U.P.B. Sci. Bull., Series C, Vol. 82, Iss. 4, 2020 ISSN 2286-3540

THE TRANSITION FROM HYDRAULIC TO HYBRID SERVO SYSTEMS – A WAY TO SAVE ENERGY

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The paper presents the dynamic analysis of the modern electrohydraulic, hybrid and electromechanical control systems used for driving industrial equipment, and a realistic analysis of the most adequate type of driving system for different applications. The real performances of a classical electrohydraulic steering systems are considered as reference for a new type of hybrid steering system. Both of them were designed and tested by the authors with the support of an aerospace manufacturing company. The preliminary tests have shown that the new system can be used for steering small and medium size hybrid cars.

Keywords: hydraulic, hybrid and electro mechanic servomechanisms performances, energy saving possibilities, simulations and experimental research.

1. Electric rod actuators versus electrohydraulic servo cylinders

The industrial robotics generated a remarkable progress in the field of the electric rod actuators. Step by step, the overall static and dynamic performances of these clean devices were improved both with a new ball-screw technology, and the new generation of compact power electronics, in close connection with the high-speed digital communication networks. In parallel, the new generation of digital electrohydraulic servovalves extended on a wide scale the hydraulic actuators applications in all heavy industrial, agricultural, civil and military systems.

This paper presents an objective prediction for the development of both type of actuators, starting from main real performances, found by modeling, simulation and experimental assessment, and passing through main practical conclusions of technical and economic criteria, taking into account the lack of technical staff with hybrid skills, the new technological challenges, and the overall financial efforts during all the lifetime of these important equipment. The assessment takes into account both the last decade reports published by companies

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with high tradition in R&D, and the own research of the authors carried out for innovative manufacturing companies, involved in aerospace and automotive engineering.

The assessment of different types of linear actuators for different kind of applications was systematically carried out by companies like Bosch Rexroth [1], Moog [2], Parker Hannifin [3], Siemens [4] etc. in close connection with the traditional markets and the expected ones, connected with aerospace, automotive, power, marine, agricultural and other emerging fields. Relevant information are supplied by global manufacturers only, covering all segments of the market. Such an example is presented in Fig. 1, showing the three types of Bosch-Rexroth actuators which can be promoted in any application: electrohydraulic, electromechanical, and hybrid one.

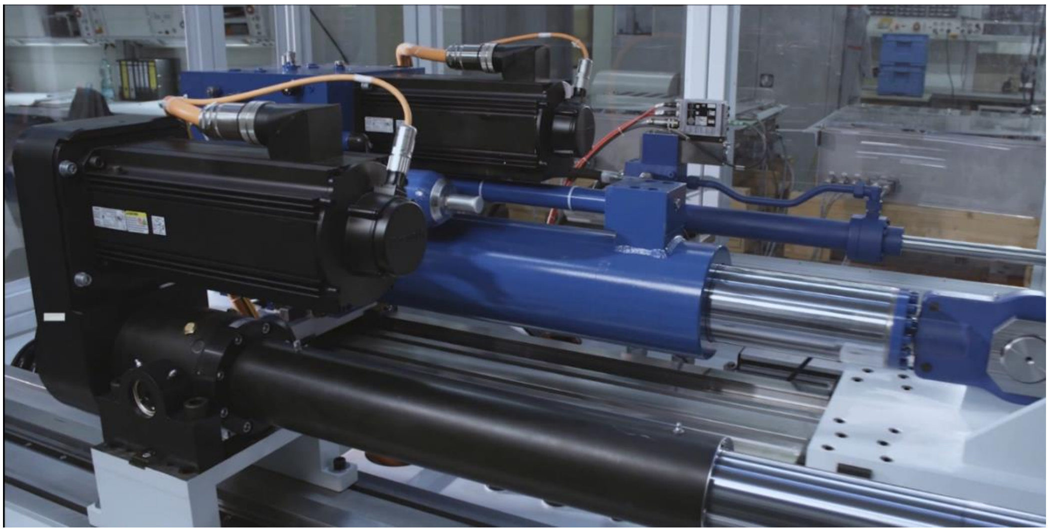

Fig. 1. Rexroth demo test bench for industrial actuators [1]

