. 2: Partial diagram of the synchronization controller in Matlab/Simulink

Position control system is designed by combining the position error and synchronization error. According to the concept of cross–coupled controller (Zhu and Chen, 2001) the coupled error e_{ic} includes the position error e_i and the synchronization error ε_i :

$$e_{ic}(t) = e_i(t) + \beta\int_0^t \varepsilon_i(\omega)d\omega \tag{4}$$

where: β is a constant (positive coupling gain), which determine the weight of synchronization error. Figure 3 present results of the control process for references pulse signal.

a) b)

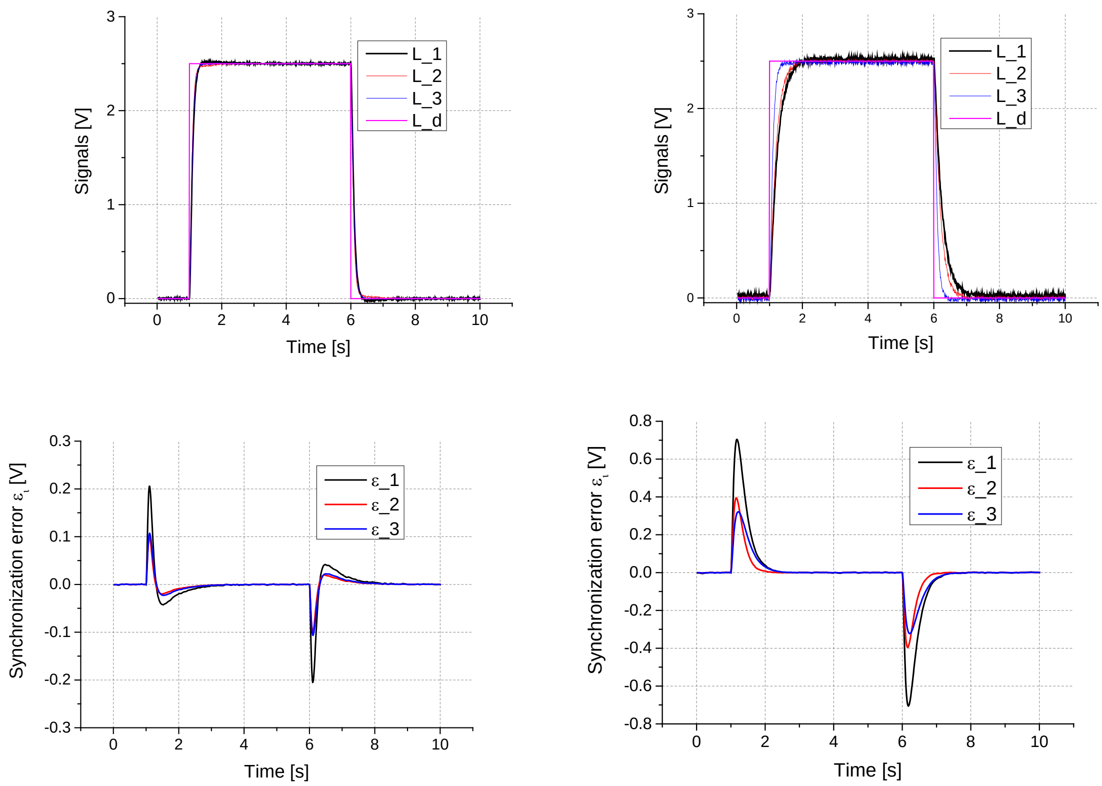

Fig. 3: Experimental results, according to the pulse trajectory: a) with synchronization, b) without synchronization

4. Conclusions

The article considers the synchronization of the hydraulic system with three actuators operating to increase the common load. Cylinders are controlled by individual proportional control valves. The results of testing the accuracy of hydraulic positioning of the HMP are presented. In order to minimize errors HMP movements used the cross-coupling control. Errors in the performance of structural elements and technological clearances are the basis for the lack of synchronization of the movement of the manipulator drives. In addition, such phenomena as non-linear friction, deformation of structural elements due to external forces, generated during operation are presented separately for each axis. The effect of these phenomena is to increase the positioning errors of the manipulator. The aim of the study was to create a control system that will counteract these phenomena by taking into account the synchronization errors of individual drive axes. Presented HMP control system uses feedback from axis position error and synchronization errors.

References

Dindorf, R., and Wos, P. (2014) Contour error of the 3-DoF hydraulic translational parallel manipulator. Adv. Mater. Res. Vol. 874. doi:10.4028/www.scientific.net/AMR.874.57

Ishizaki, K., Sencer, B., and Shamoto, E. (2013) Cross coupling controller for accurate motion synchronization of dual servo systems, International Journal of Automation Technology, 7, 5, pp. 514–522. doi:10.20965/ijat.2013.p0514

Liu, Z., Gao, Q., Yu, C., Li, X., Guan, W., and Deng, G. (2014) Collaborative synchronization digital control for double hydraulic cylinders, Advances in Mechanical Engineering, 2014, , pp. 1–18. doi:10.1155/2014/371403

Lu, W., JI, K., Dong, H., Zhang, J., Wang, Q., and Guo, L. (2017) Double position servo synchronous drive system based on cross-coupling integrated feedforward control for broacher, Chinese Journal of Mechanical Engineering, 30, 2, pp. 272–285. doi:10.1007/s10033-017-0077-5

Mengfei, S., Jianxiong, L., and Yiming, F. (2015) Adaptive cross-coupled sliding mode control for synchronization of dual-cylinder electro-hydraulic servo systems, in: 2015 34th Chinese Control Conf. IEEE, pp. 3361–3366. doi:10.1109/ChiCC.2015.7260158

Sun, D. (2003) Position synchronization of multiple motion axes with adaptive coupling control, Automatica, 39, , pp. 997–1005. doi:10.1016/S0005-1098(03)00037-2

Sun, D., Lu, R., Mills, J. K., and Wang, C. (2006) Synchronous tracking control of parallel manipulators using cross-coupling approach, The International Journal of Robotics Research, 25, 11, pp. 1137–1147. doi:10.1177/0278364906072037

Sun, H., and Chiu, G. (2002) Motion synchronization for dual-cylinder electrohydraulic lift systems, Mechatronics, IEEE/ASME Transactions On, 7, , pp. 171–181. doi:10.1109/TMECH.2002.1011254

Wos, P., and Dindorf, R. (2015) Synchronized trajectory tracking control of 3-DoF hydraulic translational parallel manipulator. Adv. Intell. Syst. Comput. Vol. 317. doi:10.1007/978-3-319-10990-9_24

Wos, P., and Dindorf, R. (2016) Practical parallel position-force controller for electro-hydraulic servo drive using on-line identification, International Journal of Dynamics and Control. doi:10.1007/s40435-014-0092-7

Yao, J., Cao, X., Zhang, Y., and Li, Y. (2018) Cross-coupled fuzzy pid control combined with full decoupling compensation method for double cylinder servo control system †, Journal of Mechanical Science and Technology, 32, 5, pp. 2261–2271. doi:10.1007/s12206-018-0437-9

Zhu, K. Y., and Chen, B. P. (2001) *Cross-coupling predictive control for two axes synchronous systems*. doi:10.1016/S1474-6670(17)34277-5