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SIMULATION OF DYNAMIC PROCESSES IN HYDRAULIC ACCUMULATORS

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Abstract. The article focuses on pressure pulsations in hydraulic systems, the means reducing them and examines the structure of hydraulic accumulators, including their features and differences. Using the method of characteristics and *Fortran* software, a dynamic model of a hydraulic system is created. By changing the content of a hydraulic accumulator, the paper analyzes the amplitude of pressure waves, the distance between hydraulic accumulators and the dependency of the pulsations of pressure waves on the aforementioned sizes.

Keywords: hydraulic system, hydraulic accumulator, diffusion of pressure waves, method of characteristics, dynamic processes.

1. Introduction

Due to the pump operating cycle, hydraulic systems have pressure pulsations adversely affecting the individual components of the hydraulic system. This process was accelerated by the fact that the hydraulic system is not completely hermetic which means that there are certain emissions. Gas is pressing, so pressure pulsation takes on a greater value. One of the possible solutions is the incorporation of hydraulic accumulators in a hydraulic main. Hydraulic accumulators reduce pressure pulsation and the work of the hydraulic system becomes stable and equal. Therefore, a dynamic model of the hydraulic system has been created applying the method of characteristics and *Fortran* software.

A modern hydraulic system consists of many elements, such as hydraulic pumps, motors, distributors, valves, hydraulic accumulators, filters, hydraulic axes, etc. The processes taking place in these systems are fast changing, i. e. working fluid pressure and speed change fast. Working fluid containing gas may be used, for example air, the existence of which in the liquid greatly reduces the speed of sound propagation. Solutions offered to physical processes in hydraulic systems, depending on the characteristics of the system itself, have great practical significance.

The hydraulic accumulator is one of the hydraulic elements of the system that will be used to reduce pressure and speed pulsation inside it; thus, the selection and workflow modelling have a significant influence on the stability of the entire system.

Hydraulic accumulators store the source of energy during loading and return it to the system when engine load is intensive or high. Hydraulic accumulators permit to reduce pump power and pressure pulsation which causes the pump, distributor and other devices work and protect the system against possible hydraulic shocks, kinetic energy absorption during the large inertia load of the engine and to compensate for pressure changes in the fluctuations of temperature.

2. Review and Analysis of Hydraulic Accumulators

To potential energy storing at hydraulic accumulators, weight, spring or gas are used, and therefore hydraulic accumulators can be divided into cargo, spring and gas accumulators. Gaseous hydraulic ones still can be classified as without and with a partition the last one of which may include a piston or elastic wall which is a partition in the form of the diaphragm, membrane or specific structure.

For energy accumulation and recovery in cargo hydraulic accumulators, changing the potential energy of weight is used. Although these accumulators have a simple structure, they are very massive, thus, sometimes may require a separate basement. Their advantage is that during discharge, pressure remains constant, whereas their weaknesses are inertia powers causing pressure changes and expensive repairs.

For energy accumulation and recovery in spring hydraulic accumulators, spring elastic deformation is

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used. These accumulators are not so inert and appear as a hydraulic system subject for the offset of hydraulic shock. These accumulators are used in hydraulic systems with closed working fluid circulation to protect against changes in possible temperature and the same working fluid. The weaknesses of this equipment embrace massive spring and large accumulator constructions.

Gas compression is used to maintain fluid pressure in gas hydraulic accumulators. Due to gas compression, such accumulators are widely used as protectors and elastic elements. Considering proper construction and compact opportunities, gas hydraulic accumulators are widely used in mobile plants. This type of accumulators with a piston partition may be used at high pressures. However, weaknesses such as the tightness of the piston at high pressures and low temperatures, production costs, tearing sealing measures, limitation in size and piston friction should be taken into account. Gas hydraulic accumulators with plunger use the multiplier principle allowing obtain high pressure in oil environment substantially exceeding pressure in gas environment. A gas hydraulic accumulator with an appointment of an elastic diaphragm ideally separates gas and fluid working environments. Inertia powers disappear which prolongs working time without charge. Accumulators are widely used in plants with small fluid depletion. These accumulators are made like a sphere used in the applicable mobile devices, especially in aircraft industry. Due to the unsatisfactory elasticity wall and default of friction forces, gas hydraulic accumulators with membrane are very sensitive. Gas hydraulic accumulators without partitions are almost exclusively used in stationary hydraulic equipment. Gas is directly in contact with fluid, and therefore is in a partial mix with fluid. To reduce the absorption area and gas and fluid volumes in order to solve these accumulators made in the form of a thin cylinder, the minimum amount of fluid was conducted through closure valves or other equipment. Accumulators with mixed compressed gas and fluid are widely applied.

