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SIMULATION OF PRESSURE AMPLITUDE CHARACTERISTICS OF PIPE WITH HYDRAULIC ACCUMULATOR IN MATLAB - SIMHYDRAULICS

SIMULACE AMPLITUDOVÉ FREKVENČNÍ CHARAKTERISTIKY TLAKU POTRUBÍ S HYDRAULICKÝM AKUMULÁTOREM V MATLAB - SIMHYDRAULICS

Abstract

The paper deals with the simulation of pulsating flow in the pipeline for options with and without the hydraulic accumulator, when the throttle valve is at the outlet of pipeline. Time dependent flow through the pipeline is simulated in the software Matlab - SimHydraulics. Numerically simulated amplitude-frequency characteristics of pressure are verified experimentally.

Abstrakt

Příspěvek se zabývá simulací pulzujícího průtoku v potrubí pro varianty bez hydraulického akumulátoru a s akumulátorem, kdy na konci potrubí je umístěn škrticí ventil. Nestacionární proudění v potrubí je simulováno v prostředí software Matlab - SimHydraulics. Numericky simulované amplitudové frekvenční charakteristiky tlaku potrubí jsou ověřeny experimentálně.

1 INTRODUCTION

The periodical pulsations of liquid dynamically stress the single elements in the hydraulic circuit, reduce the service life of these elements and they are significant sound sources. The amplitudes of pressure pulses in the circuit depend significantly on exciting signal frequency. When the exciting frequency is close to the eigenfrequency of the circuit, the amplitudes of pulsating pressure increase remarkably and it may lead to the system failure.

Amplitude and phase of pulsating pressure at given point of long pipe is frequency dependent. The time courses of pressure in single points along long the pipeline are periodical for inlet periodical exciting signal with given amplitudes and frequency. The amplitudes of pressure time courses in the single points are different and courses are mutually time-shift, but the frequencies are the same.

2 NUMERICAL SIMULATION

For the numerical simulation was considered steel pipe P with following parameters length L = 58.9 m, inner diameter d = 0.012 m and wall thickness s = 0.002 m. The operating liquid is mineral oil with density $\rho = 869.7\ kg\cdot m^{-3}$ and kinematic viscosity $\nu = 5.06\cdot 10^{-5}\ m^2\cdot s^{-1}$. The bulk modulus of mineral oil $K = 1.5 \cdot 10^9$ Pa including the effect of air bubbles and compressibility of pipe was determined experimentally.

To simulate the pipeline was used the segmented pipeline model with concentrated parameters connected in series. The elements of segmented pipeline in the software Matlab - SimHydraulics are

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symmetrical T element in case of single and L elements for the other elements, both with concentrated parameters [3]. The connection of the segmented pipeline elements could be seen in the Fig. 1 [4].

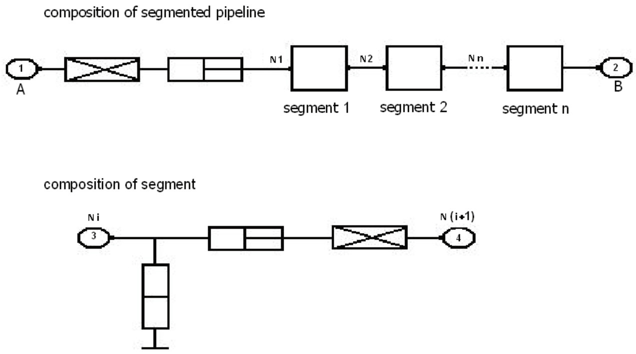

Fig. 1 Composition of segmented pipeline

Fig. 2 Motion resistance R

Fig. 3 Acceleration resistance H

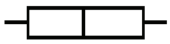

Fig. 4 Deformation resistance D

The following equations were used:

$$\Delta p = R \cdot Q^n, \tag{1}$$

$$\Delta p = H \cdot \frac{dQ}{dt}, \tag{2}$$

$$\Delta p = D \cdot \int Q \cdot dt. \tag{3}$$

For laminar flow is n = 1, for turbulent flow n = 2.

Where:

Δp – pressure gradient $[\mathrm{Pa}]$,

Q – flow $[\mathrm{m^3 \cdot s^{-1}}]$,

t – time $[\mathrm{s}]$,

R – motion resistance, for laminar flow $[\mathrm{N \cdot m^{-5} \cdot s}]$, for turbulent flow $[\mathrm{N \cdot m^{-8} \cdot s^2}]$,

H – acceleration resistance $[\mathrm{N \cdot m^{-5} \cdot s^2}]$,

D – deformation resistance $[\mathrm{N \cdot m^{-5}}]$.

