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# MULTI-POLE MODELING AND SIMULATION OF DYNAMICS OF AN ELECTRO-HYDRAULIC SERVO-SYSTEM

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**Abstract:** *The paper presents the construction of multi-pole models of an electro-hydraulic servo-system and the simulation of its dynamic characteristics. Using the NUT programming environment as a tool enables one to describe graphically multi-pole models, to automatically compose the algorithm, and to perform the simulations. The outputs of each multi-pole model are computed separately. In case of loop dependencies between multi-pole models, the iteration procedure for equalising the values of variables is used. The modifying of characteristics is observed.*

Key words: *electro-hydraulic servo-system, dynamic response, multi-pole models, simulation, NUT programming environment.*

## 1. INTRODUCTION

The electro-hydraulic servo-systems are in various applications (Grossschmidt, 2004).

For dynamic characteristics of the electro-hydraulic servo-system, the following requirements can be pointed out:

- high positioning accuracy,
- smooth positioning,
- short positioning time,
- high speed of dynamic response,
- good quality of dynamic response.

When using an ordinary regulator, the positioning and the dynamic responses proceed slowly.

The existing simulation systems (Grossschmidt, 2004) have not possibilities to simulate the dynamic responses in each working point.

For modelling the multi-pole mathematical models with various causality of system elements are used, which correspond to the physical nature of technical systems.

Using the NUT environment as a tool enables one to describe graphically the simulation problem and automatically compose the algorithm and perform computation.

The NUT system is a programming environment, which supports declarative object-oriented programming in a high-level language, visual programming and automatic program synthesis.

To achieve better work of the servo-system, it is necessary to adjust its regulator. The adjusting method must be changed, depending of working parameters (positioning distance, positioning direction, load size and direction, motion direction).

Elaborating the algorithm for such a regulator (which must be different for each system) experimentally is time consuming and expensive.

## 2. USED MULTI-POLE MODELS

For modelling of dynamic responses the following multi-pole models of functional elements are used (Fig. 1 - 9).

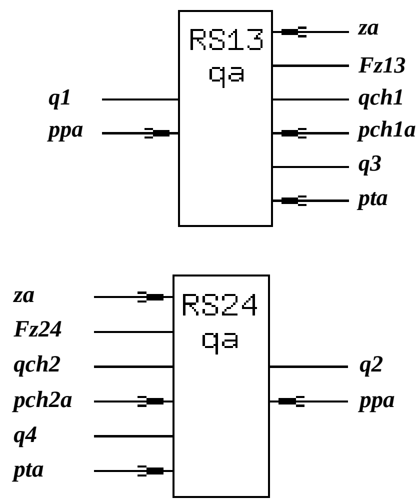



Fig.1. Multi-pole models **RS13qa** and **RS24qa** of servo-valve slot pairs, where

| | |
|---|---|
| ***za*** | displacement of servo-valve from initial position, |
| ***Fz13, Fz24*** | hydrodynamic force of jets trough slots 1, 3 and through slots 2, 4, |
| ***q1, q2, q3, q4*** | volumetric flows through slots 1, 2, 3 and 4, |
| ***qch1, qch2*** | volumetric flow at connection into/out of hydraulic cylinder left and right chamber, |
| ***pch1a, pch2a*** | pressure at the connecting port to left and right chamber of hydraulic cylinder, |
| ***ppa, pta*** | pressure at the supply port and pressure at the return port. |

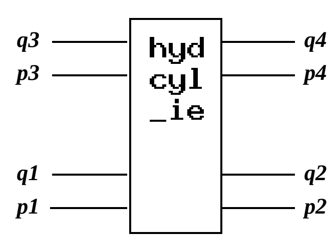



Fig.2. Multi-pole model **hydcyl_ie** of hydraulic interface element with four connections, where

| | |
|---|---|
| ***p1, p2, p3, p4*** | pressures, |
| ***q1, q2, q3, q3*** | volumetric flows. |