After reviewing scientific works, the following cases of using hydraulic accumulator were established: enables an economical use of fuel in excavators (Godin and Schubert 2008); prevents from water shocks in various hydraulic systems (Nachtwey 2006); prolongs the exploitation of hydraulic systems (Flippo 2008; Nachtwey 2006); makes the administration of hydraulic systems easier (Nachtwey 2006); reduces noise in hydraulic machines (Godin 2009; Song *et al.* 2009), military naval machines (Luo *et al.* 2006) and vehicle industry (Izrailovich *et al.* 2007); protects against pressure pulsations; a pool of energy reserves in hydraulic elevators (Xu *et al.* 2005); reduces pressure pulsations allows connecting smaller pumps and motors for the system which permits to reduce hydraulic system (Godin and Schubert 2008) and machine (Flippo 2008; McGehee 2009; Bogdevičius 2002, 2005) costs.

With reference to the publications of different authors, Quan *et al.* (2009) examines hydraulic accumulators as a hydraulic shock absorber in hydraulic systems, Hu and Luo (2009) – as a means of reducing pressure pulsation in a general hydraulic system of submarine steering arrangement, Zhang *et al.* (2009) – as a measure of energy savings in oil extraction industry, Rydberg (2009) – as energy savings and as a reuse measure in different types of machinery hydraulic systems, Prodan *et al.* (2007) – as an energy source of the hydraulic system, Ding *et al.* (2007) – as a braking energy absorber and electric energy source in electromobiles, Okoye *et al.* (2005) – as a measure of energy savings in electricity lines.

3. Hydraulic System Solutions

Create a dynamic model of a hydraulic accumulator without a partition (Fig. 1).

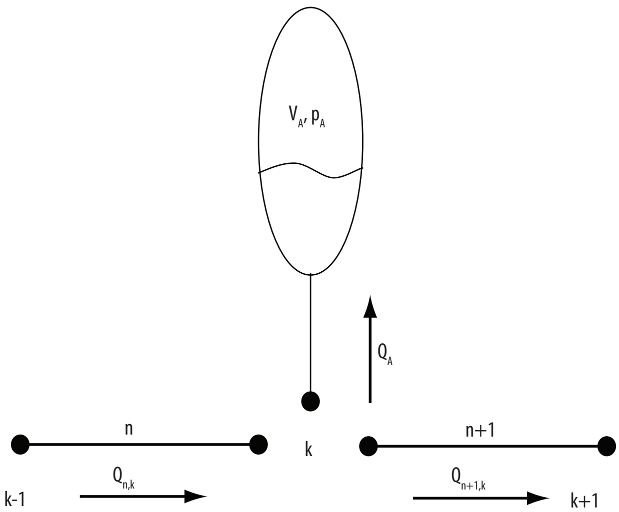

Fig. 1. A dynamic model of a hydraulic accumulator without a partition

Fluid debit at the point of main k:

$$Q_{n,k} - Q_{n+1,k} = Q_A , \tag{1}$$

where:

$$Q_{n,k} = A_{n,k} u_{n,k} ;$$

$$Q_{n+1,k} = A_{n+1,k} u_{n+1,k} ;$$

$$Q_A = \frac{dV_A}{dt} ;$$

$A_{n,k}$, $A_{n+1,k}$ – main cross sector at the point k of the n-th and n+1 pipeline, respectively; $u_{n,k}$, $u_{n+1,k}$ – fluid velocity at the point k of the n-th and n+1 pipeline, respectively.

Depending on a hydraulic accumulator between pressure and volume:

$$V_A P_A^{\gamma} = V_{A_0} P_{A_0}^{\gamma} , \tag{2}$$

where: γ – adiabatic gas rate.

