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Simulation model of hydraulic generator with variable flow direction

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Abstract.

The paper presents a simulation model of a hydraulic pump generator with variable flow direction. Current solutions are based on a steady flow of hydraulic fluid. This article presents the results of simulations for a system in which the flow will have a sinusoidal (alternating) progression. The simulation will be performed using MatLAB Simulink. The results of the simulations will be used in the next phase to develop the design assumptions and make a prototype system. Ultimately, the prototype of the hydraulic system will be used in a hydrostatic transmission with oscillating flow. The subject of the dissertation will be the assessment of the hydraulic and dynamic properties of the prototype transmission with the oscillating flow.

Keywords. Hydrostatic drive system, generator with variable flow direction, simulation model

1. INTRODUCTION

The natural resources of the Earth are limited. Their excessive use has a negative impact on ecology [1]. In recent years, more and more emphasis has been placed on renewable energy sources. Regulations aimed at reducing carbon dioxide emissions are a good example. As a result, there is again a dynamic development of the industry related to recuperation and efficient energy storage. Many concepts of hybrid drives are developing in the automotive industry. In most of them, the vehicle's kinetic energy is recuperated on the electric way [2, 3] during braking [8, 9]. There are many solutions and configurations. Last time the Audi company introduced into production vehicles with energy recuperation from shock absorbers. The principle of operation is presented in Fig.1. An innovative solution based on an electromechanics system. The maximum power that this solution could generate is up to 600 Watts [4].

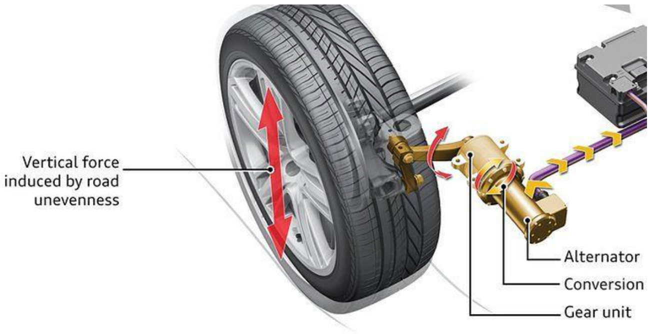


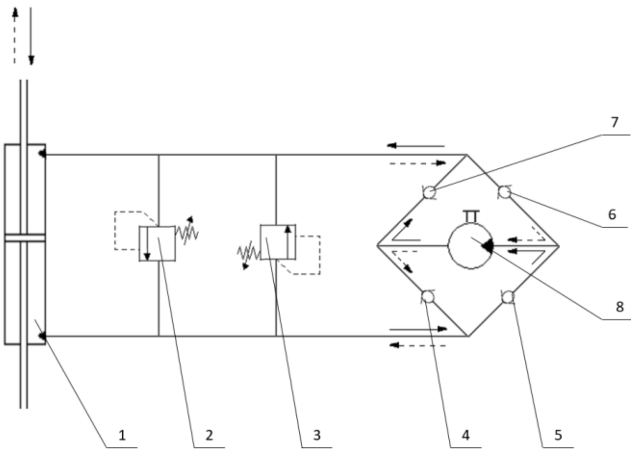
Figure 1.1. The operating principle of the Audi erupt system [4]

This paper aims to present a simplified simulation model of an oscillating hydrostatic transmission that allows to recuperate energy from shock absorbers of civil vehicles.

2. MATHEMATIC MODEL

The simulated hydraulic system is shown in Fig. 2. The drawing alludes to the patent application [10]. It consists of a double-acting cylinder, four check valves, a hydraulic motor and two maximum valves. The check valve system creates a hydraulic rectifier, which is characterized by the ability to straighten the direction of the flow of the working fluid [5, 11]. A number of simplifications have been made to the model:

- no oil temperature change,
- perfect forcing the actuator,
- no line and local losses,
- no inertia in valves,
- is no included loading on the piston rod, such as spring, inertia, friction.



- Figure 2.1. Hydraulic system scheme; 1- double-acting hydraulic cylinder, 2,3-pressure relief valve, 4-7- check valve, 8- hydraulic motor [10]

2.1. *Double-acting hydraulic cylinder*

As the first element in the system, it is the source of stream energy. The compulsion is the ideal shift model. Any kind of leakage, internal or external, is not taken into account.