Hydraulic deformation resistance D is equal to reciprocal of hydraulic capacity C.

The throttle valve is characterised by Δp-Q characteristics displayed in the Fig. 5 [1].

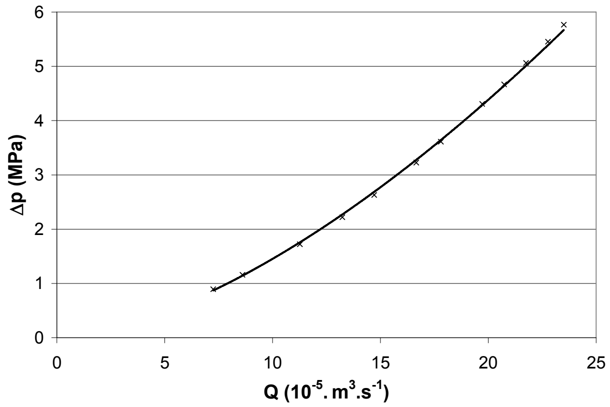

Fig. 5 Δp - Q characteristics of the throttle valve

The proportional directional valve was placed at the inlet of pipeline for the simulation. This valve is characterized by Δp_{pr} – Q characteristics for various valve opening. For individual valve opening, which correspond to control voltage value U (V), were measured the dependences of flow Q trough the directional valve on pressure gradient Δp_{pr} at this valve, see Fig. 6. The higher voltage U (V) corresponds to higher flow through this valve for the same pressure gradient Δp_{pr}.

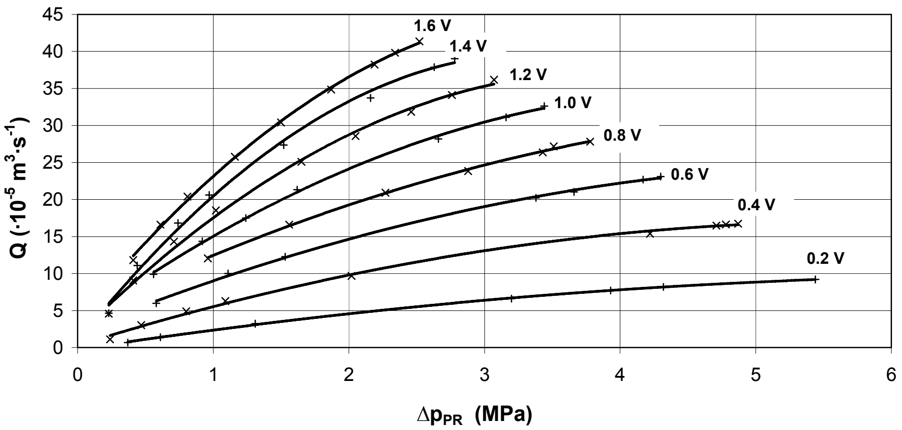

Fig. 6 ΔQ – Δp_{pr} characteristics of proportional directional valve for various voltages U

Scheme of simulation in Matlab - SimHydraulics for pipe P with hydraulic accumulator is displayed in Fig. 7 [5]. The considered pipe P of length L = 58.9 m was in numerical model divided in two sections, the pipe P1 of length L1 = 51.25 m and pipe P2 of length L2 = 7.65 m. For the pipe P1 was used model of segmented pipeline with 30 segments and for the pipe P2 with 27 segments. The throttle valve TV was placed at the outlet of P2 and was characterized by Δp – Q characteristics, see Fig. 5.

