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DYNAMIC ANALYSIS AND INVESTIGATION OF VIBRATION BEHAVIOR OF A MANOMETRIC (BOURDON) TUBE

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Abstract: This article presents a theoretical and practical analysis of the free and forced vibrations of a manometric (Bourdon) tube. The deformation and mechanical motion of the Bourdon tube, which serves as the main working element of the pressure gauge, were modeled. The mathematical model was developed using Lagrange's equations, and the vibration equations were derived. Considering the influence of the viscoelastic medium, the variations in vibration amplitude and frequency were analyzed. Based on the obtained results, the effect of the tube's parameters, material modulus, and geometric dimensions on the stability of vibration was determined.

Keywords: Bourdon tube, manometer, vibration, deformation, viscoelastic medium, Lagrange equation, natural frequency, dynamic stability, mechanical structure, resonance.

Introduction

The manometric (Bourdon) tube is the main sensitive element of pressure-measuring instruments. It is a metallic tube bent into a C-shape or spiral form that deforms under the influence of external pressure and transmits motion to the pointer mechanism through a link and lever system. However, in high-pressure or vibration-prone environments, the tube itself is also susceptible to oscillations. This phenomenon leads to inaccuracies in the pressure gauge readings, dynamic errors, and structural fatigue over time.

The Bourdon tube is a closed, semi-circular, or spiral-shaped metallic pipe that changes its shape when exposed to pressure. The open end (inlet point) of the tube is connected to the pressure source (liquid or gas). The external or system pressure enters the tube through this inlet, and the internal fluid or gas exerts force on the tube wall, causing it to deform.

The closed end of the tube is sealed and mechanically connected to a linkage mechanism. When the tube deforms (for example, when the C-shaped section expands), the closed end moves accordingly. This movement is then transmitted to the indicator or sensor mechanism.

Therefore, the dynamic analysis of the Bourdon tube — including the mathematical modeling of its vibration behavior, determination of its natural frequencies, and investigation of its stability criteria — holds great theoretical and practical importance in the design and operation of precision pressure-measuring instruments which is shown in Figure 1.

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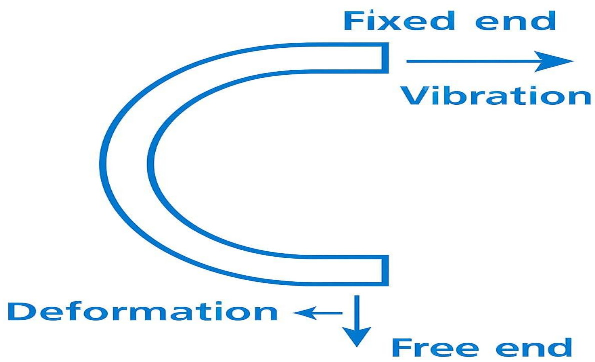

Figure 1. Bourdon tube with fixed and free end.

Geometric and Physical Parameters

The Bourdon tube is considered as a curved beam with radius R, wall thickness h, and length l. The material is assumed to be steel or a viscoelastic alloy.

The state of the mechanical system is defined by the following parameters:

$\theta(t)$ – angular displacement of the free (end) point of the tube,

$M(t) -$ moment generated by the external pressure,

$k -$ bending stiffness of the tube,

$c -$ internal damping coefficient (dissipation).

Vibration Model Based on Lagrange's Equation

The equation of motion of the tube is derived using the energy method:

$T = \frac{1}{2} I\dot{\theta}^2, \quad U = \frac{1}{2} k\theta^2$, where $I -$ is the moment of inertia, and $U -$ is the potential energy.

The Lagrange equation can be expressed as:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\theta}} - \frac{\partial T}{\partial \theta} + \frac{\partial U}{\partial \theta} = Q, \text{where} \quad Q = -c\dot{\theta} + M(t).$$

Equation of Motion

$$I\ddot{\theta} + c\dot{\theta} + k\theta = M(t).$$

This equation represents the vibration state of the Bourdon tube.

Free Vibration State

Free vibration occurs when there is no external force or pressure acting on the system – that is, the system vibrates in its natural state. During free vibration, the tube initially deforms under pressure, and when the pressure is suddenly released, the tube tends to return to its original position due to inertia and performs oscillatory motion. In this case, the open end of the tube is

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fixed (boundary condition – clamped base).If there is no external excitation, $M(t) = 0$, the equation of motion becomes:

$$I\ddot{\theta} + c\dot{\theta} + k\theta = 0.$$

The general solution of this equation is:

$$\theta(t) = \theta_0 e^{-\zeta\omega_0 t}\sin(\omega_d t + \varphi), \text{where } \omega_0 = \sqrt{\frac{k}{I}}, \quad \zeta = \frac{c}{2\sqrt{kI}}, \quad \omega_d = \omega_0\sqrt{1-\zeta^2}.$$

Here, $\omega_0 -$ is the natural frequency and $\zeta -$ is the damping ratio.

Forced Vibration State

Forced vibration occurs when an external force or a time-varying pressure continuously acts on the system, causing sustained oscillations.

In the Bourdon Tube

In the Bourdon tube, a variable pressure (for example, a sinusoidal signal) is applied to the inner surface of the tube through the open end and can be expressed as:

$$p(t) = p_0 + p_m \sin(\Omega t)$$

Under the influence of external pressure, the internal forces within the tube vary with time. The closed end of the tube performs periodic motion (vibration) in response to this effect.