2.2. *Hydraulic motor*

A hydraulic motor as an element that converts the energy of steady flow of the working fluid into a mechanical rotary motion. The engine model takes into account the losses: mechanical and volumetric. Volumetric losses are related to internal leakages between the engine inlet and the engine outlet. The described mechanical losses are related to internal friction. The hydraulic motor model has the ability to impart inertia. These dependencies are described by the following formulas [6, 7].

Rated flow:

$$q_{Real} = q_{Ideal} + q_{Leak} \tag{1}$$

where:

q_{Real} - real volumetric flow rate

q_{Ideal} - ideal volumetric flow rate

q_{Leak} - internal leakage volumetric flow rate

Torque:

$$\tau = \tau_{Ideal} - \tau_{Friction} \tag{2}$$

where:

τ - net torque

τ_{Ideal} - ideal torque

$\tau_{Friction}$ - friction torque

Ideal volumetric flow rate:

$$q_{Ideal} = D\omega, \tag{3}$$

where:

D - the value of the hydraulic motor displacement

ω - instantaneous angular velocity of the rotary shaft

Ideal generated torque:

$$\tau_{Ideal} = D\Delta p \tag{4}$$

where:

Δp - instantaneous pressure drop from inlet to outlet

Leakage:

$$q_{leak} = K_{HP}\Delta p \tag{5}$$

where:

K_{HP} – Hagen-Poiseuille coefficient for laminar pipe flow

2.3. Check valve

The check valve allows the working liquid flow in one direction. Due to the design, exist a minimum pressure, above which the valve opens. The opening is linear until the maximum value of the valve area is reached. Leakage for a closed valve was determined as a constant value for the leakage area. The dependencies are shown in Fig. 3.

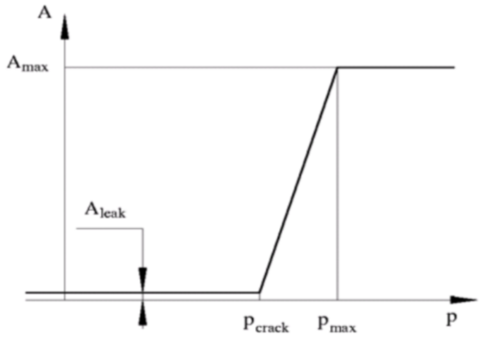


Figure 2.2. Dependence of pressure and area [7]

Check valve equation:

$$\Delta p = p_A - p_B \tag{6}$$

where:

p_A – pressure before valve

p_B – pressure after valve

Flow area:

$$A(p) = \begin{cases} A_{leak} & \text{for } p \leq p_{crack} \\ A_{leak+k\cdot(p-p_{crack})} & \text{for } p_{crack} < p < p_{max} \\ A_{max} & \text{for } p_{max} \leq p \end{cases} \tag{7}$$

where:

A_{max} - fully open passage area

A_{leak} - closed valve leakage area

p_{crack} - valve cracking pressure

p_{max} - fully open pressure

2.4. Pressure relief valve

The system is protected by two maximum valves. They allow the working liquid to flow into a parallel line in case of too much load on the hydraulic motor. The dependencies of pressure and passage are shown in Fig. 3.

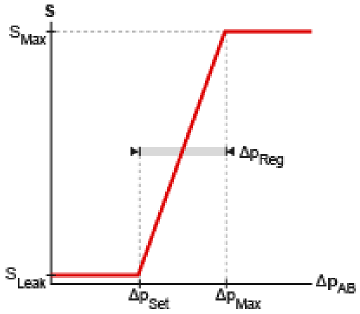


Figure 2.3. Dependence of pressure and area in pressure relief valve [7]

Leakage for a closed valve was determined as a constant value for the leakage area. The opening is linear according to the following equation:

$$S(\Delta p_{AB}) = S_{leak} + k(\Delta p_{AB} - \Delta p_{set}) \qquad (8)$$

where:

$S(p_{AB})$ – relief valve opening area

S_{leak} – leakage area

Δp_{set} – valve pressure setting

Δp_{AB} – pressure drop from port A to B

2.5. Inertia

The inertia was modeled for the hydraulic motor model. It is expressed as follows:

$$T = J\frac{d\omega}{dt} \qquad (9)$$

where:

T - inertia torque.