All the three types are connected to an overall controller by the modern Multi-Ethernet Connectivity System, in which a set of nodes sends and receives frames over a shared link. Both the dynamics and the accuracy of all the three systems are the same, but the maximum force is different, according the available supply power. Companies with different basic profiles (electric, hydraulic or hybrid) underline the qualities and the limits of other manufacturers, not considering the applications peculiarities like the environmental ones. A typical example in this matter is offered by Tolomatic Inc. from USA, a company directed to the electric actuators. The comparison between hydraulic and electric actuators has the following main aspects [5]: a) Hydraulic actuators do offer a long service life, in any environmental conditions, but they are not as efficient operators as electric systems; b) Electric systems need smaller overall space requirements than hydraulic systems, but clean and without strong electromagnetic disturbances. They also provide precise position, velocity and speed control with more efficient operation. They operate in a closed loop environment for easy data collection, and they are virtually maintenance free; c) Preferred for their higher level of accurate performance, electric servo systems can be more costly than hydraulic to initially implement. However, the increased efficiency of operation with little or no maintenance over the life of the system makes their total cost of ownership lower over the life of the equipment and an attractive alternative to the hydraulic one; d) As electric rod-style actuators become capable of achieving high-end hydraulic forces, they will continue to be viable candidates for replacing hydraulic systems in many small and medium size applications, under environmental restrictions. The conclusion of this analysis is a natural one: the evaluating capabilities and restrictions to aligning them with system objectives can help determine the best choice for the application.

2. Performances of the electrohydraulic servo systems with servovalve

The dynamics of the modern servosystems with classical servovalves remains devoted for aerospace field, nuclear power stations, the military systems and high dynamics industrial applications such as materials dynamic testing machines. The last generation of high performance servovalves use a torque motor or a piezo ceramic actuator to convert the electrical input (analogue or digital) into a flapper or nozzle displacement, but use also an additional electrical position feedback from the spool by the aid of a high resolution inductive transducer. A good example of this combination is offered by the Parker Series SE2E servovalve, which use the additional feedback for minimizing the flow hysteresis and for monitoring the on-board electronics.

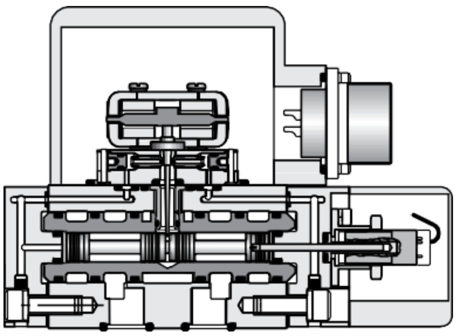

Fig. 2. Main section through the servovalve PARKER SE2E [6]

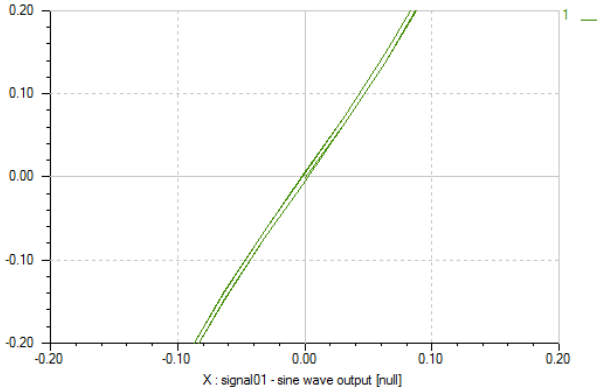

Fig. 3. The hysteresis of the servovalve SE2E (<0.5%) confirmed by AMESim simulation [7]

The new generation of direct drive valves (DDV) extended the use of the industrial flow control to all the analogue and digital servosystems. Three different type of spool linear actuator have similar static and dynamic performances: with moving coil (Fig. 4), with proportional solenoid (Fig. 5), and differential electromagnetic actuator (Fig. 6).

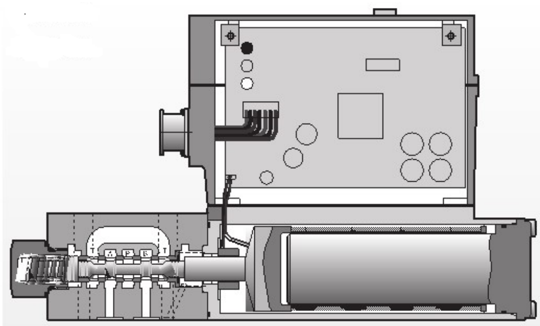

Fig. 4. High speed industrial moving coil servovalve DF1Plus [7].