After differentiation P_A from (2) in time:

$$\frac{dp_A}{dt} = -\frac{1}{\gamma}\frac{P_A}{V_A^{\gamma}}\frac{dV_A}{dt}. \quad (3)$$

The equation is solved applying Euler's method:

$$P_{A,t+\Delta t} = P_{A,t} + \Delta t F\left(V_{A,t}\right)\left(A_{n,k}u_{n,k,t} - A_{n+1,k}u_{n=1,k,t}\right), \quad (4)$$

where: Δt – step of integrating.

$$F = -\frac{1}{\gamma}\frac{P_A}{V_A^{\gamma}}. \quad (5)$$

Pressure in main junction k is equal to hydraulic accumulator pressure: $P_{n.k} = P_{n+1,k} = P_A$. The flow of a viscous and compressive fluid is described by differential equations with partial derivatives expressing the laws of mass movement, quantity and conservation of energy. Non-stationary quasi-linear one-dimensional fluid flow models are widely applied (Bogdevičius 1999, 2000). In these models, the condition of flow at every moment of time is characterized by the average values of pressure, velocity and density. When estimating the average values of fluid flow parameters, the following preconditions such as pressure, density, internal energy and temperature change inconsiderably in a cross-section of a pipeline are taken into consideration. The speed of movement on the walls of a pipeline is equal to zero. The one-dimensional non-stationary isothermal movement of a viscous and compressive fluid in a pipeline is considered, i.e. when fluid velocity vector is directed longitudinally to the axis of a pipeline, and speed and pressure changes during time and longitudinally to the axis of a pipeline.

The movement and continuity equations of a viscous compressible fluid in a pressure pipe have the following form:

$$\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} + \frac{fv|v|}{2d} + a_x = 0; \quad (6)$$

$$\frac{\partial p}{\partial t} + v\frac{\partial p}{\partial x} + c^2\rho\frac{\partial v}{\partial x} = 0, \quad (7)$$

where: p, v – fluid pressure and velocity; ρ – fluid density; c – sound velocity; f – non-dimensional hydraulic coefficient of friction.

Differential equations of fluid movement in the hydraulic system are solved by the method of characteristics (Bogdevičius 1999, 2000, 2002, 2005; Bajoraitytė and Bogdevičius 2002, 2003; Bogdevičius *et al.* 2004; Bogdevičius and Suslavičius 2007; Junevičius and Bogdevičius 2007, 2009) and received non-linear system of algebraic equations is solved by Newton method.

General information on the system: pump speed – 3000 times/min, the number of pistons – 7, angular speed – 2198 rad/s, pressure at point k-1 10 MPa, pipeline diameter – 0.02 m, pipe wall thickness – 0.002 m. The solution was achieved using *Fortran* software.

Solve the hydraulic system with one hydraulic accumulator (Figs 2–5).

Solve a hydraulic system with two hydraulic accumulators (Fig. 6).

Look for solutions to two hydraulic accumulators parallel and subservient to the hydraulic system and compare pressure pulsation at points k-1 and p (Figs 7, 8).

Find solutions to the hydraulic system with three hydraulic accumulators (Figs 9–11).

Find the dependence of pressure pulse on the distance between hydraulic accumulators parallel and subservient to the hydraulic main increasing the distance between hydraulic accumulators to 3 meters (Fig. 12).

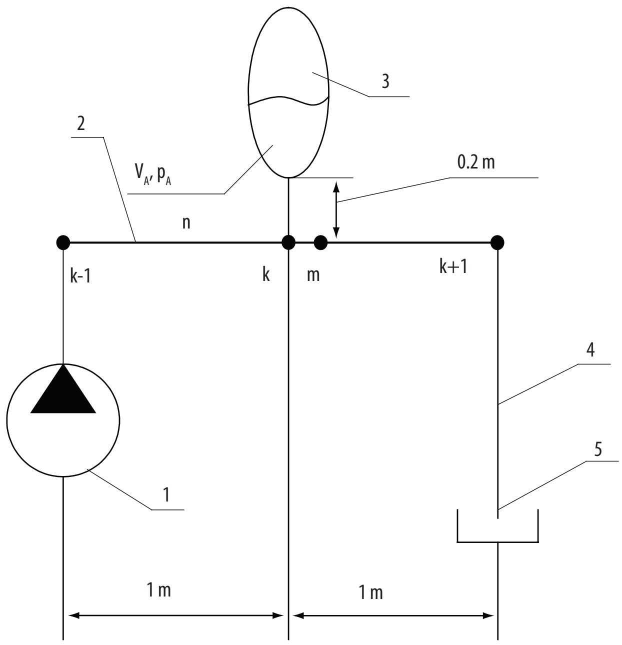

Fig. 2. A scheme of a hydraulic system with one hydraulic accumulator: 1 – axial piston pump; 2 – hydraulic main; 3 – hydraulic accumulator; 4 – choke; 5 – hydraulic tank