J - inertia.

ω - angular velocity.

t - time.

3. SIMULATION

The MatLAB Simulink program with the Simscape extension was used to create the simulation model. After selecting the simulation parameters, the input was implemented. The source that drives the entire system is an external displacement source connected to a double-actuator cylinder. The input force is a sinusoidal function.

3.1. Simulation without inertia

The simulation is shown in Fig. 5. which presents the velocity of the double-actuator cylinder. Fig. 6. shows the dependence of the rotational speed of the hydraulic motor shaft. Fig. 7. shows the flow rate of the hydraulic motor as a function of time.

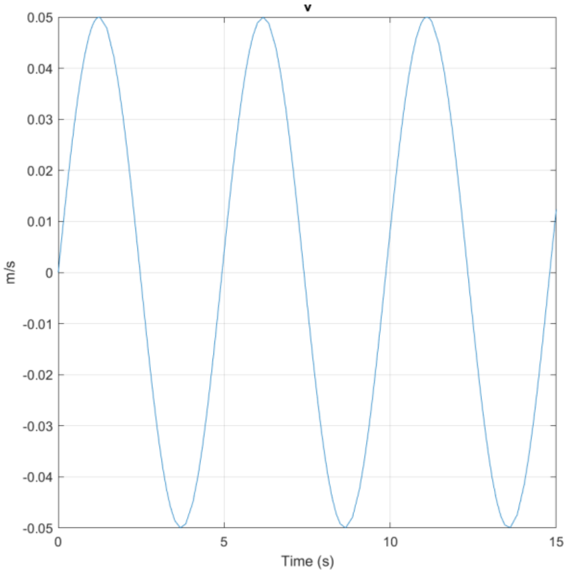


Figure 3.1. Simulation without inertia – extortion signal

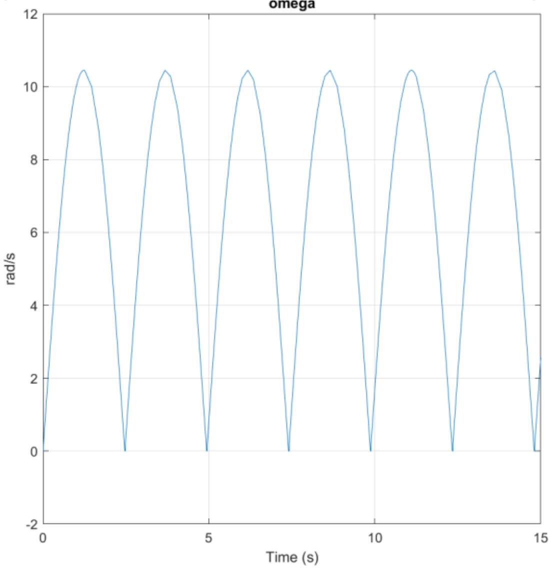


Figure 3.2. Simulation without inertia - *motor* rotational *speed.*

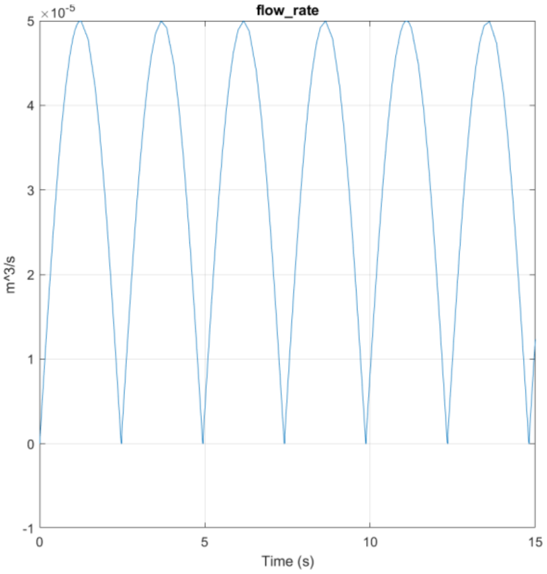


Figure 3.3. Simulation without inertia – flow rate.

