Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 14th International Scientific and Practical Conference. Volume 3, 106-111

Modelling and Simulation of Electropneumatic Positioning System Including the Length of Pneumatic Lines

Georgi Iliev
dept. Power Engineering
Technical University of Gabrovo
Gabrovo, Bulgaria
spigil@abv.bg

Hristo Hristov
dept. Power Engineering
Technical University of Gabrovo
Gabrovo, Bulgaria
chisto@tugab.bg

Abstract. **This paper presents a mathematical model of electropneumatic positioning system including the length of pneumatic lines for the determination of flow and pressure in unsteady operating modes. A simulation model is developed to study the dynamic processes in an electropneumatic positioning system. Simulation of the mathematical models of the screw compressor, proportional directional valve, pneumatic lines, pneumatic cylinder and PID controller were designed in "MatLab Simulink". The simulation models of the transients in the electropneumatic positioning system at different line lengths from 1m and 10m with stepwise variation of the input setpoint are simulated developed. Graphical comparison is made of the obtained experimental results and simulation model influence of the pneumatic line length on the dynamics of the electropneumatic positioning system are made**

Keywords: electropneumatic positioning system; mathematical model; pneumatic lines; simulation models.

I. INTRODUCTION

Electropneumatic positioning system by proportional directional control valve allows adaptive positioning control to fractions of a millimeter as well as the ability to control the speed and acceleration of pneumatic actuators. Another unique characteristic of electropneumatic positioning system is smooth braking, which extends its application to metallurgy, robotics, machine tools, aerospace, food and beverage, as well as in simulators and simulators for equipment testing, etc. This calls for higher performance levels, requiring a continuous evolution of pneumatic actuators [4].

Pneumatic actuation systems as computer technology advances, control algorithms can be created and refined to make the systems better and more reliable. Through the use of advanced proportional directional control valve, various control laws can be implemented to optimize dynamic processes and improve the accuracy and quality of operation, as well as increase the system's efficiency [2], [8], [9].

Pneumatic systems are modelled in the form of a computer simulation in which a virtual system is designed. Software that uses models are primarily designed for pneumatic and hydraulic system [2], [4] or are for use in CAD environments and allow the pneumatic system to interact with external mechanical elements [5]. Most software is designed more for practicing engineers rather than for fundamental research in pneumatic systems.

Computer simulations in "MATLAB Simulink" of models for pneumatic and hydraulic systems give good results, the processes are compared with those obtained from computer modeling and simulation, and the results are used to verify the models [1], [3], [6], [8].

Despite the proven advantages of electropneumatic positioning systems, which are generally known, in the modern stage of development of science and technology there are a number of prerequisites for improving their characteristics:

- flexibility and speed compared to conventional electric and hydraulic drive systems;
- their low cost compared to other classic drive systems;

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2023vol3.7186
© 2023 Georgi Iliev, Hristo Hristov. Published by Rezekne Academy of Technologies.
This is an open access article under the Creative Commons Attribution 4.0 International License.

– eco-friendliness and energy efficiency.

Some of the quantities under investigation, which were assumed to be negligible or were engineered guesses in the past, can now be measured, analyzed, and used to improve existing drive system models. Application of modern automated data acquisition and processing systems can substantially improve the modeling and dynamic-mode properties of electropneumatic actuator systems.

In many cases, low-order linear models are used to facilitate the studies, but a comparison with experiments reveals that the agreement in the characteristics is not very good. To improve the control process, it is necessary to use models that account for the essential nonlinearities.

The signal delay along the pneumatic lines needs further investigation. Due to the relatively few adequate models, research is needed. In practice, it is assumed that relatively short pneumatic lines have minimal impact on the system delay. However, for relatively long pneumatic lines, this delay would significantly affect the dynamics of the pneumatic system. The mathematical models presented are extremely complex and difficult to solve. Some of them use parameters that are engineering proven in practice. A more accurate and detailed mathematical model is required. It is necessary to verify the model thus created with experimental results [7-13].

II. MATHEMATICAL MODEL

The mathematical models of the screw compressor, proportional directional control valve, pneumatic lines, pneumatic cylinder and PID controller.

For a detailed description of the complete mathematical model of the electropneumatic positioning system is in [3].

