MANUSCRIPT DEVELOPING INHERENT CHARACTERISTICS OF REACTIVE PRESSURE PULSATION DAMPER

Tatiana Mironova, Andrey Prokofiev

Samara University, Power Plant Automatic Systems, Samara, Russia
email: mirtb@bk.ru

In this paper, we consider the finite element method and the analytical method of calculating inherent characteristics of reactive pressure pulsation damper. The distributed constants finite element method developed in Ansys software. The frequency depended coefficients of transfer matrix calculated with three computational experiments. In the experiments was defined the complex amplitude of pressure oscillation in three sections of hydraulic system with known dynamic characteristic. Results from Ansys were used for calculating inherent characteristic of pressure pulsation dampener. Modeling spatial extension elements of the damper in Ansys - the expansion chamber and central channel, let us take into account the distributing of constants. Than was defined the inherent characteristic of pressure pulsation damper with the analytical method. The analytical method in lumped constants based on the method of electroacoustical analogy. Analysis of two methods shows that in the low-frequency range can used analytical method but in the high-frequency range the analytical method give incorrect results because of distributed constants of spatial extension elements. In the high-frequency range necessary to use the finite element method.
Keywords: inherent characteristic, pressure pulsation dampener, finite element

1. Introduction

The problem of pulsating flow-induced pipeline vibration is relevant for the petroleum industrial equipment operation [1], conventional gas transmission [2] and power plant operation [3, 4, 5, 6, 7]. Pressure pulsation damper are much used in a hydraulic system for reducing fluid pulsation and pipeline vibration [8, 9, 10].

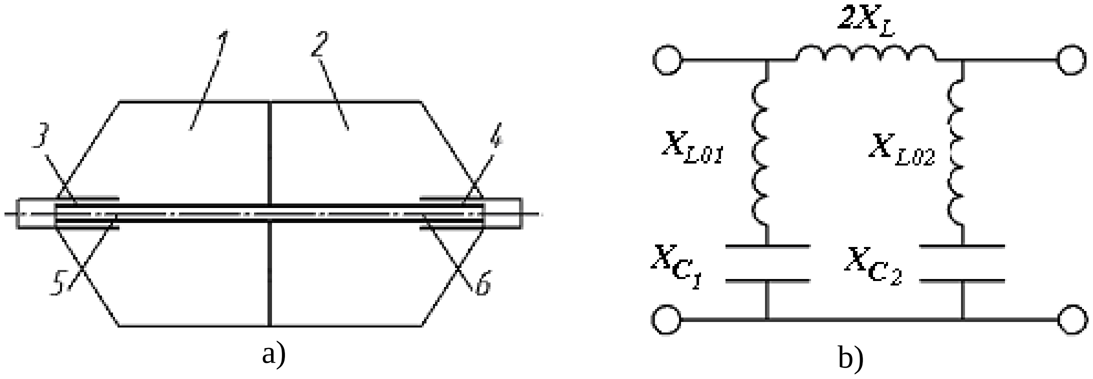
Pulsation damper have several advantages. Pulsation damper are flexible and can be fitted for nearly any type of machine or system. A pulsation damper has a relatively simple design and provides a number of important properties to a system, such as reducing the workload, increasing efficiency, and decreasing down time. This allows more work to be done and more money to be made. Pulsation dampers also serve the primary function of regulating pressure levels and reducing the number of gaps in between intake and discharge strokes.

Pressure pulsation dampers improve pump system efficiency by removing pulsating flows from positive displacement pumps, insuring a smooth and continuous fluid flow and metering accuracy, eliminating pipe vibration and protecting gaskets and seals [11, 12]. Installation of mechanic damper of the fluid flow pulsations preventing their propagation through pipeline system [13-16]. A pulsation damper is used in a piping system, generally adjacent to the source of the flow or pressure disturbance, which is typically a modulating element like a pump or a flow control valve.

The type selection of the pressure pulsation dampers depends a specific type of system. Fundamentals of calculating theory considered in the works [17, 18]. One of them is based on the three experiments for the pipeline with the known dynamic characteristics and defined the pressure oscillation complex amplitudes in three sections of the system [18]. In this paper we suggest to use the Ansys finite element model for definition the pressure oscillation complex amplitudes in three sections of the system with the damper. The results calculated with the Ansys finite element model and the analytical matrix model of electroacoustical analogy were compared. The recommendations about use of this techniques were offered [17, 19, 20].

2. Ansys model

The two cascade reactive damper was considered (Fig. 1).