3.2. Simulation with inertia

The simulation was carried out with joined inertia. Similar to the simulation without inertia: Fig. 8. shows the velocity of a double-actuator cylinder, Fig. 9. shows the dependence of the rotational speed of the hydraulic motor shaft, and Fig. 10. shows the flow rate shown in hydraulic motor as a function of time.

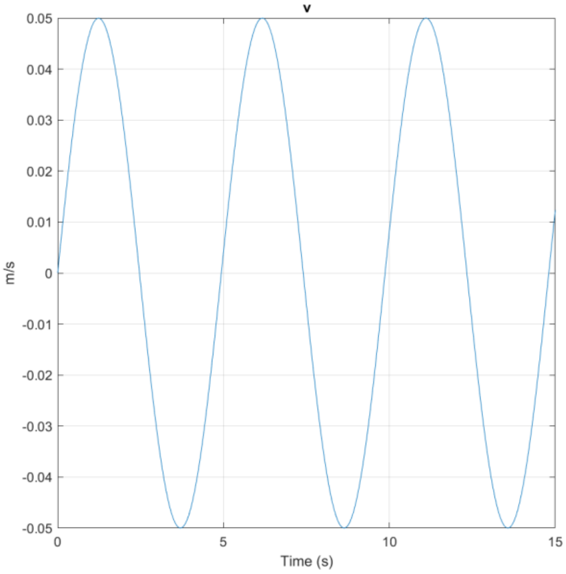


Figure 3.4. Simulation with inertia – extortion signal.

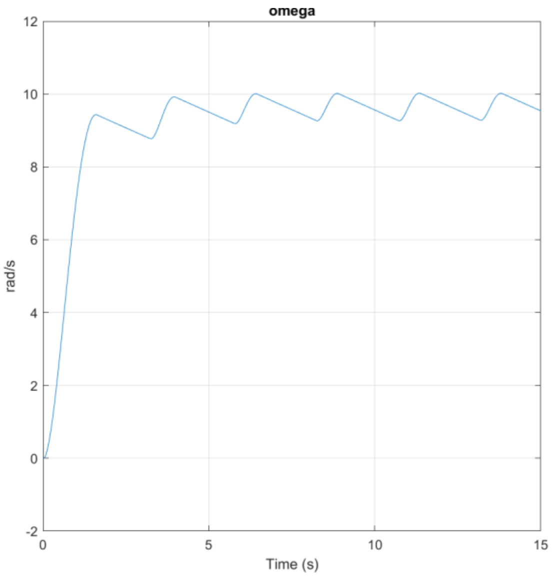


Figure 3.5. Simulation with inertia – rotational speed of the motor.

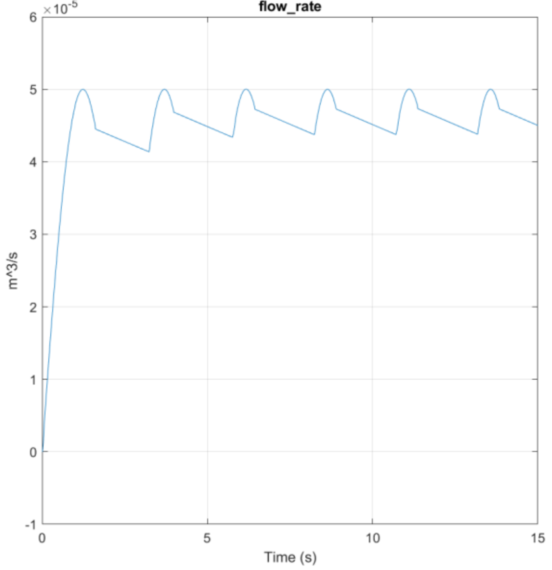


Figure 3.6. Simulation with inertia – flow rate.

3.3. *Simulation with inertia and high frequency*

The simulation was carried out with joined inertia. Similar to the simulation without inertia: Fig. 11. shown velocity of the double actuator cylinder, Fig. 12. shown dependence of the rotational speed of the hydraulic motor shaft, Fig. 13. the flow rate shown in the hydraulic motor in the function of time.