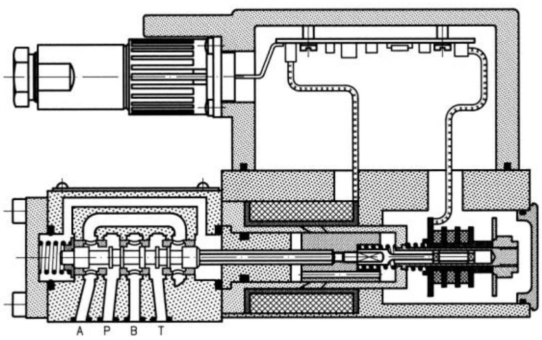

Fig. 5. High speed industrial solenoid servovalve 4WRPEH 6 [8]

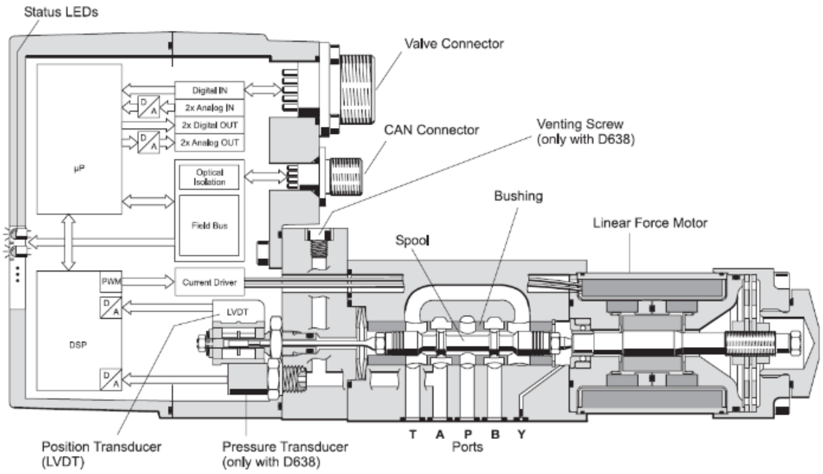

Fig. 6. Digital MOOG DDV S638 with CAN BUS [9]

All the above technical sollution have good enough performances for any industrial application. The voltage corresponding to the spool travel (±10V) can be measured during the operation, giving a fair information about the dynamic behavior. The frequency response of the three types was near the same when they were tested in Fluid Power Systems Laboratory [10]. A typical example is presented in figure 8 for DF1Plus Parker servovalve. If excited with a chirp signal of 5% from the nominal one (10V), the phase lag of 90 degrees reaches 200 Hz!

Fig. 7. Partial view of the servovalves test bench from the Fluid Power Systems Laboratory

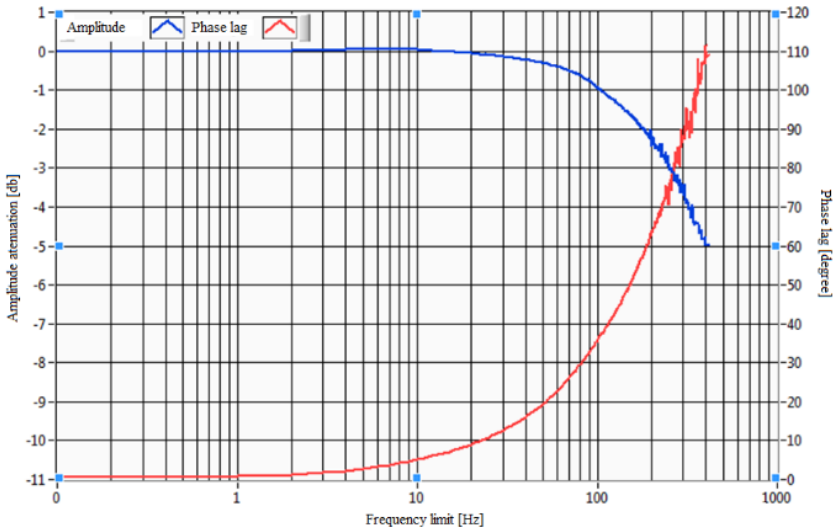

Fig. 8. Frequency response of the servovalve DF1Plus Parker

In the next stage of this research, the above servovalves were assesed on a new test bench (Fig. 9) designed by the authors, and manufactured by the fine mechanics manufacturing Romanian company ICPEST [10]. The main load of the servocylinder is a very strong helical spring, set up to be compressed symmetrically by the piston, in both motion direction. The hydraulic diagram includes good quality devices needed to obtain all the behavioral information (Fig.10).

