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THE DYNAMICAL BEHAVIOR OF Y-SHAPED TUBES CONVEYING FLUID

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Abstract

The present work deals with the vibrational characteristics of a Y-shaped tube conveying flowing fluid. The tube is considered to be composed of 3-stright tube segments mathed at the intermediate junction. The governing equation of straight tube conveying fluid is used with each of the three segments. This work introduce the clamped-pinned and clamped free boundary conditions. The coupled effects of the type of boundary conditions, angle between the two Y-segments, fluid velocity and length ratio of segments on the dynamics of the tube are studied. It seen that the Y-tube loses its stability at flow velocity higher than that for straight tube of the same characteristics.

1-Introduction:

One of the main usages of tubes is to convey fluid such as fuel lines, heat exchangers and transportation of different types of fluids. The analysis of tubes conveying fluid has an important theoretical application to prevent these tubes from failure. Sometimes the importance of modeling tubes conveying fluid because these system suffer from instability due to self excitation.

The problem was studied since the 1950 when Ashly and Haviland [1] attempted to describe the vibration in the Trans Arabia pipelines. Housner [2] was corrected the governing equation which was derived by Ashly [1]. Long [3] was the first who studied the vibration and stability problems of simply supported pipes as well as cantilever pipes. The effect of fluid pressure on the vibration of pipes was studied by Heinrich [4] and Chang & Shia [5]. They derived the equation of motion of pipe including the effect of fluid pressure. Benjamin, Gregory and Paidoussis [6] studied the problem of articulated cantilever tubes conveying fluid. They concluded that a cantilever pipe loses its stability by flutter at a certain flow velocity.

Paidoussis and Laithier [7] and Huang [8] carried out two separate investigations to study the effect of rotary inertia and shear deformation on the vibration characteristics of straight tube conveying fluid. They concluded that these forces tend to reduce the natural frequencies with insignificant effect of the pipe length and thickness.

The in-plane and out-of plane vibrations of an intermediately supported U- Bend tubes conveying fluid was studied by Lee [9]. He concluded that the out-of plane natural frequencies depend on the material properties and the shape of the cross section. An exact analysis for the free vibration of U-Bend tubes with multi intermediate supports was investigated by Gorman [10]. He investigate in detail all of the required interface boundary conditions for tube possess and that which do not possess geometric symmetry.

Al-Jumaily and Ismaeel [11] studied the effect of improper intermediate support mispositioning on the vibrations and stability of multispan pipe. They concluded that sever vibrations as well as instability might occur if not significant attention is focused on the position of the intermediate support.

Al-Rajihy [12] studied the coupled effect of improper intermediate support positioning and the thermal gradient on the dynamical behavior of a continuous multispan pipe convey fluid. He concluded that the pipes becomes unstable when the thermal force reachs a critical value.

Al-Maaitah and Kardsheh [13] investigated the out-of plane vibration of a Y-shaped tube conveying fluid with clamped ends condition. They investigate the effect of branching angle and geometrical configuration on the natural frequency and mode shape. He concludes that increasing the flow velocity results in decreasing the natural frequencies for the first three modes.

In this paper other types of boundary conditions such as simply-simply, clamped-simply are investigated.

2-Governing Equation:

To derive the governing equation of the tube, the following assumptions are considered:

1-The effect of gravity is neglected.
2-The tube is inextensible.
3-Small motions.
4-Small scale details of flow are neglected.

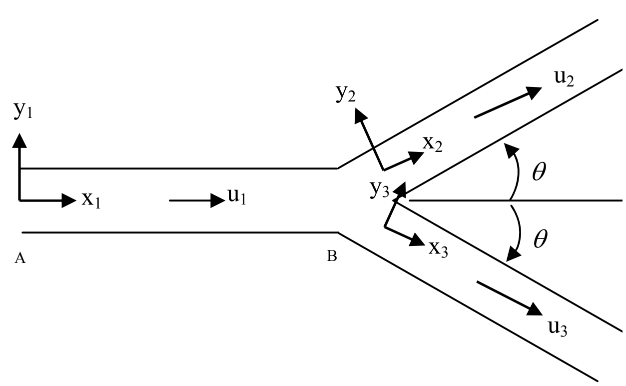

Fig. (1) : Coordinates system of the Y-shaped tube

As illustrated in Fig. (1), the tube system composed of three straight tube segments matched at the junction (point

B). Three coordinate systems are taken coinciding with each of the three segments. The coordinate of the main segment is taken as $y_1(x_1,t)$ while the other two branches are assumed to be symmetric and take the coordinates of $y_{2,3}(x_{2,3},t)$. The motion of the tube system is assumed to be out-of-plane of the tube system.