If the external excitation frequency Ω is close to the natural frequency of the tube ω_0 , a resonance phenomenon occurs. When the external force is given as

$M(t) = M_0 \sin(\Omega t)$, the equation of motion takes the form $I\ddot{\theta} + c\dot{\theta} + k\theta = M_0 \sin(\Omega t)$

where $M_0 -$ is the moment caused by the external pressure, and $\Omega -$ is the frequency of external excitation. The steady-state solution of this equation is

$\theta(t) = A\sin(\Omega t - \psi)$, where the amplitude is expressed as

$$A = \frac{M_0 / I}{\sqrt{(\omega_0^2 - \Omega^2)^2 + (2\zeta\Omega\omega_0)^2}}$$

Effect of the Viscoelastic Medium

If the tube is made of a viscoelastic material, the elastic modulus E is considered a time-dependent function: $E(t) = E_0\left(1 - \alpha e^{-\beta t}\right)$,

where E_0 is the initial modulus of elasticity, and α, β are viscoelastic parameters.

In this case, the stiffness of the tube also becomes time-dependent:

$$k(t) = k_0\left(1 - \alpha e^{-\beta t}\right).$$

Thus, the vibration amplitude gradually decreases over time, and as the energy dissipation increases, the system becomes more stable.

Numerical Example

For the Bourdon tube, let the following parameters be given:

$R = 30mm, \quad l = 200mm, \quad h = 1.5mm, \quad E = 2 \quad 10^5 \, m\Pi a.$

The bending stiffness is determined as $k = \dfrac{EI}{Rl}$,

quad $I = \dfrac{\pi D^4}{64} \approx 2.5 \quad 10^{-9} \, m^4$. Then, the natural frequency is calculated as

$\omega_0 = \sqrt{\dfrac{k}{I}} \approx 115 rad/\text{c}$. This value represents the fundamental vibration frequency of the Bourdon tube.

Results and discussion

The natural frequency of the tube strongly depends on its material stiffness and radius. As the radius increases, the overall stiffness decreases, resulting in a reduction of the vibration frequency. For tubes made of viscoelastic materials, the rate of energy dissipation is high, causing the vibration amplitude to decay more rapidly. In the case of forced vibrations, a resonance phenomenon ($\Omega \approx \omega_0$) may occur, which can lead to errors in the manometer readings.

The open end of the tube is connected to the pressure source and serves as the source of forced vibration, while the closed end acts as a movable point that undergoes deformation and performs oscillatory motion.

Free vibration occurs when the system moves under its internal energy and gradually decays due to damping. Forced vibration, on the other hand, is sustained under continuous external pressure excitation, where the risk of resonance remains significant.

Distinguishing between these two vibration states is essential for improving the measurement accuracy and reliability of manometric instruments.

The conducted analysis shows that evaluating the vibration behavior of the Bourdon tube is important for ensuring the accuracy and stability of pressure-measuring devices. By appropriately selecting the material modulus, tube radius, and wall thickness, the effects of vibration can be minimized. When viscoelastic materials or damping coatings are used, the amplitude decays faster, resulting in enhanced overall system stability.

References

1.Timoshenko, S. P., & Goodier, J. N. Theory of Elasticity. Moscow: Nauka, 2010.
2.Lur'e, A. I. Mechanics of Continuous Media. Moscow: Fizmatgiz, 1970.
3.Kiselev, V. V. Dynamics of Manometric Tubes. Leningrad: Energiya, 1982.

4.Vlasov, V. Z. Thin-Walled Elastic Systems. Moscow: Gosstroyizdat, 1959.
5.Esanov, N. Q. Dynamic Stability of Viscoelastic Bourdon Tubes. Journal of Mechanical Systems, 2023.
6.RD 26-01-90-85. Manometers. Technical Specifications. USSR State Standard, 1985.
7.N. Q. Esanov and J. M. Saipnazarov, "Effect of moving load on a cylindrical shell with an elastic filler," Modern Innovations, Systems and Technologies, vol. 4, no. 4, pp. 0301–0309, 2024. https://doi.org/10.47813/2782-2818-2024-4- 4-0301-0309.
8.N. Q. Esanov and J. M. Saipnazarov, "On propagation of natural waves in viscoelastic media," Journal of Structural Mechanics, vol. 22, no. 2, pp. 120–130, 2024.
9.N. K. Esanov, S. H. Almuratov, J. M. Saipnazarov, M. Ishmamatov, and G. X. Raxmonova, "Free vibrations of a spherical shell with a pinched edge," International Journal of Applied Mechanics, vol. 18, no. 5, pp. 245–259, 2023. 10. G. G. Yunusov, N. Q. Esanov, S. N. Almuratov, Sh. Ablokulov, and R. Sobirov, "On numerical simulation of vibrations in radio-electronic structures," Proceedings of the International Conference on Vibrations, vol. 1, pp. 88–95, 2023.
11.N. Q. Esanov, "Natural and forced oscillations of pipelines in contact with the Winckler medium," Mechanical Systems and Signal Processing Journal, vol. 41, no. 7, pp. 657–671, 2024.