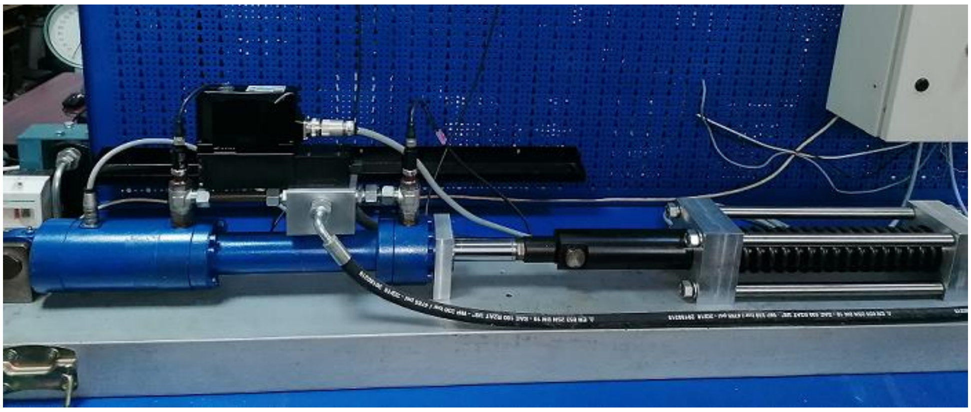

Fig. 9. Main view of the new dynamic test bench of the industrial servovalves developed in the FLUID POWER LABORATORY of the University POLITEHNICA of BUCHAREST [10]

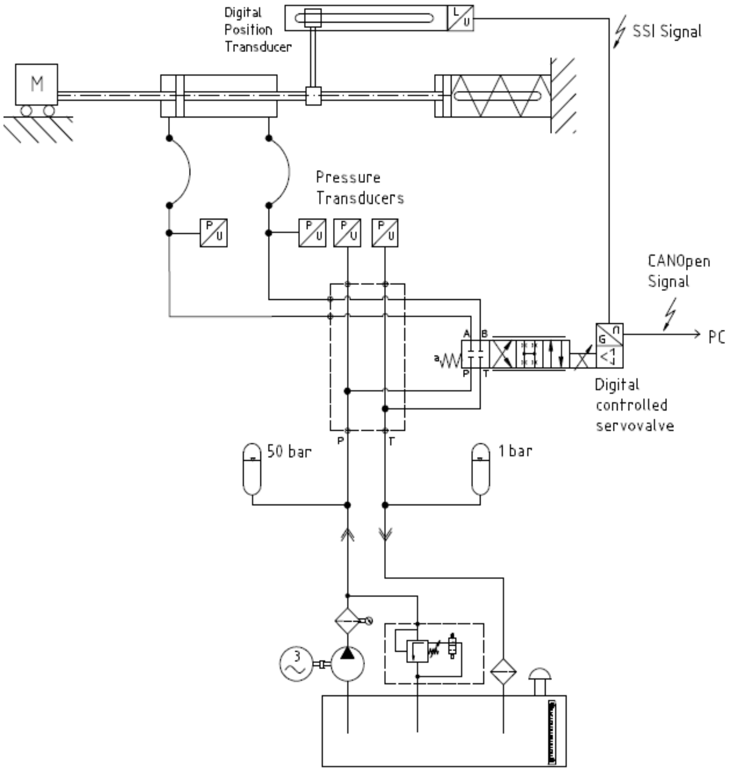

Fig.10. Hydraulic diagram of the new test bench

The experimental results obtained with the test bench were found in good agreement with the simulated ones. The steady-state behavior shows a small hysteresis (Figs. 11 and 12). The dynamics is also good enough for any industrial application (Figs. 13 and 14).