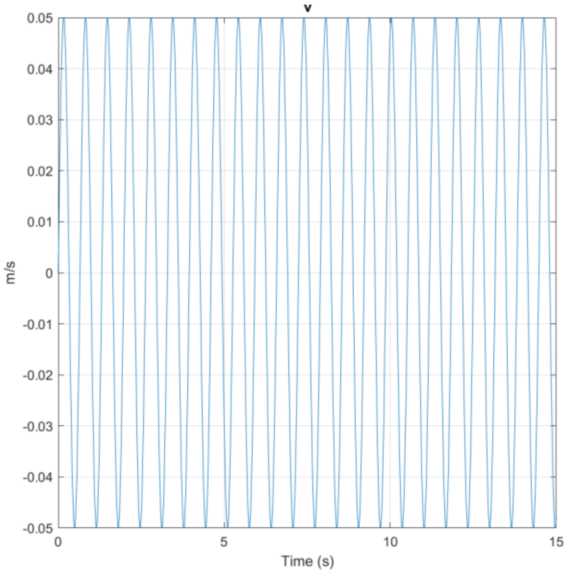


Figure 3.7. Simulation with inertia and high frequency – extortion signal.

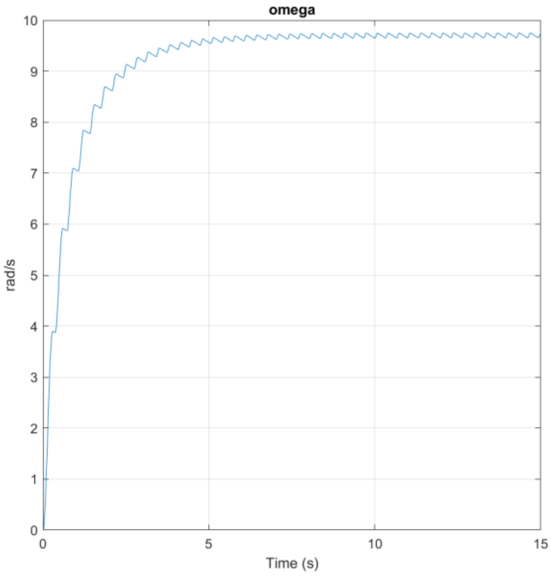


Figure 3.8. Simulation with inertia and high frequency – rotational speed of the motor.

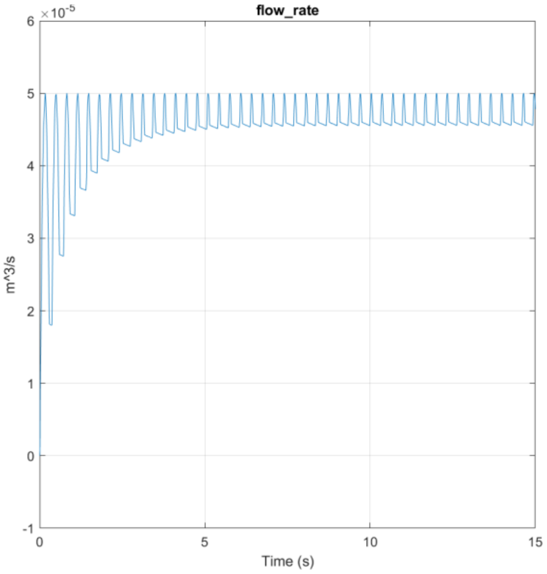


Figure 3.9. Simulation with inertia and high frequency – flow rate.

4. CONCLUSIONS

The results obtained in the simulation process presented in the article are preliminary. They do not consider many important physical phenomena. The next step will be to reduce the simplifying assumptions. The most important step in reducing simplification assumptions will be to remove the inertia of the check valves. This will allow the system to be checked at high frequencies. To verify the simulation model, it is planned to test the real system during the experimental tests. The experimental research will be performed on the real object for validation (checking) of the adopted mathematical model. Comparison of the experimental results with the calculation values will allow us to determine the impact of the simplifications adopted.

By analyzing Fig. 5, 6, and 7 it can be concluded that the hydraulic motor without inertia moves as expected.

If inertia (Fig. 8, 9, and 10) and high frequency of forcing (Fig. 11, 12, and 13) are taken into account, the cylinder speed is the same as the input speed.

For the rotational speed of a hydraulic motor, the influence of inertia is significant; after a few rotations, the value of the rotational speed or flow rate value does not drop below the specified value.