Mathematical model of the pneumatic compressed air unit:

The mass theoretical flow rate of a screw compressor is determined.

$$M_t = \left[\rho\left(\frac{\pi}{4}\left(d_v^2 - d_i^2\right)t_v\frac{\omega}{2\pi}\right)\right] \tag{1}$$

Where:

d_v - outside diameter of the screw;

d_i - inside diameter of the screw;

t_v - screw pitch;

ω - angular velocity;

ρ - density.

The mass flow through the directional valve can be calculated by multiplying the volumetric flow rate (2) to the air density ρ in standard conditions:

$$M = \left(8.6.10^{-8}C_v.p_{in}\left(1-\frac{X}{X_T}\right)\sqrt{\frac{X}{T_{air}}}\right).\rho \tag{2}$$

Where:

C_v - coefficient of conductivity;

p_{in} - inlet in the distributor;

X - pressure relations;

X_T - critical pressure drop;

T_{air} - air temperature;

ρ - density.

The model for the flow rate through the proportional directional control valve includes the coefficient of conductivity C_v and the critical pressure drop coefficient X_T which has to be determined experimentally [3]:

$$C_v = 0.274;\ X_T = 1$$

Electronic PID controller equation:

$$U = k_k\left(\Delta U + \frac{1}{T_I}\int_0^t \Delta U dt + T_D\frac{d\Delta U}{dt}\right) \tag{3}$$

Where:

k_k - amplifying factor of the regulator;

ΔU - input voltage;

$T_I;T_D$ - time constants of integration and differentiation of the regulator.

Mathematical model of pneumatic lines

We're examining a cylindrical tube (line) on fig. 1 with length L_t .The mass flow rate of the air through the line is [1], [3]:

$$M = \frac{R_r^2 L_t}{8a_s\rho^2}e^{-\frac{R_r L_t}{2\rho a_s}}f\left(t - \frac{L_t}{a_s}\right) \tag{4}$$

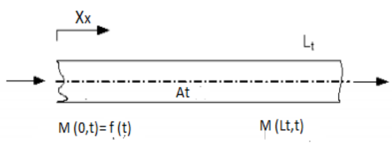

Fig. 1. Pneumatic line

Where:

R_r - the tube resistance;

L_t - cylindrical tube with length

ρ - density;

a_s - denotes the sound speed;

t - time variable.

The equation for the movement of a pneumatic cylinder piston with a double sided extended rod is expressed as follows [3]:

$$m_t \frac{d^2 y}{dt^2} + \beta_c \frac{dy}{dt} + F_{mp} = (p_{c1} - p_{c2})A_b - p_{atm}A_b \quad (5)$$

Where:

m_t - mass of the load;

y - cylinder rod displacement;

A_b - area of the pneumatic cylinder piston;

F_{mp} - static friction force;

β_c - viscous friction coefficient;

p_{atm} - atmospheric pressure;

p_{c1} - pressure in the left chamber of the pneumatic cylinder;

p_{c2} - pressure in the right chamber of the pneumatic cylinder;

Given that $\frac{dm_1}{dt} = M_{b1}$, the mass flow rate entering the pneumatic cylinder is presented in the following equation:

$$M_{b1} = \frac{1}{RT_{air}} \left[(W_{1H} + A_b y)\frac{dp_{c1}}{dt} + p_{c1} A_b \frac{dy}{dt} \right] \quad (6)$$

Where:

W_{1H} - Initial gas volume in the cylinder;

y - cylinder rod displacement;

R - air gas constant;

p_{c1} - pressure in the left chamber of the pneumatic cylinder;

T_{air} - air temperature;

A_b - area of the pneumatic cylinder piston.

EXPERIMENTAL STUDY OF THE INFLUENCE OF THE LENGTH OF PNEUMATIC LINES ON THE ELECTROPNEUMATIC POSITIONING SYSTEM

For the study of an electropneumatic positioning system, a laboratory rig was constructed and developed as shown in fig. 2. The stand allows to experimentally investigate the dynamic processes in an electropneumatic positioning system. It is possible to model for experiments of pneumatic elements of different nature, to study the influence of the length of pneumatic lines, to determine the friction forces in pneumatic cylinders.

The process control of the experiment, data collection and processing, and data archiving is performed automatically by a personal computer and the corresponding interface board of the company "National Instruments" for the purpose of the experiment uses specialized software controlling the processes of the experiment. The "LabView" software is a state-of-the-art product capable of unlimited measurements and real-time data processing.