1, 2– capacitance (X_{C1}, X_{C2}), 3, 4 – inductance (X_{L01} and X_{L02}), 5, 6 – inductance (X_L).
Figure 1: The acoustic a) and electrical b) models of the two-cascade reactive damper.

The first cascade of the damper consist of: X_{C1} - capacitance; X_{L01} - inductance of the resonant pipe of damper; X_L - inductance of the central channel, $X_{R1} = \infty$ - resistance. The second cascade of the damper consist of: X_{C2} - capacitance; X_{L02} - inductance of the resonator pipe of damper; X_L - inductance of the central channel, $X_{R2} = \infty$ - resistance. The damper is symmetric.

The finite element model in Ansys is shown in the Fig. 2.

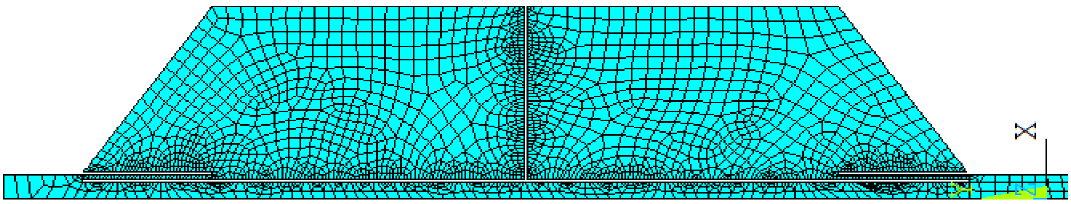


Figure 2: The Ansys finite element model.

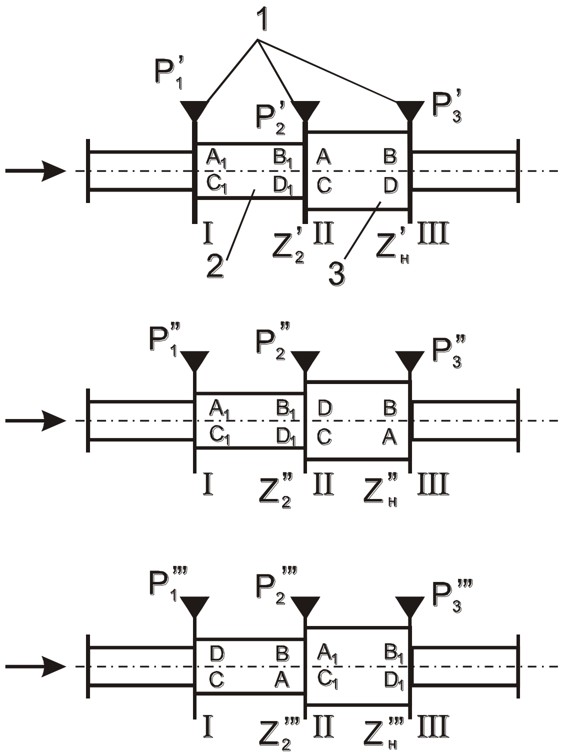
Take the damper with the following parameters. The work fluid is hydraulic oil AMG-10: fluid density ρ=870 kg/m^3; acoustical velocity c=1300 m/s. The material properties: плотность ρ=7850 kg/m^3, modulus of elasticity E=2·10^{11} Pa, Poisson ratio ν=0.2.

The parametric model in Ansys was developed. ANSYS Parametric Design Language (APDL) is used for modelling. Harmonic analysis was used.

The finite element FLUID29 is used for modeling the fluid and the interface in fluid/structure interaction. The boundary conditions are the pressure oscillation amplitude of the pipeline inlet section and the fluid oscillation frequency.

The three numerical models are used for calculation the frequency dependent coefficients of the transfer matrix of damper $A(\omega)$, $B(\omega)$, $C(\omega)$, $D(\omega)$ (Fig.3) [17, 18].

A_1, B_1, C_1, D_1 – sections parameters of the known dynamic characteristics A, B, C, D – sections parameters of the unknown dynamic characteristics.



1 –sections of unknown dynamic characteristics; 2 – sections of known dynamic characteristics; 3 – damper.
Figure 3: Diagram of developing inherent characteristics of the damper.

The frequency dependent coefficients of the transfer matrix of damper *A(ω), B(ω), C(ω), D(ω)* can be calculated:

$$A = \frac{P_2'}{P_3'};B = \frac{P_1''' - A_x P_2'''}{C_1 P_3'''};C = \frac{P_1' - A_1 P_2'}{B_1 P_3'};C = \frac{P_1'' - A_1 P_2''}{B_1 P_3''};D = \frac{P_2''}{P_3''}.. \qquad (1)$$

The calculation results in Ansys are presented in Figs. 4.