Hydraulic generator with variable flow direction as the first step to create a system to recuperating energy from dampers in vehicles, ultimately consisting of four actuators and one receiver. The results show that a hydraulic re-approval system can be created, allowing more environmentally friendly vehicles to be built.

5. REFERENCES

[1] IPCC report, Climate Change 2022 Summary, and Policymakers,

[2] B. M. Al-Alawi, T. H. Bradley, Review of hybrid, plug-in hybrid, and electric vehicle market, Renewable and Sustainable Energy Reviews 21, 2013, pp. 190–203

[3] P. Slowik, N. Lutsey, Expanding the electric vehicle marker in U.S. cities, the ICCT, 2017, pp. 7.

[4] V. Jacota, M. Matache, Calibration of a system capable to recover the dissipated energy into an automobile suspension, U.P.B Sci. Bill., 2018, pp. 100-101

[5] C. Li, R. Zhu, M. Liang, S. Yang, Integration of shock absorption and energy harvesting using a hydraulic rectifier, Journal of Sound and Vibration, 2014, pp. 3904-3906

[6] MatLAB v. R2021b help on-line documentatoion

[7] N. D. Manring, R. C. Fales, Hydraulic Control Systems, University of Missouri–Columbia, 2020

[8] Z. Domagała, K. Kędzia, M. Stosiak, Ways to improve energy efficiency in hydraulic drives (Sposoby zwiększenia efektywności energetycznej w napędach hydraulicznych), Oficyna Wydawnicza Politechniki Opolskiej, 2019. pp. 39-51

[9] K. Kędzia, An algorithm for the determination of the control parameters of a multisource drive system, Czasopismo Techniczne-Technical Transactions. 2017, pp. 173-182.

[10] P. Osiński, K. Kędzia, K. Dąbek, Hydraulic close transmission with hydraulic bridge rectifier (Przekładnia hydrostatyczna zamknięta z hydraulicznym mostkiem prostowniczym), patent application: P.440311, 2022

[11] Z. Domagała, K. Kędzia, M. Stosiak, The use of innovative solutions improving selected energy or environmental indices of hydrostatic drives, IMTech 2019 Scientific and Technical Conference, 2019, Szczyrk, pp. 1-12.

Biographies

Kacper Dąbek is PhD student at the Wrocław University of Science and Technology. In the research work, he analyzes pressure pulsations and hydrostatic transmissions with an oscillating flow. Co-author of three patent applications and speaker at two international scientific conferences. Multiple medalist of the Polish Academic Championships in Karate WKF.

Piotr Osiński works at the Faculty of Mechanical Engineering of the Wrocław University of Science and Technology. Specializes in the following areas: hydraulic drive and control, and vibroacoustics of machines and devices. Since 2013 he has been the head of the Laboratory of Hydraulic Drives and Vibroacoustics of Machines (www.lhiw.pwr.edu.pl). The acquired construction experience and mastered measuring workshop in the field of diagnostics of hydraulic systems and vibroacoustic measurement resulted in his participation as a project manager or main contractor in several research projects financed by the Ministry of Science and Higher Education and NCBR. The author has about 250 works in his scientific achievements, of which over 110 have been published in periodicals and books of national and international reach, other works are research and design and technological studies carried out in cooperation with industry. Close cooperation with industry has resulted in numerous implementations, including the introduction of PZ4 and PC series pumps into production. The developed constructions have been awarded many times at trade fairs, both domestic and foreign.

Krzysztof Kędzia is assistant professor at the Department of Technical Systems Operation and Maintenance Faculty of Mechanical Engineering Wrocław University of Science and Technology. Deals with drives and control of multi-source drive systems, in particular hydrostatic ones. As part of his scientific activity, he deals with building simulation models (Matlab SIMULINK) and their analysis. Author and co-author of over 70 publications and articles. Also the president of the Chamber of Commerce for Components and Technology, vice-president of the Corporation of Hydraulic and Pneumatic Drives and Controls, scuba diving instructor and president of the PIRANIA Academic Scuba Diving Club, editor in the Hydraulika i Pneumatyka magazine, member of the board of the Hydraulics Section of the Association of Polish Engineers and Mechanics.