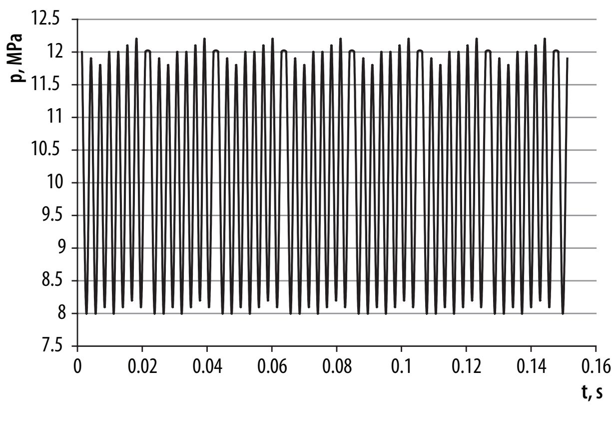

Fig. 3. Pressure at incoming point k-1

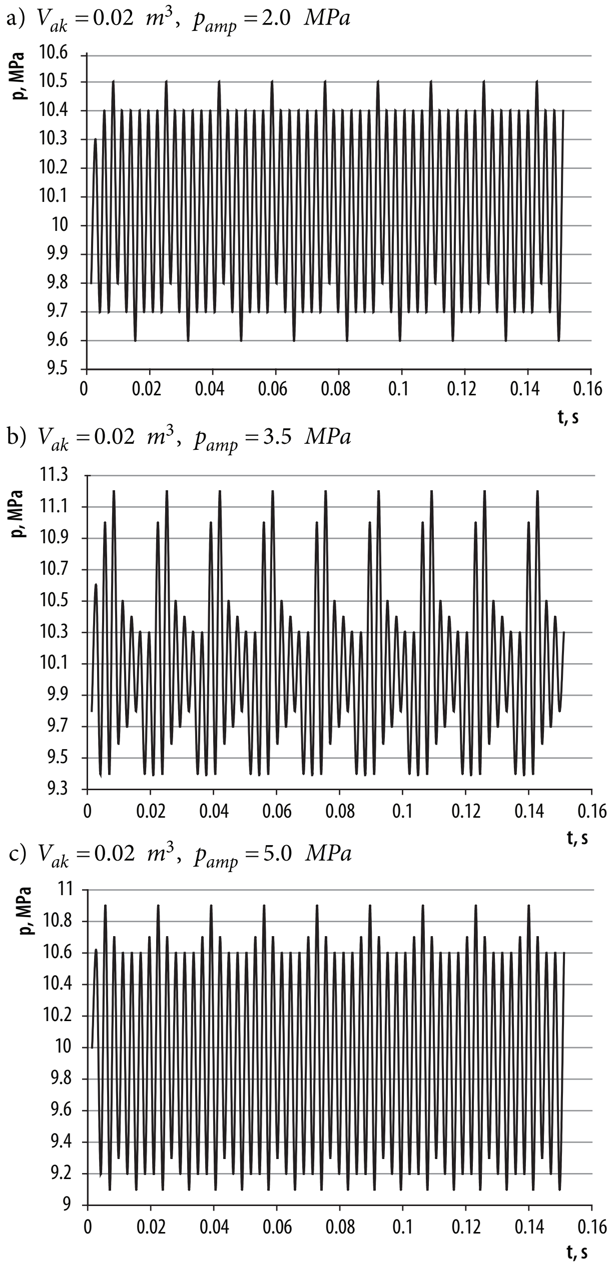

Fig. 4. A diagram of pressure variation when a hydraulic system has one hydraulic accumulator, accumulator volume is constant and the amplitude of pressure is changing