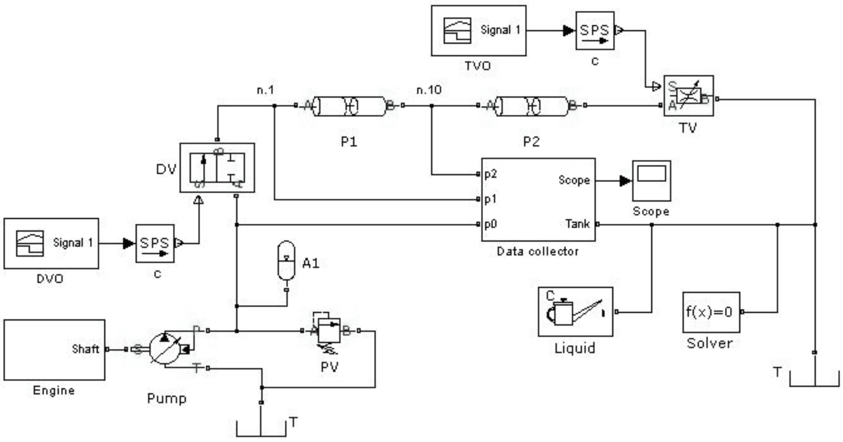

Fig. 7 Simulation scheme in Matlab – SimHydraulics, pipeline without accumulator

The time courses of exciting periodical pressure signal were generated using the element hydraulic directional valve DV, which make possible to set proportional opening and the corresponding flow. The above-mentioned element agrees with the real proportional directional valve with characteristics displayed in Fig. 6. The element DVO defined the opening of directional valve DV, when following simuling converter c convert the dimensionless signal to real physical signal. The constant pressure source was Pump (Variable Displacement Pressure Compensated Pump) with accumulator A1, the drive of pump was defined by subsystem Engine. The tank with liquid was defined by element T. The circuit was protected against the overload by pressure relief valve PV. The simulation scheme contains the solver configuration element Solver and element Liquid with parameters of liquid. Value of relative air amount contained in the liquid was $1 \cdot 10^{-12}$. The subsystem Data collector including the element Scope served to display and evaluate of simulated data.

The time courses of pulsating pressure p1 at the inlet of pipeline P1 and the p2 at inlet of pipeline P2 were numerically simulated for option without hydraulic accumulator in the software Matlab – SimHydraulics, see Fig. 7. The simulations were realized for various exciting frequency f. The numerically simulated time courses of pressures p1 and p2 for option without hydraulic accumulator for exciting frequency f = 5.127 Hz are displayed in Fig. 8.

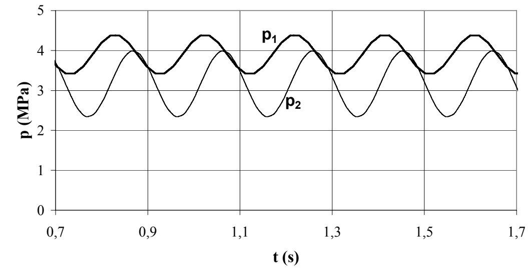

Fig. 8 Simulated time courses of pressures p1 and p2, f = 5.127 Hz

The simulation scheme of the pipeline, with the hydraulic accumulator placed in the distance 0.25 m from the pipeline P outlet, was set in software Matlab – SimHydraulics see Fig. 9 [5]. There are some changes comparing to circuit displayed in the Fig. 7. The pipeline is divided in three sections: segmented pipeline P1 length L1 = 51.25 m (with the same parameters as above), segmented pipeline P2 length L2 = 7.4 m with 30 segments and hydraulic pipeline P3 length L3 = 0.25 m. There is the gas-charged accumulator A2 placed between the outlet pipeline P2 and inlet of pipeline P3. The preload pressure in the accumulator was p_{pt} = 2.5 MPa and its volume was $V_A = 3 \cdot 10^{-4}$

m^3, specific heat ration was k = 1.4. Mathematical model of gas-charged accumulator in software Matlab - SimHydraulics is based on following equations [4]:

$$Q_A = \frac{dV_k}{dt}, \tag{4}$$

$$V_k = 0 \text{ pro } p \le p_{pt}, \tag{5}$$

$$V_k = V_A \cdot (1 - (\frac{p_{pt}}{p})^{\frac{1}{k}}) \text{ pro } p > p_{pt}. \tag{6}$$

Where:

V_k – volume of accumulator $[m^3]$,

Q_A – volume flow through the accumulator $[m^3 \cdot s^{-1}]$,

t – time $[s]$,

p – pressure at the accumulator inlet $[Pa]$,

p_{pt} – preload pressure in accumulator $[Pa]$,

k – specific heat ration $[1]$.

Mathematical model of accumulator A2 does not include its resistances against the motion and against the acceleration. These resistances are simulated by individual elements resistive tube Ra and fluid inertia La. These elements include also resistances of inlet pipe to accumulator in the real circuit.