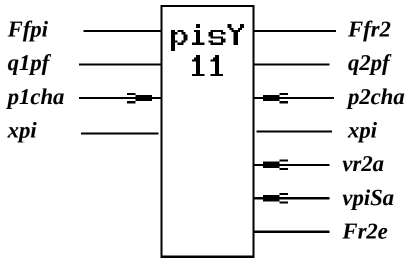



Fig.3. Multi-pole model **pisY11** of a piston,
where

***Ffpia, Ffr2a*** friction force of a piston sealings and a piston rod sealings,
***q1pf, q2pf*** volumetric flow at the right at the left end of a piston,
***p1cha, p2cha*** pressure in the left and right chamber ***o***f a cylinder,
***xpi*** displacement of a piston,
***vr2a*** piston right rod velocity,
***vpiSa*** piston stationary velocity,
***Fr2e*** force at the piston right rod.

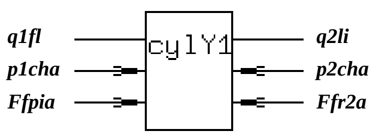



Fig.4. Multi-pole model **cylY1** of a hydraulic cylinder,
where

***q1fl, q2li*** volumetric flow depending on the cylinder flange shift and cylinder lid shift,
***p1cha, p2cha*** pressure in the left and in the right chamber of a cylinder,
***Ffpia, Ffr2a*** friction force of piston sealings and piston rod sealings.

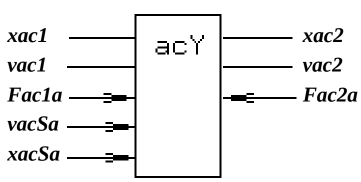



Fig.5. Multi-pole model **acY** of an actuator,
where

***xac1, xac2*** displacement at the left and right port,
***vac1, vac2*** velocity at the left and right port,
***Fac1a, Fac*** force at the left and right port,
***vacSa*** stationary velocity of an actuator,
***xacSa*** static displacement of an actuator.

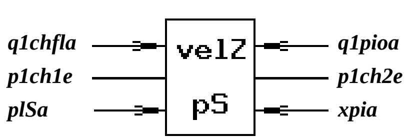



Fig.6. Multi-pole model **velZpS** of the volume elasticity of the left chamber of a hydraulic cylinder.

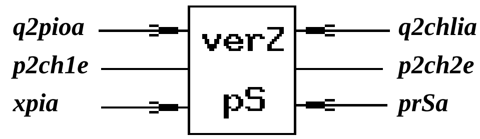



Fig.7. Multi-pole model **verZpS** of the volume elasticity of the right chamber of a hydraulic cylinder.

The variables in Fig.6 and Fig.7 are:

***q1chfla, p1ch1e*** volumetric flow and pressure at the left end of the hydraulic cylinder left chamber,
***q1pioa, p1ch2e*** volumetric flow and pressure at the right end of the hydraulic cylinder left chamber,
***q2pioa, p2ch1e*** volumetric flow and pressure at the left end of the hydraulic cylinder right chamber,
***q2chli, p2ch2e*** volumetric flow and pressure at the right end of the hydraulic cylinder right chamber,
***plSa, prSa*** static pressure in the hydraulic cylinder left and right chamber,
***xpia*** displacement of a piston.

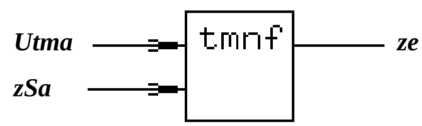



Fig.8. Multi-pole model and multi-pole model **tmnf** of torque motor and nozzle-and-flapper valve, where

***Utma*** voltage to the torque motor,
***zSa*** static displacement of a servo-valve spool,
***ze*** displacement of a servo-valve spool.