Two experiments were performed on the pneumatic rig under identical conditions with different length from 1m and 10 m pneumatic lines.

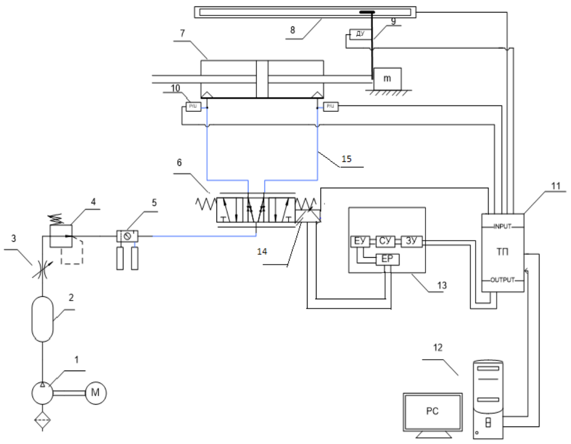

Fig. 2. Schematic representation of a electropneumatic positioning system with a measuring system.

1 – screw compressor; 2 - receiver; 3 - stopcock; 4 - safety valve; 5 - air preparation system preparatory; 6 – proportional directional control valve; 7 - pneumatic cylinder; 8 – position sensor; 9 - acceleration sensor; 10 – pressure/flow sensor; 11 - interface board; 12 - PC; 13 - electronic controller; 14- coil of proportional directional control valve; 15- pneumatic line.

VIRTUAL INSTRUMENT

For the purpose of the experiment, a virtual tool was developed to perform the following main functions Fig. 3:

Read the input channels in the following order:

Measure the input signal, measuring the pressure, flow measurement, measuring displacement of the piston pneumatic cylinder etc.

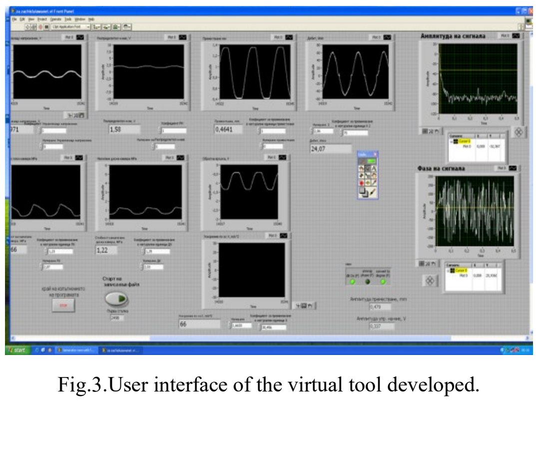

Fig.3.User interface of the virtual tool developed.

MODELLING AND SIMULATION OF THE ELECTROPNEUMATIC POSITIONING SYSTEM WITH CONSIDERATION OF THE LENGTH OF THE PNEUMATIC LINES

A mathematical model [1], [3] was simulated on the program "MatLab Simulink", and the simulation model is shown in Fig.4.

Simulation models of the screw compressor, proportional directional control valve, pneumatic lines, pneumatic cylinder and PID controller.

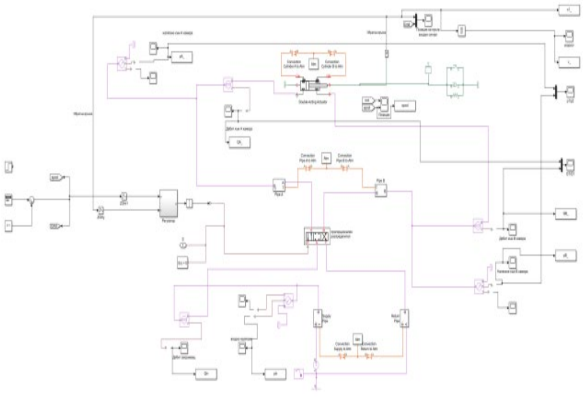

Fig. 4 Simulation model of an electropneumatic positioning system with changing length of pneumatic lines.

Results comparison of experimental and simulation transients in an electropneumatic positioning system with different length pneumatic lines fig. from 5 to 9.