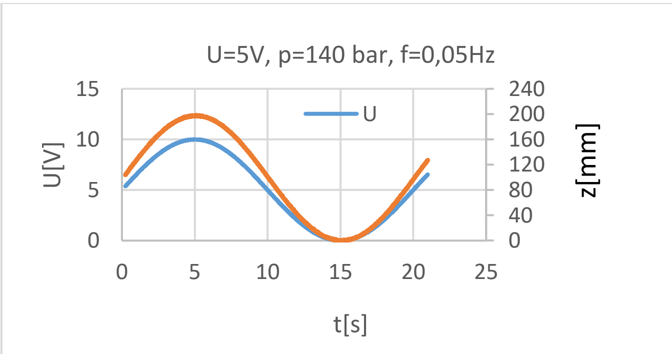

Fig. 11. Typical response of the servomechanism for low frequency

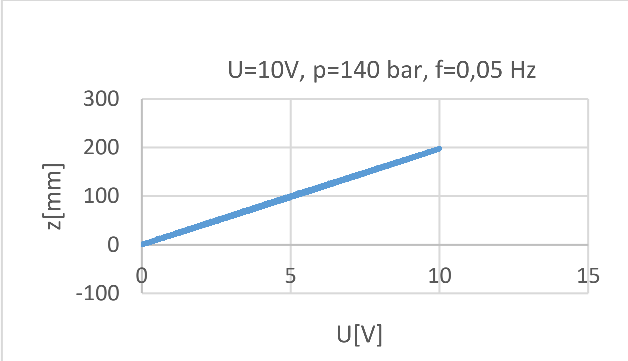

Fig.12. Steady-state characteristics for the entire piston stroke

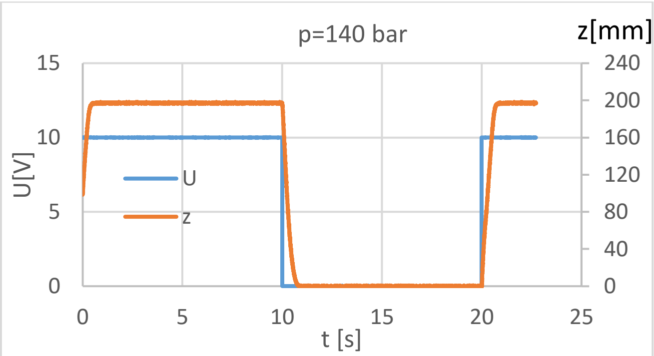

Fig. 13. Servo's response to a square nominal voltage input

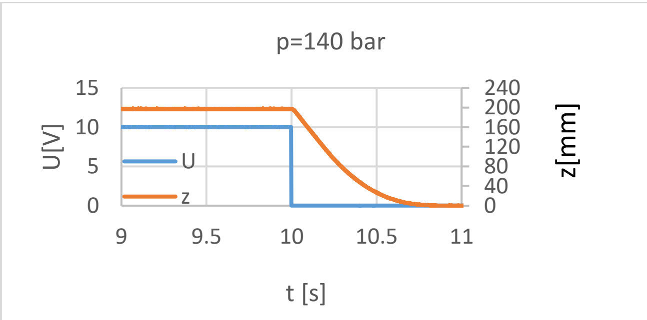

Fig. 14. Typical servo's response for a nominal step input

All the above experiments and simulations revealed the high performances of the classical servomechanism. However, the overall efficiency remains poor, even in the case of cyclic operation with a heavy elastic or mass load, using two or three stages industrial servovalves [11]. The very heavy load hydraulic cylinders are controlled by swash plate axial pistons servopumps using single stage high speed industrial servovalves [12]. The new generation of electrohydraulic servosystems needs a better energy management to face the concurrence of the electromechanical ones in normal environmental conditions.

3. Research on experimental models of hybrid servomechanisms

The final qualification of A380 flight control electro hydrostatic actuator (EHA) in 2005 [13, 14], and the successfully implementation of the MOOG redundant actuation units on F35 [15, 16] proved the possibility of an important energy economy, and the elimination of a lot of hydraulic components. The recent researches in the field [17, 18 and 19] generated many industrial achievements, which penetrated immediately in the new industrial digitally controlled robots and other similar complex engineering achievements.

Most of the steering actuators have a symmetrical hydraulic circuit, which allow the use of a classical control algorithm. However, many industrial driving systems require asymmetrical configuration, with a much greater force in the active stroke than in the passive one. The first change of the common symmetrical scheme is the use a three-way check valve in order to allow the fluid from the great chamber to fill the hydraulic accumulator under a small overpressure (Fig. 15).

In the phase “cylinder extending”, the pump displaces fluid from A to B. The effective area is A_1, and the fluid flows from chamber A_2 via the pump into piston chamber A_1. The differential volume of piston rod A_3 is supplied from the accumulator to piston chamber A_1.

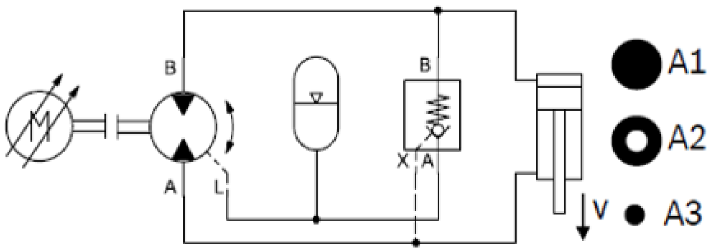

Fig. 15. Fluid flows in the phase of cylinder extension [19]

În the “cylinder retracting” phase the pump displaces fluid from B to A, and the effective area is A2. The fluid from piston chamber A_1 flows via the pump to chamber A_2. The differential volume of piston rod A_3 is displaced into the accumulator. In the simple case of the simmetric cylinder, the accumulator serves mainly to compensate the leackages and temperature variations, which can reach a hundred degrees. The difference between the active surfaces of a differential cylinder can’t be covered without an accumulator and a three way check valve.