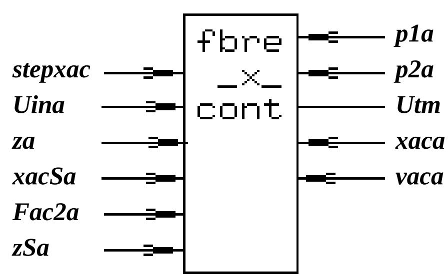



Fig.9. Multi-pole model **fbre_x_cont** of feedback and regulator,
where

***stepxac*** needed displacement of the actuator for positioning,
***Uina*** control voltage,
***za*** displacement of a servo-valve spool,
***xacSa*** static position of the actuator,
***Fac2a*** force at the right port of an actuator,
***zSa*** static displacement of a servo-valve spool,
***p1a, p2a*** pressure in the left and right chamber of a hydraulic cylinder,
***Utm*** voltage to the torque motor.

## 3. SIMULATION PROBLEM DESCRIPTION

The composed problem description for simulation of dynamic response ***xac = F(t)*** is shown in Fig.10.

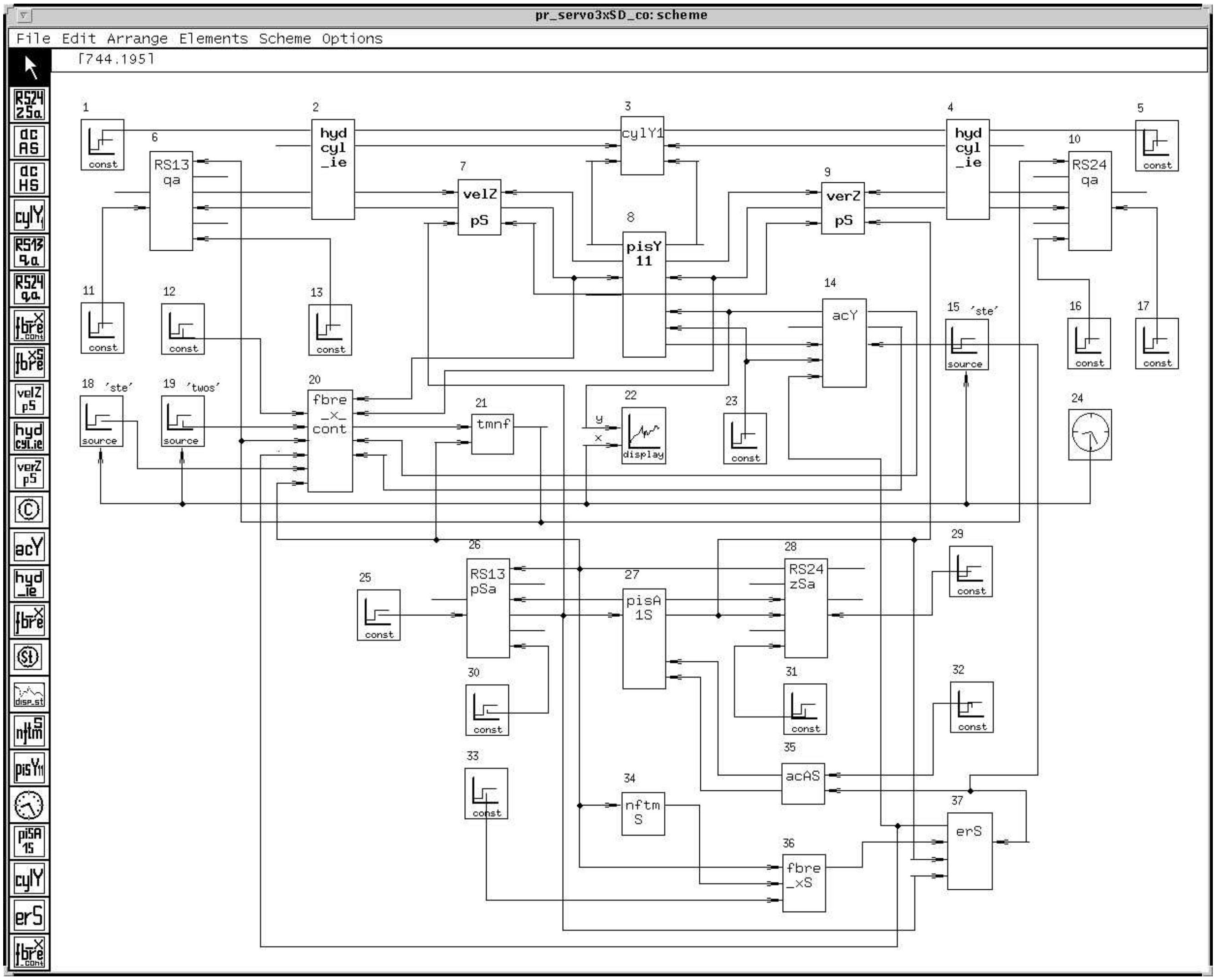



Fig.10. Problem description for simulation of dynamic response ***xac = F(t)***.

The simulation problem description in Fig.10 consists of two parts – the upper part immediately for computing of the dynamic and the lower part for computing of the static initial values ***zaS, p1S, p2S, xacS*** for dynamics.

Each external input of the dynamic part can be used as input for disturbance. In this simulation problem description the disturbance inputs are defined for control voltage ***Uina*** (19) and actuator force ***Faca*** (15 and 18). The other external inputs are defined as constants.

The time is given by class **"clock"** (24). Any output variable can be computed and displayed. In this example the actuator displacement ***xac*** is given out to the **"display"** (22). The dynamic process can be modified by the class "**fbre_x_cont"** (20) (class "feedback and regulator").

## 4. EXAMPLES OF SIMULATION

The main parameters for computing the dynamic characteristics, in addition to parameters for statics (Grossschmidt, 2004), are chosen as follows (all dimensions are in SI system).