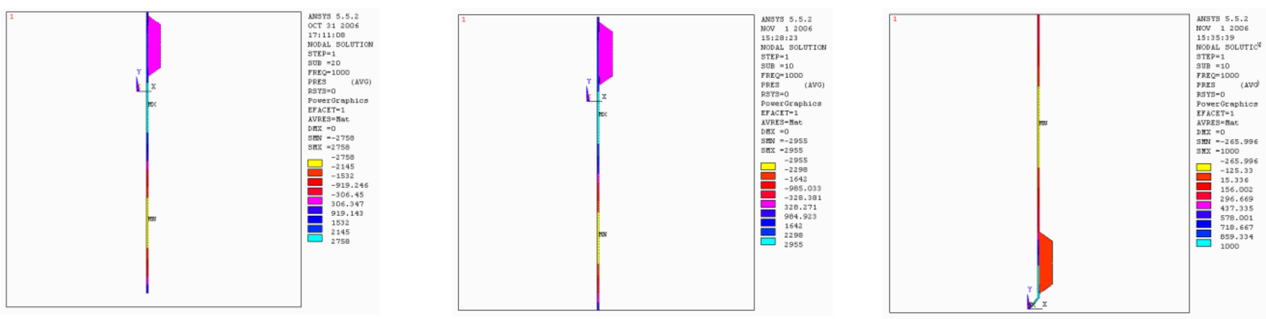


Figure 4: The calculation results of pressure pulsation in the hydraulic system with the damper.

Then, the calculating coefficients *A(ω), B(ω), C(ω), D(ω)* was substituted in the equations for inherent characteristics of damper

$$Z_{c1} = \sqrt{\frac{A(\omega)\cdot B(\omega)}{C(\omega)\cdot D(\omega)}},$$

$$Z_{c2} = \sqrt{\frac{B(\omega)\cdot D(\omega)}{A(\omega)\cdot C(\omega)}}, \qquad . \qquad (2)$$

$$K_c = \left|\sqrt{A(\omega)\cdot D(\omega)} + \sqrt{B(\omega)\cdot C(\omega)}\right|.$$

The inherent characteristics of damper calculating with Ansys model are shown in Fig. 4.

2.1 Analytical model of the damper in the lumped constants

The next stage is define the frequency dependent coefficients of the transfer matrix of damper by the analytical model based on the electroacoustic analogy in the lumped constants: $l << \lambda$, where l - maximum geometrical size of the damper elements, λ - acoustic wave length.

In electroacoustical analogy, we may write [17-20]

$$X_L = \begin{bmatrix} 1 & j\omega L \\ 0 & 1 \end{bmatrix};\ X_C = \begin{bmatrix} 1 & 0 \\ j\omega C & 1 \end{bmatrix};\ X_R = \begin{bmatrix} 1 & R \\ 0 & 1 \end{bmatrix}. \quad (3)$$

After mathematical manipulation we can write equations for the inherent characteristics of damper: input wave impedance Z_{C1}, output wave impedance Z_{C2}, attenuation coefficient K_C:

$$\begin{gathered} Z_{C1} = Z_{C2} = (1-\omega^2 L_{01} C)\sqrt{\frac{L}{C(1-\omega^2 C(L_{01}+L))}} \\ K_C = \left| 1 - \frac{2\omega^2 LC}{1-\omega^2 L_{01} C} + 2j\omega\sqrt{\frac{LC}{1-\omega^2 L_{01} C}\left(1-\frac{\omega^2 LC}{1-\omega^2 L_{01} C}\right)} \right|. \end{gathered} \quad (4)$$

The calculation results are shown in Fig. 5.