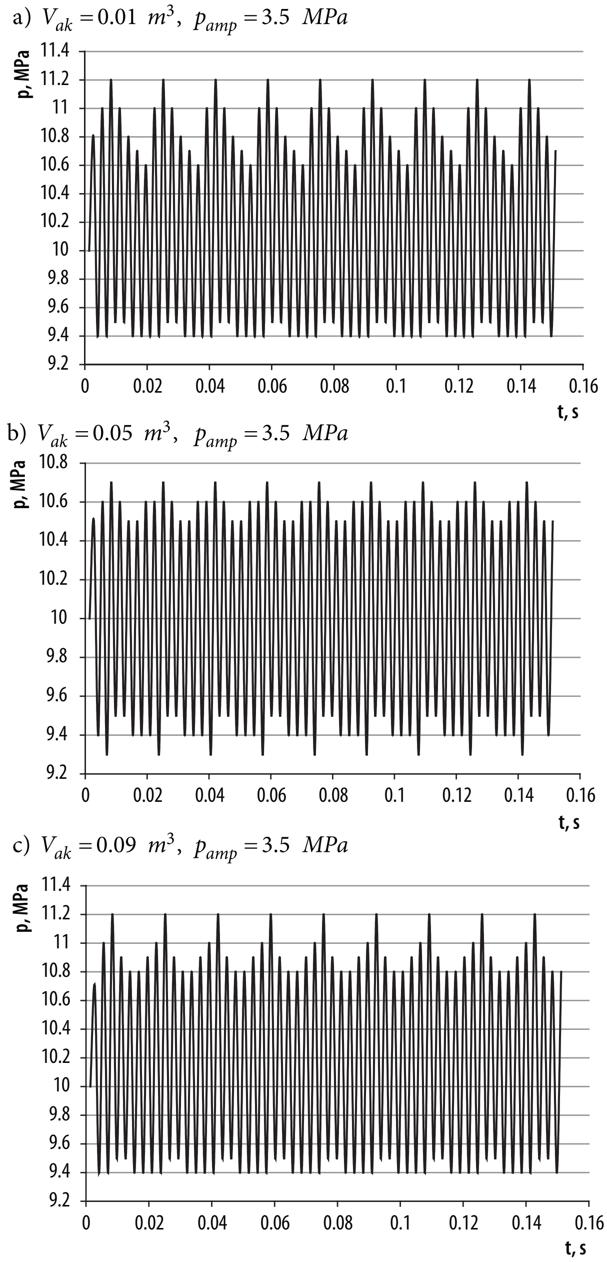

Fig. 5. A diagram of pressure variation when a hydraulic system has one hydraulic accumulator, accumulator volume is changing and the amplitude of pressure is constant

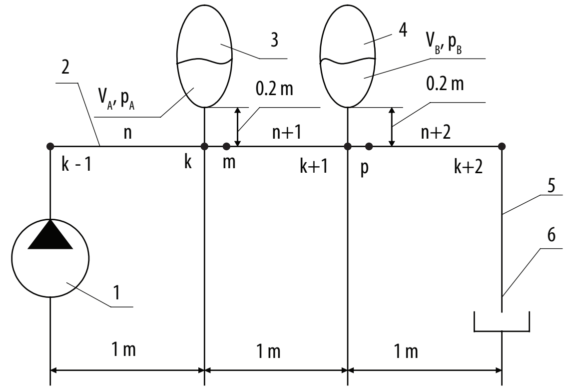

Fig. 6. A scheme of a hydraulic system with two hydraulic accumulators 1 – axial piston pump; 2 – hydraulic main; 3 – hydraulic accumulator; 4 – second hydraulic accumulator; 5 – choke; 6 – hydraulic tank