***For cylinder:*** equivalent friction coefficient of a fixing *hfi* = 1e+06, mass *mcy* = 20.

***For piston with a rod:*** equivalent friction coefficient *hpir* = 1e+06, mass *mpir* = 15.

***For volume elasticities of cylinder chambers:*** piston stroke *lpi* = 0.1, initial length of left chamber *l10* = 0.01, initial length of right chamber *l20* = 0.01.

***For torque motor and nozzle-and-flapper valve:*** delay time constant *T* = 0.001.

***For regulator:*** delay time constant for whole regulator *Tl* = 1e-06, delay time constant for differentiator *Tv* = 0.003.

***For actuator:*** equivalent friction coefficient *hac* = 5e+04, mass *mac* = 20.

***For computing process:*** inverse value of the timestep *tau* = 4e+04, allowed absolute iteration error for pressure *epsapi* = 2e+03, allowed relative iteration error *epsri* = 2e-03, iteration adjusting coefficient *adjust* = 0.7.

The regulator is universal – for positioning control and for continuous control. The switching occurs by a key. Using the regulator with a differentiator (PD regulator), the dynamic response of the servo-system, especially at high actuator force, proceeded slowly.

To attain a short positioning time and high positioning precision, an additional signal was inserted in the regulator, depending on the distance ***dx*** to the target position. The additional signal has been taken as depending on an additional servo-valve spool shift ***dz***, which value is calculated according to the graph Fig.11, for position distance ***stepxac*** = + 0.4 mm. For other position distances, for position in the back direction, to attain fast and precise positioning, the values in the dependency shown in Fig.11 must be changed. In the regulator, also the signal for correcting the displacement of the actuator is additionally inserted, which is due to servo-system elasticities.

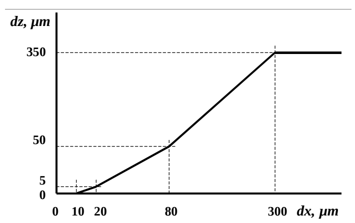



Fig.11. Additional servo-valve spool shift ***dz***, depending on distance ***dx*** to target position, for positioning distance of 0.4 mm (if ***dx*** < 0, then also ***dz*** < 0).

The simulated positioning process for positioning distance ***stepxac*** = 0.4 mm, by force at actuator ***Fac*** = 1e+05 N is shown in Fig.12.