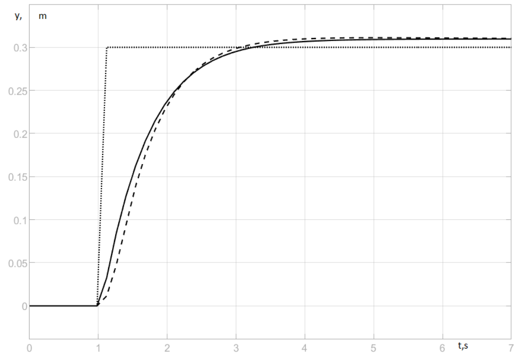

Fig. 5 Displacement of the piston rod at 1m (-) and at 10 m (- - -), input setpoint (|), computer simulation.

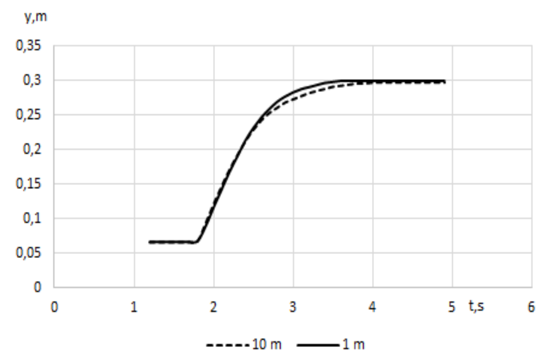

Fig. 5a Experimental data of cylinder rod displacement at 1 m (-) and at 10 m (- - -).

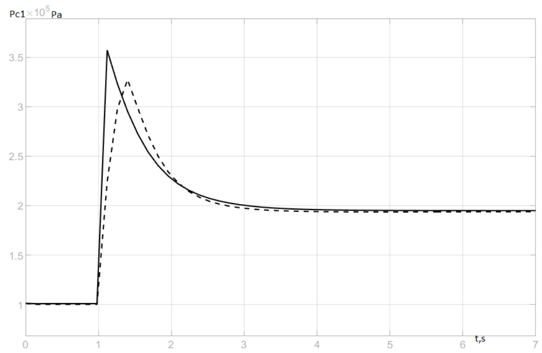

Fig. 6. Pressure in the left chamber of the pneumatic cylinder at 1 m (-) and at 10 m (- - -) computer simulation.

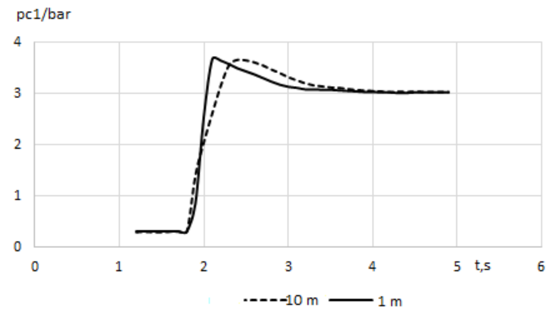

Fig. 6a. Experimental data of pressure in the left chamber of the pneumatic cylinder at 1 m (-) and at 10 m (- - -).

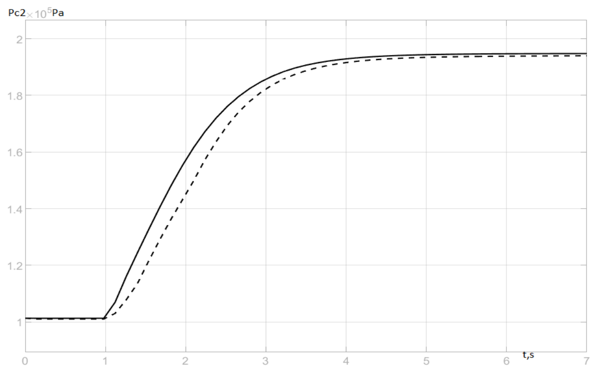

Fig. 7. Pressure in the right chamber of the pneumatic cylinder at 1 m (-) and at 10 m (- - -) computer simulation.

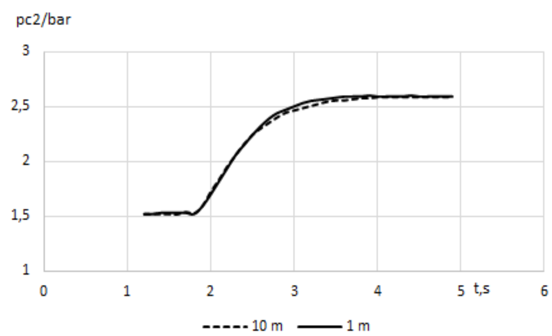

Fig. 7a. Experimental data of pressure in the right chamber of the pneumatic cylinder at 1 m (-) and at 10 m (- - -).