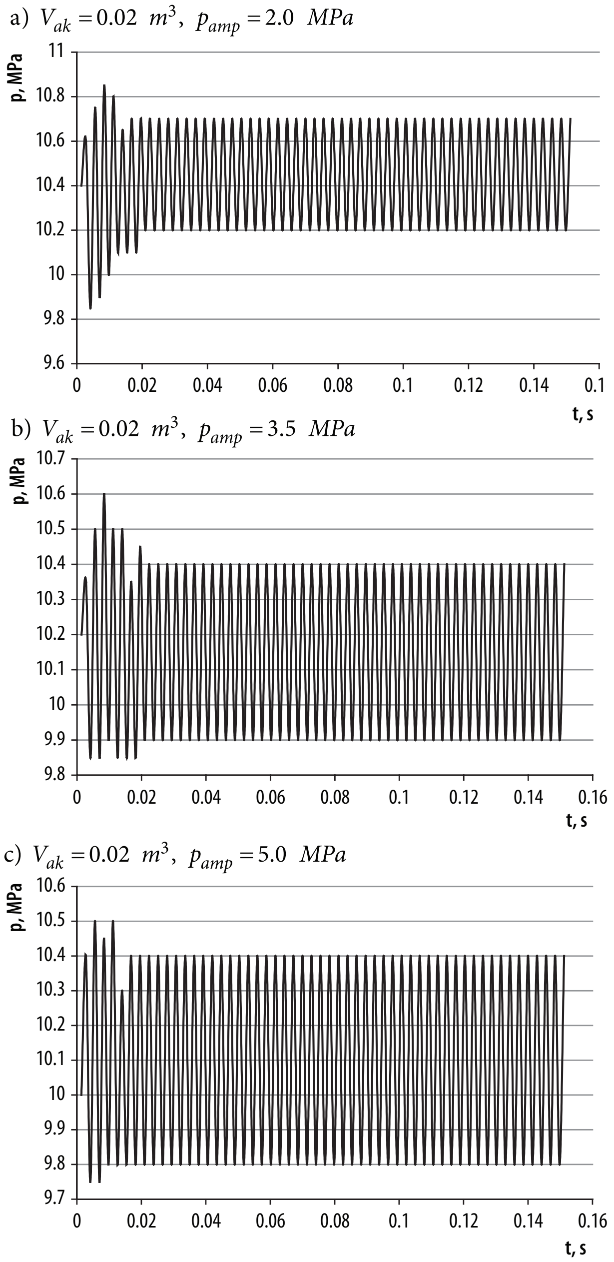

Fig. 7. A diagram of pressure variation when a hydraulic system has two hydraulic accumulators, accumulator volume is constant and the amplitude of pressure is changing

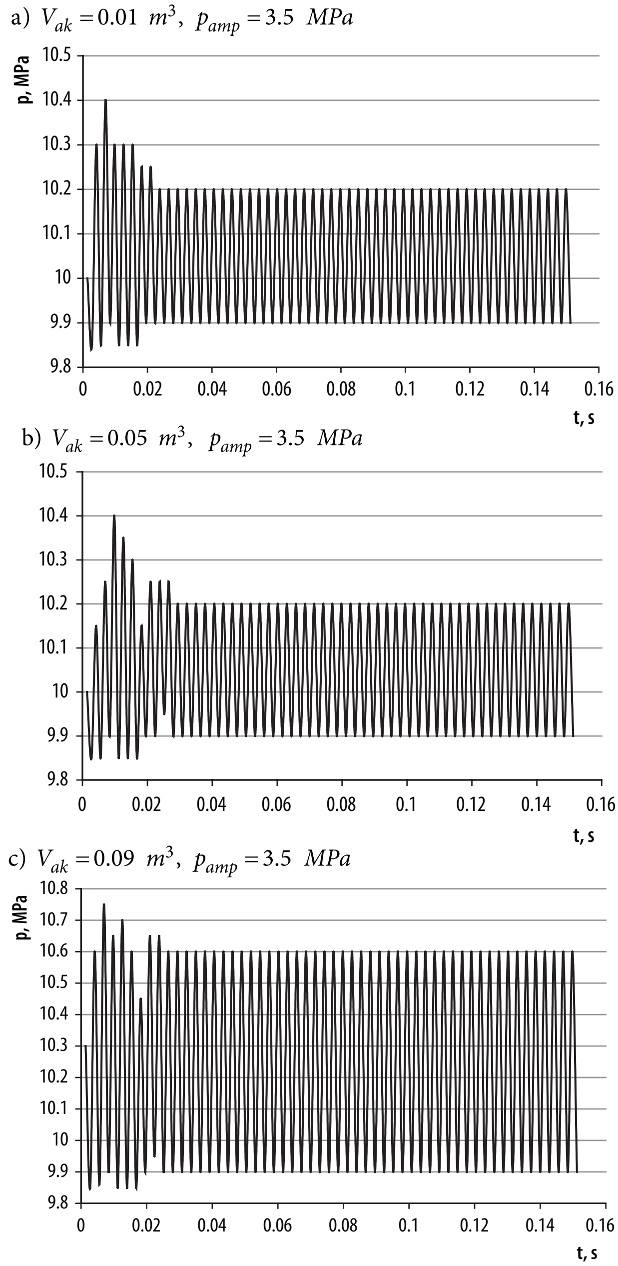

Fig. 8. A diagram of pressure variation when a hydraulic system has two hydraulic accumulators, accumulator volume is changing and the amplitude of pressure is constant