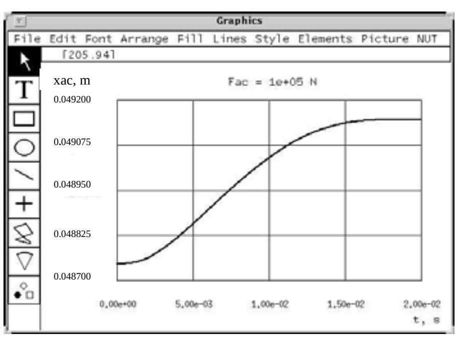



Fig.12. Simulated positioning process for positioning distance ***stepxac*** = 0.4 mm, by force at actuator ***Fac*** = 1e+05 N.

For making the continuous control faster an additional signal has been inserted in the regulator, which gives an additional servo-valve spool shift ***dzn = F(dz, zS, sign(dUepsS))***. In this case the servo-valve spool shift ***dz*** is taken in dependence on ***dUepsS = Ueps – UepsS***, where ***Ueps = Uin – Ufb*** (***Uin*** - input control voltage, ***Ufb*** – feedback voltage) and ***UepsS = UinS – UfbS*** (***UinS*** – actual static input control, ***UfbS*** – actual static feedback voltage).

The proposed dependence ***dz = F(dUepsS)*** is shown in Fig.13.

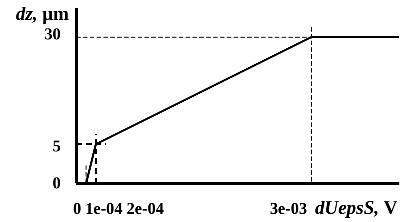
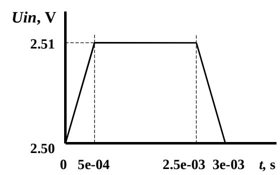



Fig.13.Servo-valve spool shift ***dz***, depending on ***dUepsS*** (if ***dUepsS*** < 0, then also ***dz*** < 0).

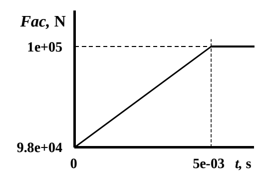
The graph of a dynamic response by an input voltage ***Uin*** pulse (Fig.14) and an input actuator force ***Fac*** step (Fig.15) is shown in Fig.16.

Fig.14. Input control voltage




pulse ***Uin = F(t).***

Fig. 15. Input actuator force




step ***Fac = F(t).***

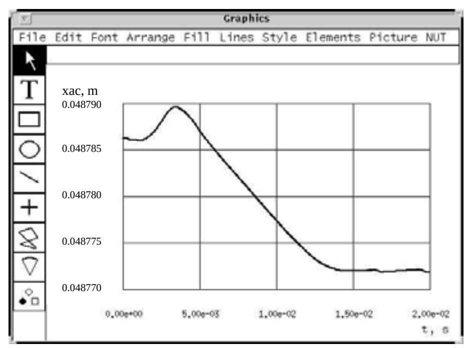



Fig.16. Simulated graph of a dynamic response by an input voltage ***Uin*** pulse and input actuator force ***Fac*** step.

## CONCLUSIONS

The multi-pole modelling of an electro-hydraulic servo-system enables to construct very detailed and adequate object-oriented mathematical models for simulating. Using of the programming and computing environment NUT enables one to compose graphical simulation problem descriptions, automatically generate computing algorithms, and perform simulations.

A method is proposed to attain fast and precise positioning, as is a method for getting faster dynamic responses in case of continuous control.

## ACKNOWLEDGEMENT

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## REFERENCES

Grossschmidt, G. & Harf, M. (2004). Simulation of statics and steady state conditions of an electro-hydraulic servo-system. Proc. of the 4th International DAAAM Conference “INDUSTRIAL ENGINEERING – INNOVATION AS COMPETITIVE EDGE FOR SME”, 29 –30th April 2004, Tallinn, Estonia.