The Simcenter Amesim model from Figure 16 allow a better understanding of the complex transients from a simple close loop, but without simetry! [21- 23].

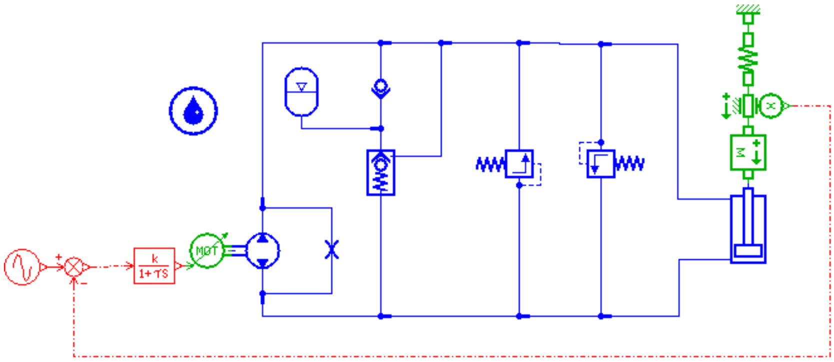

Fig.16. Simulation model of a hybrid servomechanism with a differential cylinder

The evolution of the relevant parameters is presented in the following diagrams. The numerical simulations were performed for a small power hybrid system designed and tested by the authors. For small frequency, the response of the model has a relatively small delay (Fig. 17), but the steady state characteristics has a great hysteresis (Fig. 18). Different other parameters variations are presented in figures 19…22. The rectangular inputs generate greater variations of the main parameters (Figs. 23…26).