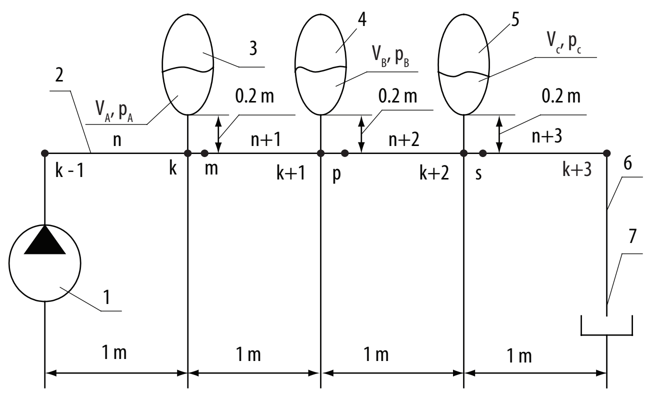

Fig. 9. A scheme of a hydraulic system with three hydraulic accumulators: 1 – axial piston pump; 2 – hydraulic main; 3 – hydraulic accumulator; 4 –second hydraulic accumulator; 5 – third hydraulic accumulator; 6 – choke; 7 – hydraulic tank

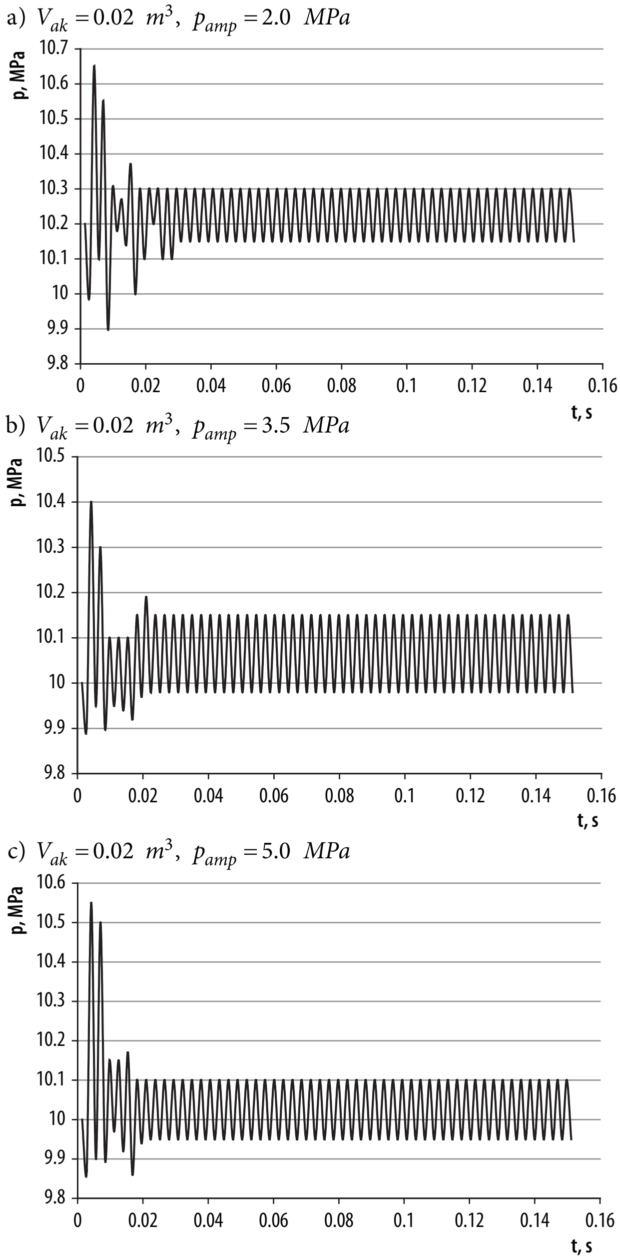

Fig. 10. A diagram of pressure variation when a hydraulic system has three hydraulic accumulators, accumulator volume is constant and the amplitude of pressure is changing