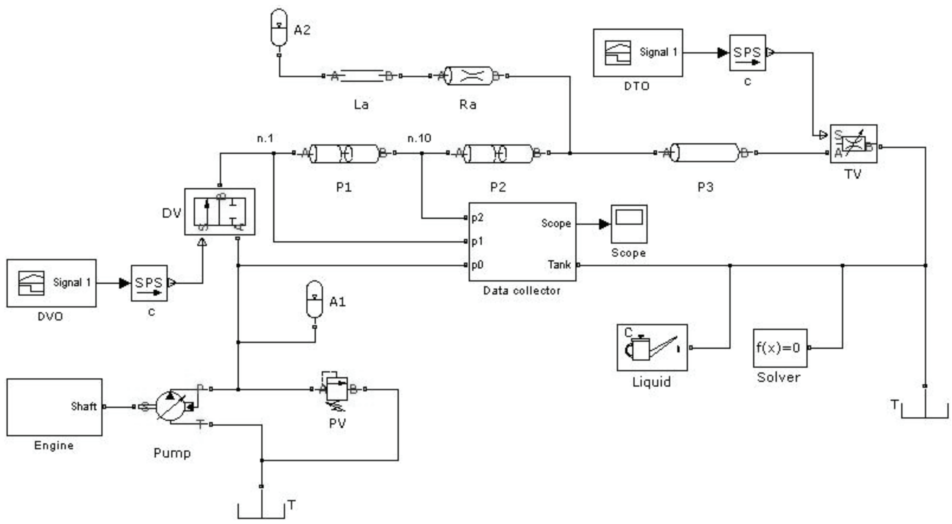

Fig. 9 Simulation scheme in Matlab – SimHydraulics, pipeline with accumulator A2

The time courses of pressures p1 at the inlet of pipeline P1 and p2 at the inlet of pipeline P2 for option with hydraulic accumulator was numerically simulated by software Matlab SimHydraulics.

The time courses of pulsating pressures p1 and p2 for pipeline P length L = 58.9 m with throttle valve at the pipeline outlet for both options (with and without accumulator) excited by various exciting frequencies were tested in the real hydraulic circuit. The pressure pulses are created by means of proportional directional valve. The accumulator 215 AGV – 0,4 Jihlavan [6] was used in the circuit as hydraulic accumulator A2.

3 AMPLITUDE FREQUENCY CHARACTERISTICS PRESSURE

From the pulsating time courses of pressure p1 and p2 were evaluated the amplitudes of frequency transmission Fp2p1 of pipeline with throttle valve at its outlet as ratio of harmonic components p_{2A} and p_{1A}.

$$F_{p2p1} = \frac{p_{2A}}{p_{1A}} \tag{7}$$

The amplitudes of harmonic components p_{2A} and p_{1A} of both pressures p1 and p2 for appropriate exciting frequencies were determined using Fast Fourier Transformation (FFT). The examples time courses of pressures p1 and p2 and appropriate spectra for exciting frequency f = 4.15 Hz for pipeline without hydraulic accumulator are displayed in the Figures 10, 11, 12 [2].

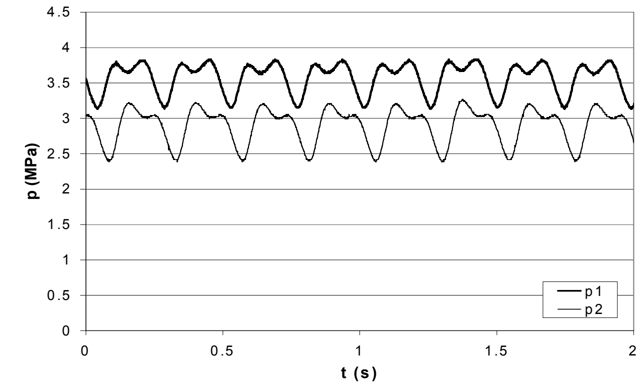

Fig. 10 Measured time dependence of pressures p1 and p2

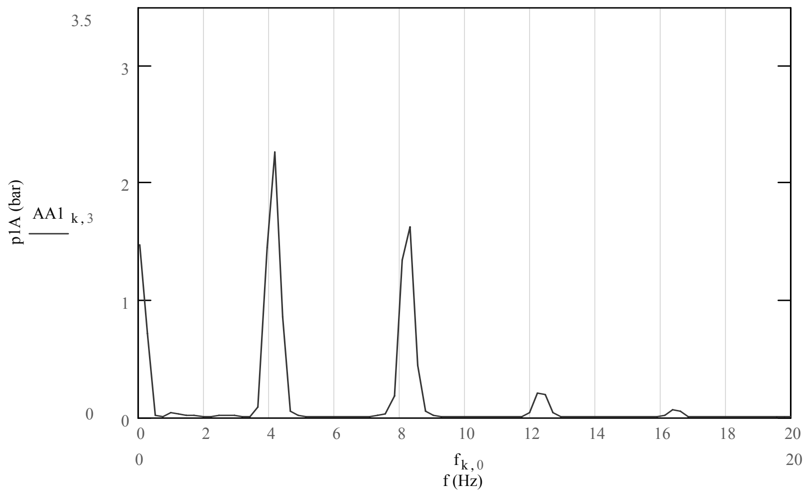

Fig. 11 Frequency spectrum of measured pressure p1 for exciting frequency f = 4.15 Hz