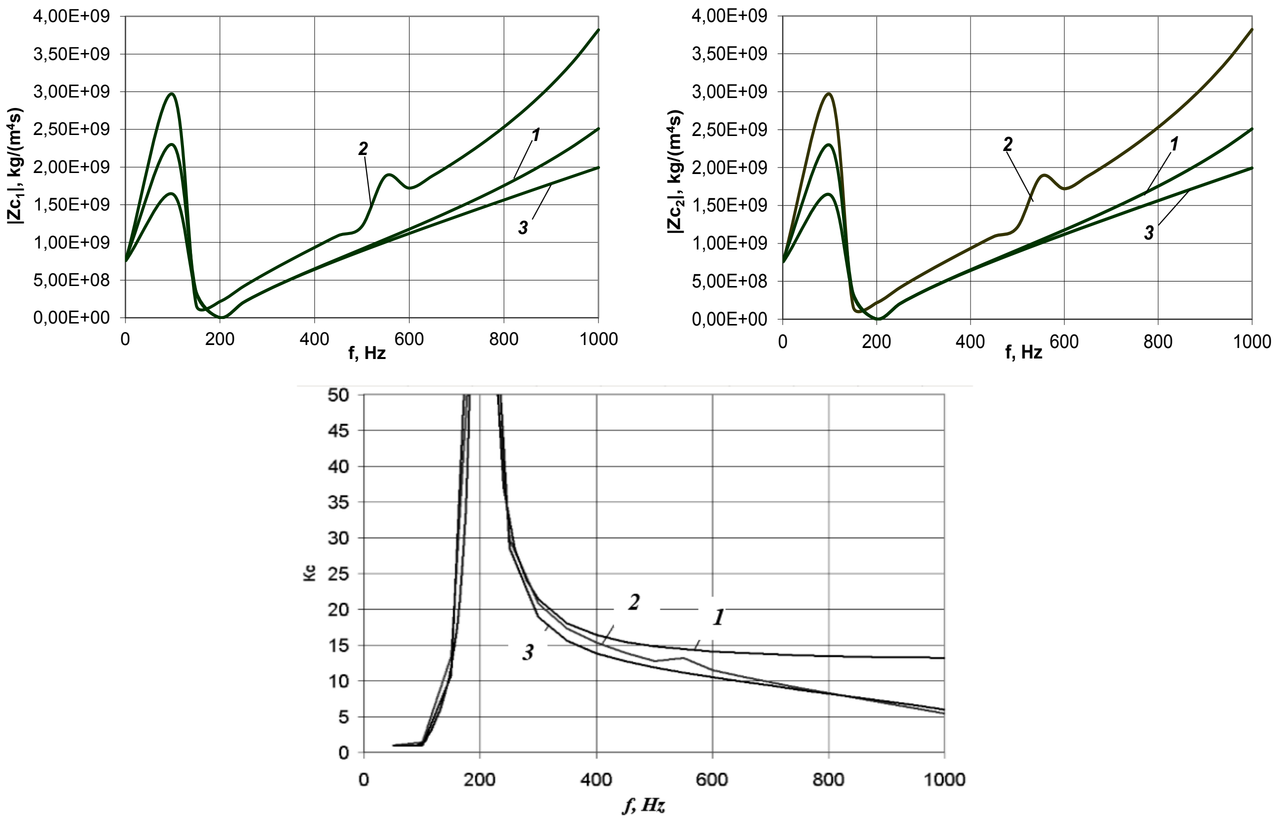


Figure 5: The inherent characteristics of damper: 1 - analytical model in the lumped constants; 2 - Ansys model; 3 - analytical model in the distributed constants.

The results, calculating with the analytical model in the lumped constants and the Ansys model, coincide on the low frequencies. Divergence of the curves on the high frequencies can explain ignoring distributed constants in the analytical model.

2.2 Analytical model of damper in the distributed constants

The pressure pulsation pamper has two element with the distributed constants: central channel and expansion chamber. Including the matrix of the central channel in the distributed constants

$$x_L = \begin{bmatrix} ch\,\frac{j\omega l}{a} & \frac{\rho a}{\pi r_1^2} sh\,\frac{j\omega l}{a} \\ \frac{\pi r_1^2}{\rho a} sh\,\frac{j\omega l}{a} & ch\,\frac{j\omega l}{a} \end{bmatrix}, \quad (5)$$

instead of the matrix X_L in the Eq. 4, can be written matrix of the damper take into account distributed constants of the central channel

$$x = \begin{bmatrix} A & B \\ C & D \end{bmatrix}, \quad (5)$$

where $A = D = 2(\frac{j\omega C}{1-\omega^2 L_{01} C}\frac{\rho a}{\pi r_1^2} sh\,\frac{j\omega l}{a} ch\,\frac{j\omega l}{a}) + 2(ch\,\frac{j\omega l}{a})^2 - 1$; $B = 2(ch\,\frac{j\omega l}{a})\left(\frac{\rho a}{\pi r_1^2} sh\,\frac{j\omega l}{a}\right)$;