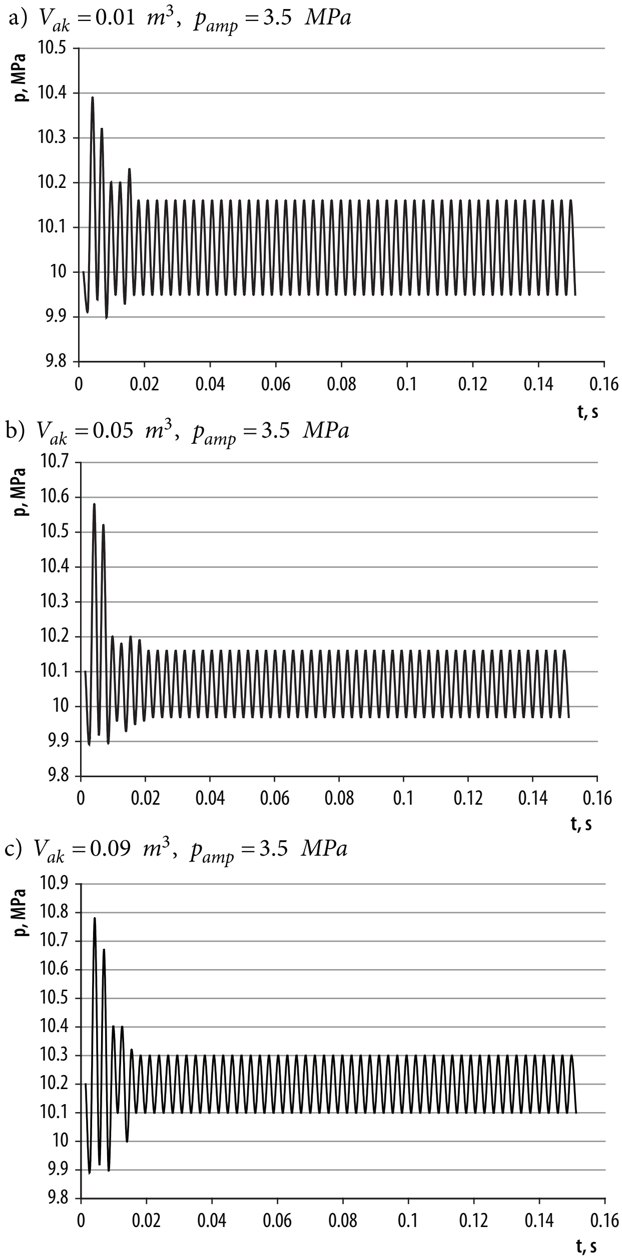

Fig. 11. A diagram of pressure variation when a hydraulic system has three hydraulic accumulators, accumulator volume is changing and the amplitude of pressure is constant

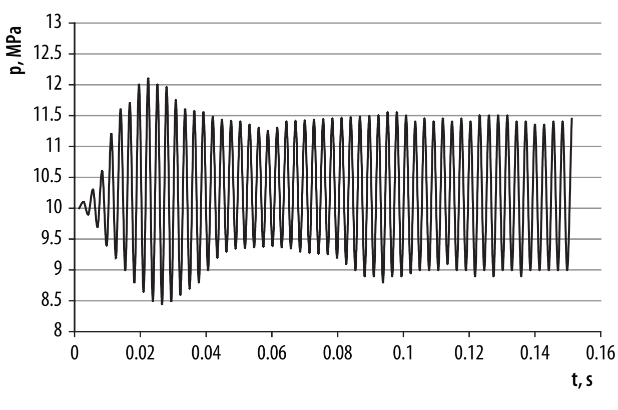

Fig. 12. A diagram of pressure variation when a hydraulic system has three hydraulic accumulators, accumulator volume – 0.09 m^3 and the amplitude of pressure – 3.5 MPa

4. Conclusions

1. The inclusion of one, two or three hydraulic accumulators into the hydraulic system leads to a reduction in pressure pulsation, respectively ± 1.78 MPa, ± 0.48 MPa and ± 0.43 MPa.
2. An increase in pressure pulse amplitude from 2.0 MPa to 5.0 MPa causes an increase in pressure pulsation from ± 0.15 MPa to ± 0.43 MPa.
3. A change in hydraulic accumulator volume from 0.02 m^3 to 0.09 m^3 causes an increase in pressure pulsation from ± 0.37 MPa to ± 0.38 MPa.
4. A mutual connection of the distance between the hydraulic accumulator causes an increase in pressure pulsation from ± 0.15 MPa to ± 3.08 MPa.

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