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Use of dynamic damper in hydromechanics

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1. Introduction

The transmission of energy from active fluid elements in the hydraulic systems leads to pressure and flow pulsations. If the excitation frequency coincides with natural fluid frequency of the system, resonance occurs similar to the mechanical systems, which can reduce the system life, affect the control and monitoring elements, increase the noise and possibility system crashes.This study explores the possibilities of using a dynamic damper to suppress pulsations and stabilize the system.

2. Computation of pulsation in tube

Continuity and equilibrium equations for flexible tube were used to calculate pressure and flow pulsations [2]

$$\frac{\partial \mathbf{w}}{\partial t} + \mathbf{B}\mathbf{w} + \mathbf{K}\frac{\partial \mathbf{w}}{\partial \mathrm{x}} = 0\,, \tag{1}$$

$$\mathbf{B} = \begin{bmatrix} \frac{b}{\rho} & 0 \\ 0 & 0 \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} 0 & \frac{S}{\rho} \\ \frac{K}{S} & 0 \end{bmatrix}, \quad \mathbf{w} = \begin{bmatrix} q \\ \sigma \end{bmatrix}.$$

Eq. (1) is solved by transfer matrices method in state space using Laplace transformation, where ρ – the fluid density, b – the fluid internal attenuation, K – the bulk modulus elasticity, S – the flow cross-section area, q – the unsteady flow and σ – the unsteady pressure.

The finite difference method is used to find eigenvalues [1, 3]. Label $\Delta(s)$ the function of a complex variable and whose zero values are the searched eigenvalues. Let the field O of complex numbers $s = a + i\omega$ be given in the Gaussian plane. If every s is assigned to exactly one complex number $\Delta(s)$, we can say that in O the function of two variables α, ω is defined as

$$\Delta(s) = u(\alpha, \omega) + i\, v(\alpha, \omega), \qquad u, v \in \mathbb{R}. \tag{2}$$

This function is based on relation $\Delta(s) = det(\mathbf{A} + \lambda\mathbf{E})$, where $\mathbf{A}$ is the system's transfer matrix and $\mathbf{E}$ is the identity matrix.

The theory of the function of complex variable states that the real and imaginary part $u(\alpha, \omega)$, $v(\alpha, \omega)$ of each holomorphic function is a harmonic function and therefore satisfies the Laplace equation (3) for boundary conditions (4)

$$\frac{\partial^2 u}{\partial \alpha^2} + \frac{\partial^2 u}{\partial \omega^2} = 0 \;\wedge\; \frac{\partial^2 v}{\partial \alpha^2} + \frac{\partial^2 v}{\partial \omega^2} = 0 \qquad \forall \alpha, \omega \in O, \tag{3}$$

$$u(\alpha, \omega) = u_\Gamma \quad \forall \alpha, \omega \in \Gamma. \tag{4}$$
$$v(\alpha, \omega) = v_\Gamma$$

The result is determined by the set of points obtained by solving the Laplace equation, for which $u = 0$, $v = 0$. In the geometric representation, the solution is a surface (see Fig. 1) that creates the isocurves at the point where it intersects the plane $u = 0$ or $v = 0$. The roots s_k are located at the intersections of these isocurves (see Fig. 2).