$$C = 2\left(\begin{array}{l} \left(\frac{j\omega C}{1-\omega^2 L_{01} C}\right)^2 \cdot \frac{\rho a}{\pi r_1^2} \cdot sh\,\frac{j\omega l}{a} \cdot ch\,\frac{j\omega l}{a} + 2 \cdot \frac{j\omega C}{1-\omega^2 L_{01} C} \cdot \left(ch\,\frac{j\omega l}{a}\right)^2 + \\ + \frac{\pi r_1^2}{\rho a} \cdot \frac{\left(ch\,\frac{j\omega l}{a}\right)^3}{sh\,\frac{j\omega l}{a}} - \frac{j\omega C}{1-\omega^2 L_{01} C} - \frac{\pi r_1^2}{\rho a} \cdot \frac{ch\,\frac{j\omega l}{a}}{sh\,\frac{j\omega l}{a}} \end{array}\right).$$

The calculation results of the analytical model in the distributed constants are shown in Fig. 5.

The calculation results of the Ansys model differ from the calculation results of the analytical models. It can explain of the distributed constants of the expansion chamber. The expansion chamber diameter and length have the same order of magnitude. But the analytical modelling of the acoustic characteristics of an expansion chamber as the two-dimensional object is so hard.

The matrix equation expansion chamber in the lumped constants

$$\begin{bmatrix} P_{вх} \\ Q_{вх} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{j\omega V_{пр}}{\rho a^2} & 1 \end{bmatrix} \begin{bmatrix} P_{вых} \\ Q_{вых} \end{bmatrix}. \quad (6)$$

According to Eq. 6 the pressure pulsation amplitude in the all points of chamber the same. But the wave interference and reflecting wave from the walls are the reason that the expansion chamber is not the ideal hydraulic capacitance.

In the Fig. 5 are shown the amplitude distribution in the expansion chamber of the damper in the axial direction and in the cross direction, where $p = f(l)$, $p = \frac{p}{p_{max}}$, l - linear size.

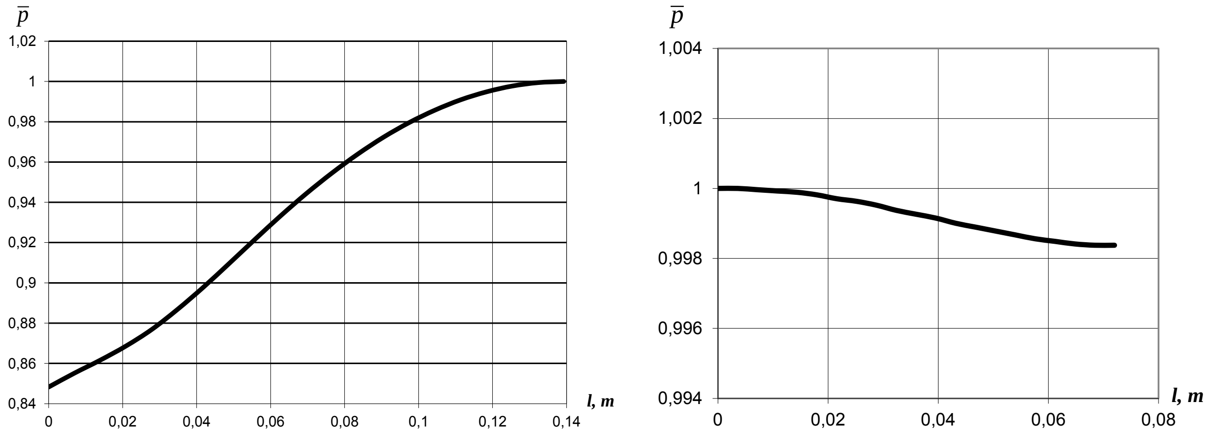


Figure 5: The amplitude distribution in the expansion chamber of the damper in the axial direction a) and in the cross direction b) on the frequency 1000 Hz

The parameters distribution in the cross direction is not large and it can be neglected. In the axial direction can see the considerable parameters distribution. This is the case of the difference in the results of calculation between the analytical and numerical models.

Conclusion

In this paper, we consider the Ansys finite element method and the analytical method of calculating inherent characteristics of the reactive pressure pulsation damper. The analysis of two methods shows that in the low-frequency range $\frac{l}{\lambda} \leq 0.1$ can used the analytical method. It let simple analyse inherent characteristics of damper depends of the elements construction and optimize the damper structure.

But in the high-frequency range the analytical method give incorrect results because of the distributed constants of spatial extension elements. In the high-frequency range necessary to use the finite element method.

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