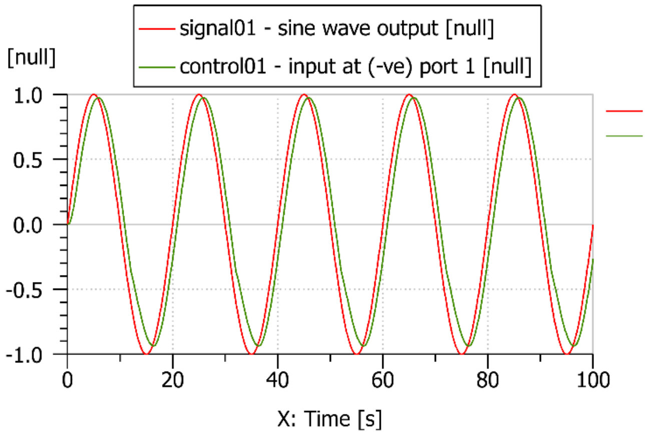

Fig. 17. Sine response of the system

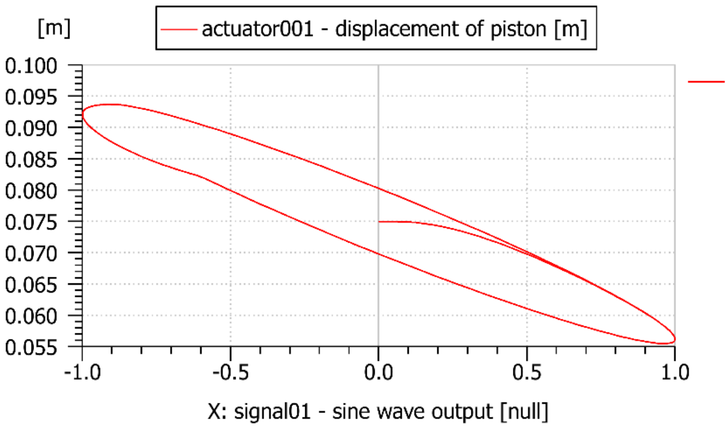

Fig. 18. The system hysteresis for half of the nominal stroke

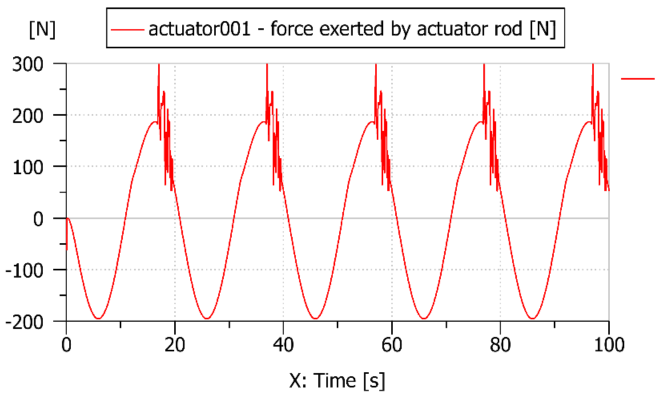

Fig. 19. Force exerted by the actuator rod on the elastic symmetric load

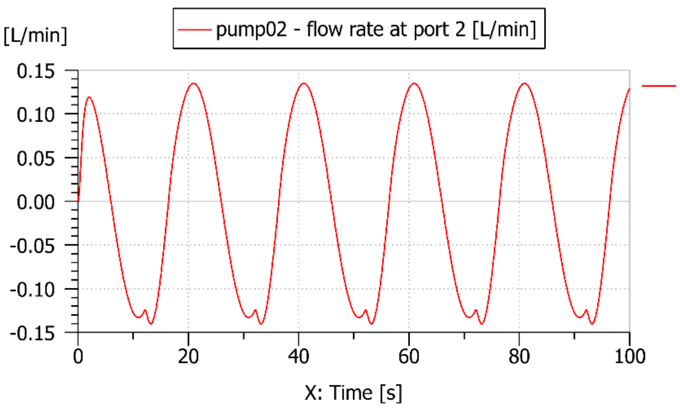

Fig.20. Pump real flow rate variation

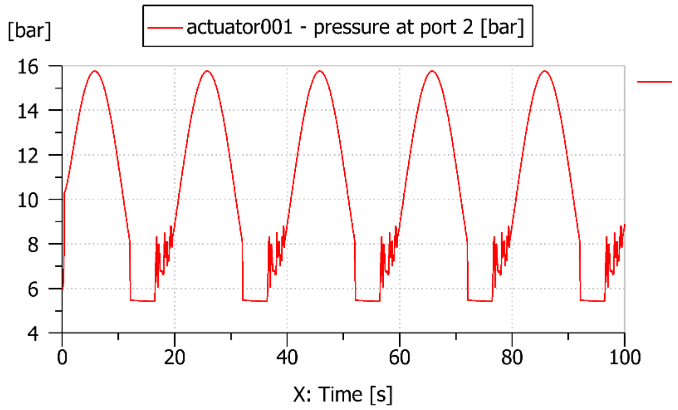

Fig. 21. Variation of the pressure in the active chamber of the cylinder

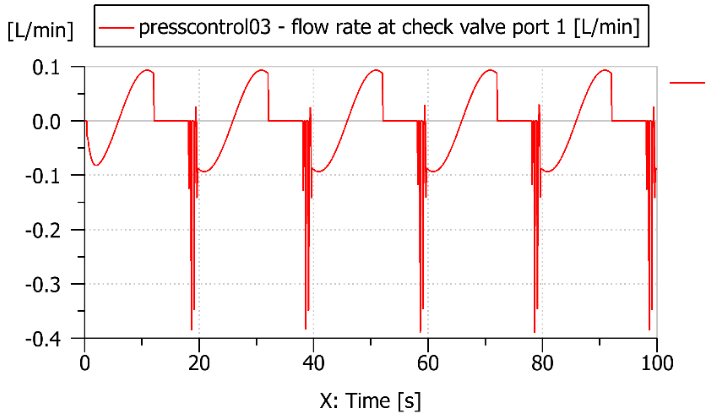

Fig. 22. The compensation flow passing through the three way check valve

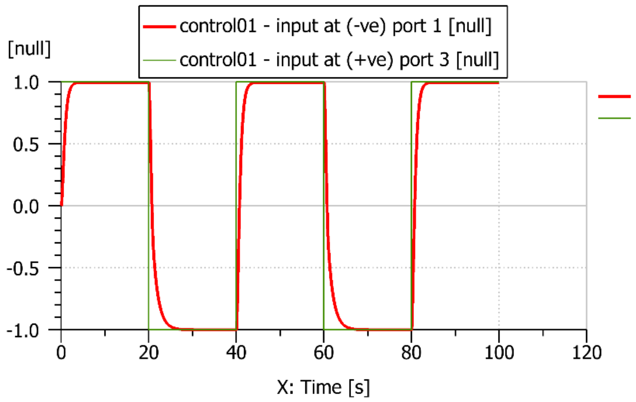

Fig. 23. The rectangular input response of the hybrid servomechanism

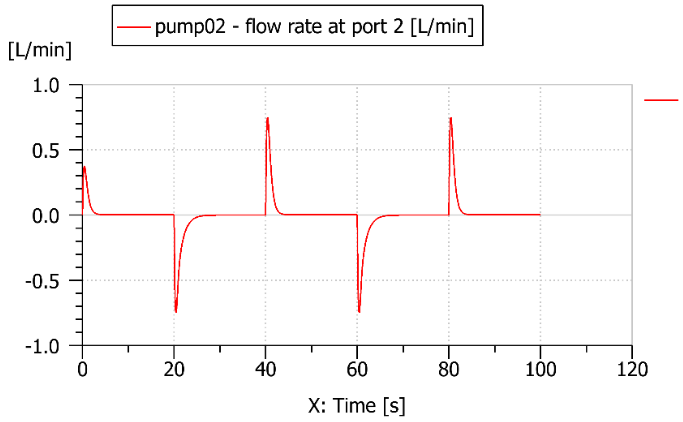

Fig. 24. Pump flow rate variation at the active port

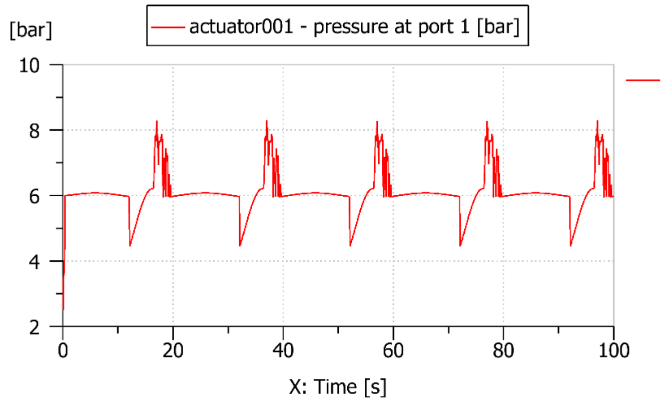

Fig. 25. Pressure variation in the passive port of the cylinder

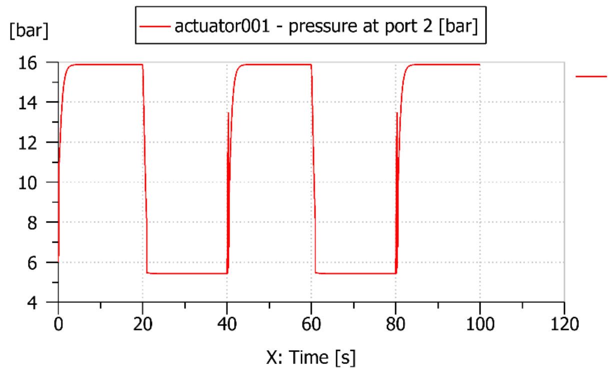

Fig. 26. Pressure variation in the active chamber of the cylinder

The simulation results were found in agreement with the experimental ones, obtained with a test bench of small power. The load line and the servopump assembly are presented in figures 27 and 28. An original structure of the controller was submitted for examination to the national patent office [22].

Fig. 27. Load section of the experimental test bench