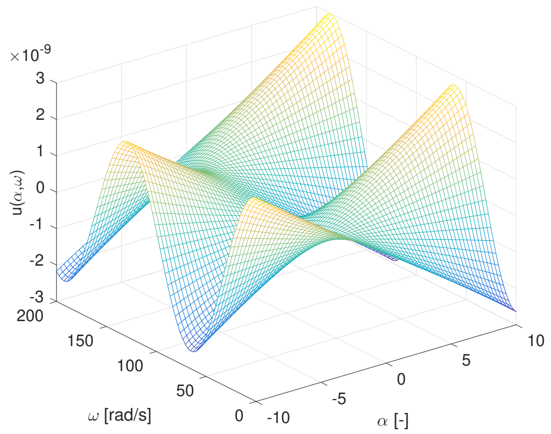


Fig. 1. Example of surface $u(\alpha, \omega)$

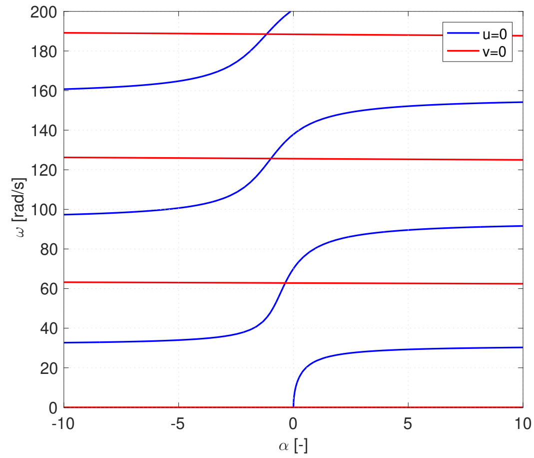


Fig. 2. Plot of isocurves

3. 1–D hydrodynamic system with dynamic damper

The influence of the damper on pressure and flow pulsations is assessed on a one-dimensional system consisting of a pulsator, two local resistors and the dynamic damper (see Fig. 3) with parameters listed in Table 1. Dynamic instability is created by a negative value of dynamic resistance b_1. The location of the damper affects its function in the system (see Fig. 4).

Table 1. Input parameters

branch length	L	50	[m]
tube diameter	ϕd	80	[mm]
speed of sound in fluid	a	1000	[m s^{-1}]
fluid density	ρ	1000	[kg m^{-3}]
fluid internal attenuation	b	12.8	[kg s^{-1} m^{-3}]
flow amplitude	Q_0	0.01	[m^3 s^{-1}]
excitation frequency	ω	63	[m^3 s^{-1}]

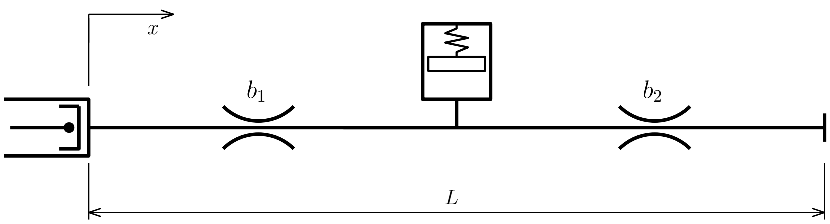
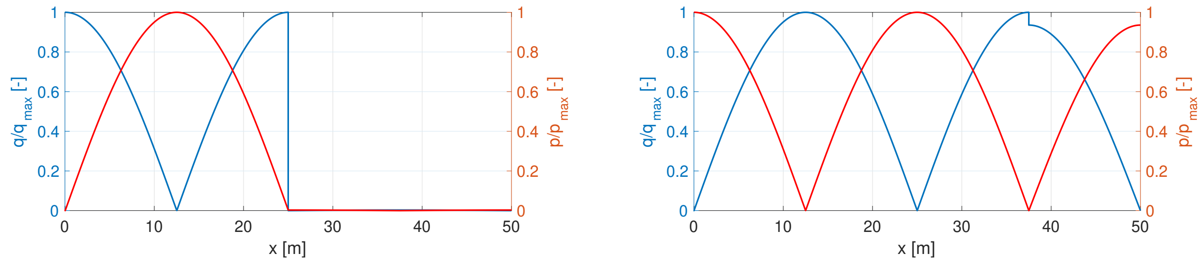


Fig. 3. Scheme of hydrodynamic system



(a) (b)

Fig. 4. Modes of 2nd eigenfrequency if damper is placed in: (a) flow node, (b) pressure node

System's boundary conditions are $q(0,t) = Q_0 \cdot \cos(\omega t)$ and $q(L,t) = 0$. Local resistance values are $b_1(x = 1\,\mathrm{m}) = -9.8 \times 10^8$ and $b_2(x = 40\,\mathrm{m}) = 9.0 \times 10^6$. The 1-DOF dynamic damper is described by mass m and stiffness k. Its natural frequency and location have impact on system stability (see Figs. 5 and 6).