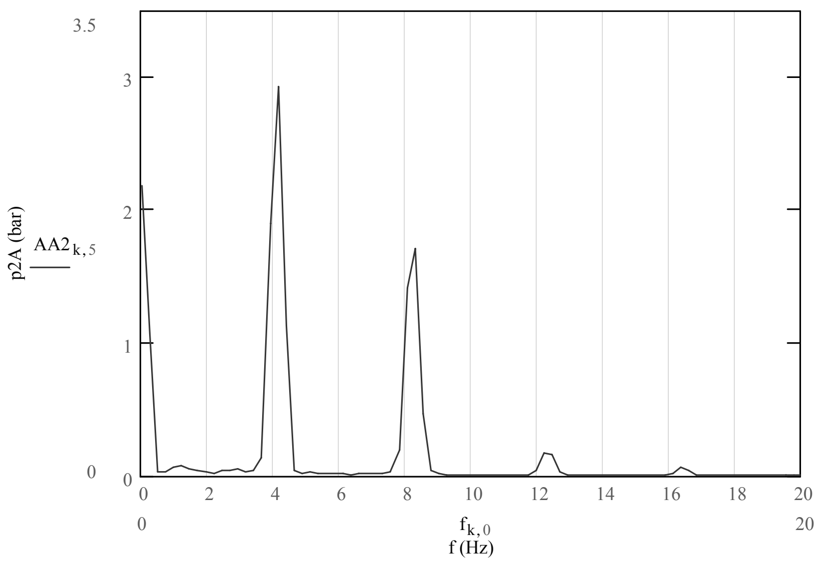

Fig. 12 Frequency spectrum of measured pressure p2 for exciting frequency f = 4.15 Hz

The frequency characteristics of pressure for the pipeline P (length L = 58.9 m) with the throttle valve were simulated numerically and evaluated experimentally. The dependences of frequency transmission Fp2p1 on frequency f are displayed in Fig. 13. Amplitude frequency characteristics of pressure were evaluated for two options. One option was pipeline TR without the accumulator and second option was with the hydraulic accumulator located 0.25 m before the outlet. [5].

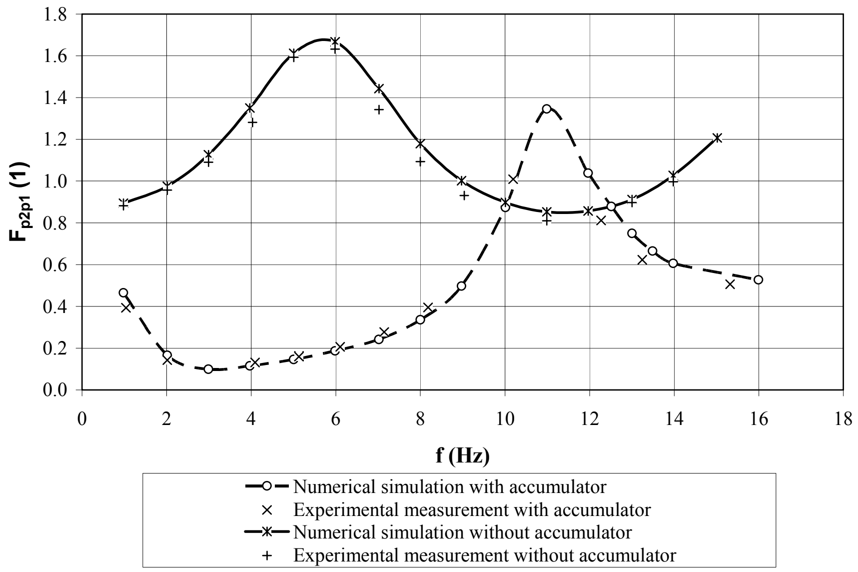

Fig. 13 Amplitude frequency characteristics of pressure for pipeline P without and with hydraulic accumulator (simulation in Matlab – SimHydraulics, experiment)

4 CONCLUSIONS

The maximum amplitude of frequency transmission for the pipeline without the hydraulic accumulator could be seen from Fig.13 around the eigenfrequency of pipeline f = 5.8 Hz. The amplitude of frequency transmission was decreased when the accumulator was connected. The eigenfrequency of the pipeline with accumulator was increased to f = 11 Hz. It is possible to see that numerically simulated values correspond to values determined in experiments. The paper was supported by project FRVŠ 2836/2006.

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