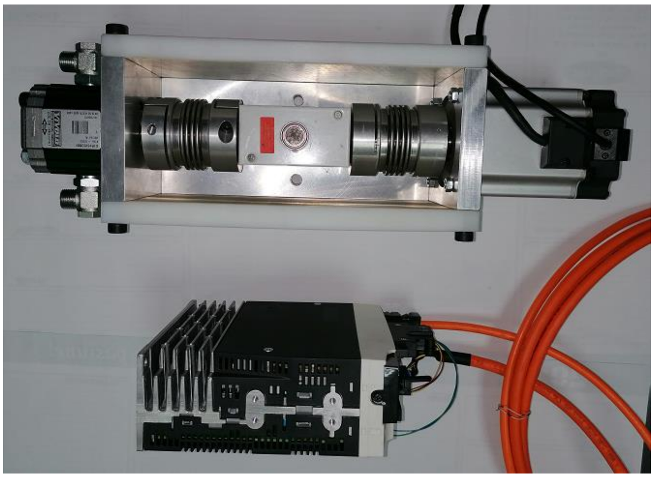

Fig. 28. Servopump section of the experimental test bench

5. Conclusions

This research may be regarded as a step in the direction of "The Digital Twin". The main ideas of this concept were exposed by two visionary researchers from SIEMENS [23]: "to integrate all data (test, operation data, ...), models (design drawings, engineering models, analyses, ...), and other information (requirements, orders, inspections, ...) of a product generated along its life cycle that leverage business opportunities". The role of this procedure is to predict and optimize performance. To this purpose simulation methods and / or data-based methods are used. Digital Twins are expected to become a business imperative, covering the entire life cycle of an asset or process and forming the foundation for connected products and services. The main target of the authors team is to promote this modern concept in the field of reducing the energy consumption by the digital fluid power systems.

Acknowledgments

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0404/31PCCD/2018.

The permanent access to Simcenter Amesim simulator, offered by Siemens PLM Software in the last ten years was very helpful for the deep understanding of the complex control systems dynamics.

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