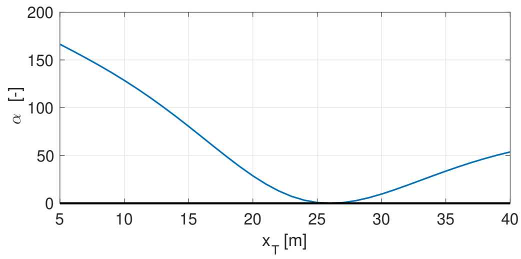


Fig. 5. α – damper location dependence

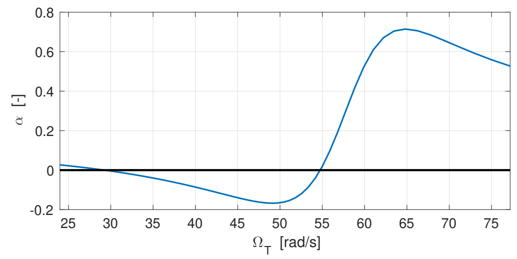
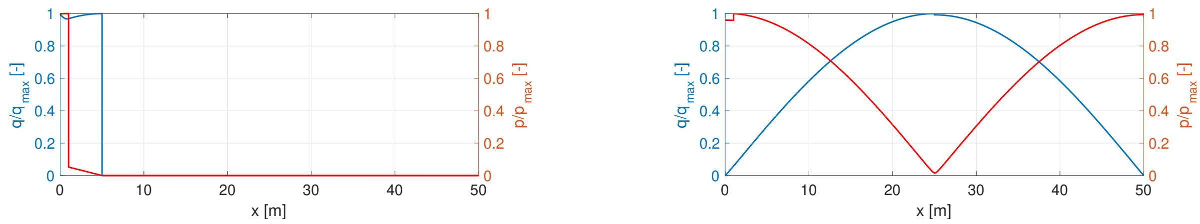


Fig. 6. α – damper eigenfrequency dependence

In order to dampen the system, it is advisable to place the damper at the point of the flow node. If the dynamic stability problem is examined, it is advisable to place the damper in the pressure node position. However, the damper does not perform the damping function at this point (see Fig. 7). The influence of the dynamic damper on the stability of the system can be best seen from the plot of the time response to the excitation of the resonant frequency (see Fig. 8). All results have been published in [4].



(a) (b)

Fig. 7. Eigenmodes the damper is located: (a) close to the flow node ($x = 5$ m), (b) in the pressure node ($x = 25$ m)

4. Conclusion

In this study, the possibility of use of the dynamic damper to stabilize the dynamic system was investigated. The aim was to use a mathematical model describing dynamic behaviour in a

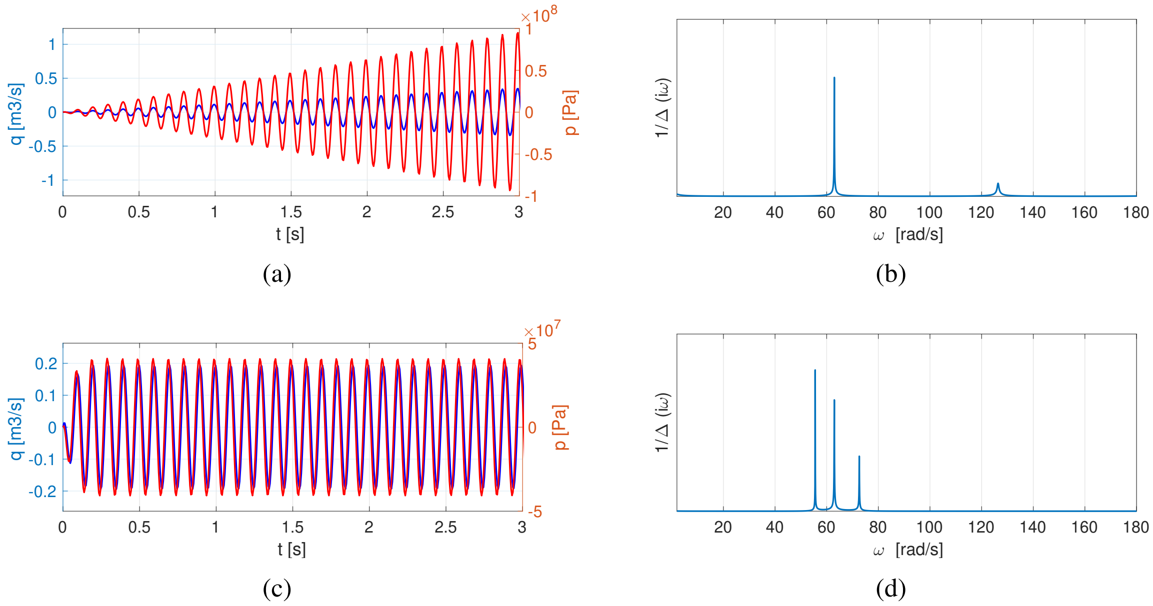


Fig. 8. Response to excitation in resonance (a) without damper and (c) with damper; and dynamic amplification of system (b) without damper and (d) with damper

flexible tube to solve a system with the dynamic damper. Using this model it was possible to assess the impact of the damper on the system.

It has been found that the damper can be used to stabilize the dynamic system. It depends on the damper tuning and its location in the tube. The damper should be placed in the node location of pressure eigenmode of given resonant frequency. In this case, the damper does not perform the damping function of the system.

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