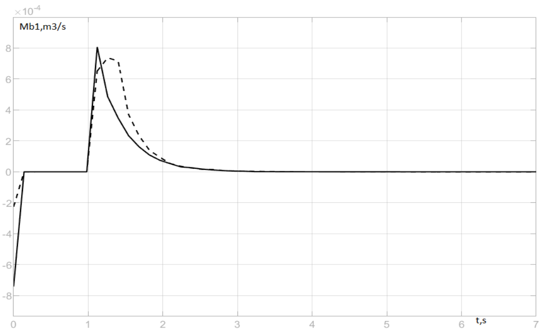

Fig.8. Mass flow rate in the pneumatic line to the cylinder left at 1m (-) length and 10 m (- - -) computer simulation.

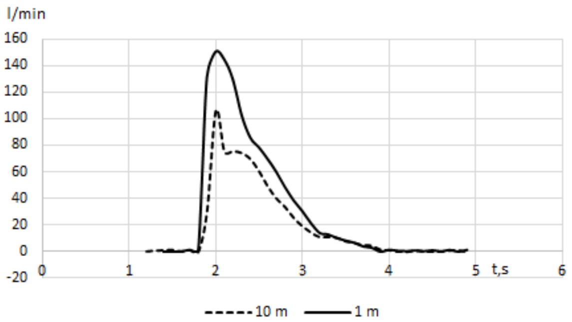

Fig. 8a. Experimental data of flow rate in the pneumatic line to the cylinder left at 1m (-) and 10 m (- - -) lengths.

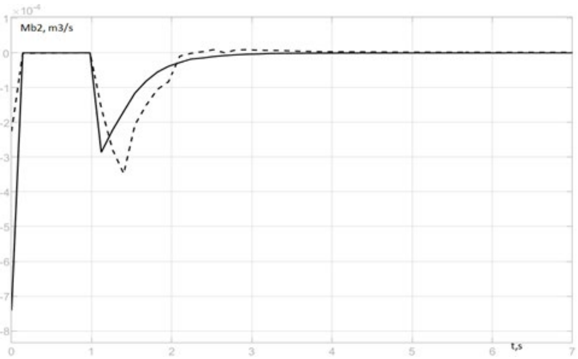

Fig. 9. Mass flow out of the right chamber of the pneumatic cylinder at 1 m (-) and at 10 m (- - -) computer simulation.

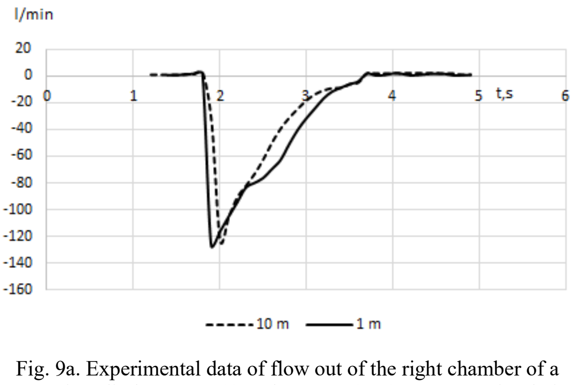

Fig. 9a. Experimental data of flow out of the right chamber of a pneumatic cylinder at 1 m (-) and at 10 m (- - -) computer simulation.

The graphs show the variation of the main observed quantities - the displacement of the rod of the pneumatic cylinder, the pressure on both sides of the piston, the flow rate on both sides of the piston of the pneumatic cylinder. The input impact varies uniformly in a stepwise manner on the input setpoint, which is electrical voltage. The quantities are shown in actual values. The value of the input signal is within the working stroke of the pneumatic cylinder. Comparing the simulations, with different lengths of pneumatic lines, it is accurately seen from the differences in magnitudes that for all transients, the length of the pneumatic lines of 1 m and 10 m has a significant bias in the parameters of the electropneumatic positioning system. Longer pneumatic lines affect the system dynamics in terms of time-delay and amplitude decay.

At = 1 m and = 10 m, the time of the transition process differs by 0.4 s. It is clearly seen that the plots are almost identical to the experimentally obtained ones, from which it can be concluded that there is a signal delay at pneumatic line lengths from =1 m to =10 m.

III. CONCLUSION

The proposed mathematical model of an electropneumatic positioning system with consideration of the signal delay in pneumatic lines is an adequate tool to determine the flow and pressure under unsteady operating modes of pneumatic systems. From the developed simulation model it is possible to simulate the dynamic processes in an electropneumatic positioning system. The simulation of the mathematical model in a programming environment on “MatLab Simulink”, models of the power unit, proportional distributor, pneumatic lines, pneumatic cylinder, PID controller were developed. Transients in an electropneumatic positioning system at different line lengths from 1m and 10 m with step change of input setpoint are simulated.

Graphical comparison is made of the obtained experimental results and simulation model influence of the pneumatic line length on the dynamics of the electropneumatic positioning system are made.

REFERENCES

[1] Andrey Andreev, Hristo Hristov, Georgi Iliev, Milena Racheva. Mathematical Model for a Pneumatic Force Actuator System. BGSIAM’15 PROCEEDINGS 10th Annual Meeting of the Bulgarian Section of SIAM. December 21-22, 2015 Sofia

[2] Iliev, G., H. Hristov, A. Anchev. „Experimental investigation of static characteristics of pneumatic proportional directional valve. Vol. 3, pp. 318-323, UNITECH’ 15, Gabrovo, 2015.

[3] Iliev,G., Hristo N. Hristov. "Mathematical model of electropneumatic positioning system including the length of pneumatic lines" Mechanics of Machines YEAR XXXI, №3,2023 pp(83-88);ISSN 0861-9727,Varna, Bulgaria.

[4] Georgi Iliev.,Experimental study of dynamic processes in pneumatic lines Heat Engineering .year 8, book 1, 2017 (pp.8-12) Bulgaria

[5] Noritsugu T. and M. Takaiwa “Robust positioning control of pneumatic servo system with pressure control loop”. IEEE International Conference on Robotics and Automation,. pp. 2613-2618. 1995.

[6] Mihai, A., V. Constantin; "Research on the designing of pneumatic positioning units controlled with valves commanded in modulated pulses"; MATEC Web Conf.Volume 290, Number of page(s)12; [21 August 2019]

https://doi.org/10.1051/matecconf/201929008003

[7] Lucian, Bogatu, Ciprian Rizescu; "Innovative Solutions for Pneumatic Positioning Systems", Innovation, Engineering and Entrepreneurship pp 530–536 book series (LNEE,volume 505) [2018] https://doi.org/10.1007/978-3-319-91334-6_72

[8] Elmadbouly E. E., Abdulsadek Nour M.: Modelling, simulation and sensitivity analysis of a straight pneumatic pipeline. Energy conversion and management 35.1 [1994], 61 - 77.

[9] Karadzhov, T., Pulov, D., Angelov, N., Contactless measuring of temperature with differential photo receiver, ENVIRONMENT. TECHNOLOGY. RESOURCES, 12th International Scientific and Practical Conference. June 20-22, 2019, Rezekne Academy of Technologies, Rezekne, Latvia, pp 101-104

[10] Saravanakumar D., B. Mohan, T. Muthuramalingam; "A review on recent research trends in servo pneumatic positioning systems precision engineering"Journal of the International Societies for Precision Engineering and Nanotechnology volume 49, July 2017, Pages 481-492

[11] Richer Edmond; Yildirim Hurmuzlu, "A High Performance Pneumatic Force Actuator System: Part I—Nonlinear Mathematical Mode"; J. Dyn. Sys., Meas., Control. [September 2000], 122(3)416–425. doi: https://doi.org/10.1115/1.1286336AbstractV

[12] Outbib R., E. Richard, "State feedback stabilization of an electropneumatic system" j. Dyn. Sys., Meas., Control. [September 2000], 122(3): 410–415. doi: https://doi.org/10.1115/1.1286625

[13] Kotkas l., N Zhurkin, A Donskoy, Zharkovskij, "Design and Mathematical Modeling of a Pneumatic Artificial Muscle-Actuated System for Industrial Manipulators" Machines [2022, 10](10), 885; https://doi.org/10.3390/Machines10100885