The equation of motion of a straight tube conveying fluid in a dimensionless form is [2, 6, & 7]:

$$\frac{\partial 4\mu_k}{\partial \eta_k^4} + \nu^2 \frac{\partial 2\mu_k}{\partial \eta_k^2} + 2\beta_k^{1/2}\nu \frac{\partial 2\mu_k}{\partial \eta_k \partial \tau} + \frac{\partial 2\mu_k}{\partial \tau^2} = 0 \qquad (1)$$

The dimensionless parameters are defined as:

$$\mu_k = y_k/L \quad , \quad \eta = x_k/L \quad , \beta = \frac{m_f}{m_t + m_f}, \quad \nu_k = \left(\frac{m_f}{EI_k}\right)^{1/2} Lu_k$$

$$, \quad \tau = \left(\frac{EI_k}{m_t + m_f}\right)^{1/2} \frac{t}{L^2} \quad , \quad (RL)_1 = \frac{\lambda_1}{L}, \quad (RL)_2 = \frac{\lambda_2}{L},$$

$$L = \lambda_1 + \lambda_2, \ (RL)_1 + (RL)_2 = 1 \qquad (2)$$

Equation (1) is a partial differential equation can be solved as:

$$\mu_k(\eta_k, \tau) = \mathrm{Re}\left(\Psi_k(\eta_k) e^{i\Omega\tau}\right) \qquad (3)$$

Where, $i = \sqrt{-1}$, Ω is the nondimensional frequency related to the circular frequency of motion (ω) by;

$$\Omega = \left(\frac{m_t + m_f}{EI}\right)^{1/2} L^2 \omega \qquad (4)$$

Substitute Eq. (4) into Eq. (1) gives the following ordinary differential equation;

$$\frac{d4\psi_k}{d\eta_k^4} + \nu_k{}^2 \frac{d2\psi_k}{d\eta_k^2} + i\nu_k \Omega \beta_k^{1/2} \frac{d\psi_k}{d\mu_k} - \Omega^2 \psi_k = 0 \qquad (5)$$

Equation (5) represents three 4th-order differential equations governing the motion of each segment of the Y-shaped tube. The solutions of Eq. (5) are;

$$\psi_k = \sum_{n=1}^{4} C_{k,n} e^{i\lambda_{k,n}} \qquad (6)$$

Substitute Eqs. (6) into Eq. (5) results in the following characteristic equations;

$$\lambda_{k,n}^4 - \nu_k^2 \lambda_{k,n}^2 - 2\beta^{1/2} \nu_k \Omega \lambda_{k,n} - \Omega^2 = 0 \qquad (7)$$

Where, k: represent the index of each branch segment, n: number of roots of the characteristic equation (7).

3-Boundary Conditions:

The more practical boundary conditions are the clamped-clamped, clamped-free, and clamped-hinged. In this work only the clamped-hinged and clamped-free boundary conditions will be investigated because the clamped-clamped were studied by [13].

I- for clamped-hinged;

a- at the clamped end (point A);

$$\begin{aligned} &\psi_k(0,\tau) = 0 \\ &\frac{\partial \psi_1}{\partial \eta_1}(0,\tau) = 0 \end{aligned} \qquad (8)$$

b- at the junction between the three segments (point B), the following conditions are imposed to fulfill the requirements of continuity of displacement, slope, bending moment, and shear force respectively;

$$\begin{aligned} &\psi_1(l_1,\tau) = \psi_{2,3}(0,\tau) \\ &\psi_1^{/}(l_1,\tau) = \psi_{2,3}^{/}(0,\tau) \\ &\psi_1^{//}(l_1,\tau) = \psi_{2,3}^{//}(0,\tau) \\ &\psi_1^{///}(l_1,\tau) = \psi_{2,3}^{///}(0,\tau) \end{aligned} \qquad (9)$$

c- at the hinged end (points D&E);

$$\begin{aligned} &\psi_{2,3}(l_{2,3},\tau) = 0 \\ &\psi_{2,3}^{//}(l_{2,3},\tau) = 0 \end{aligned} \qquad (10)$$

II- for clamped-free end;

The free end can be at the end of segment 1 (main segment) or at the ends of the branched segments;

a-when the free end is the end of the main segment (point A);

$$\begin{aligned} &\psi_1^{//}(0,\tau) = 0 \\ &\psi_1^{///}(0,\tau) = 0 \end{aligned} \qquad (11)$$

b-when the free end is the ends of the branched segments (points D, E);

$$\begin{aligned} &\psi_{2,3}^{//}(l_{2,3},\tau) = 0 \\ &\psi_{2,3}^{///}(l_{2,3},\tau) = 0 \end{aligned} \qquad (12)$$

4-Free Vibration:

The free vibration of the Y-shaped tube system can be evaluated by substituting Eqs. (6) into any set of the boundary conditions defined by Eqs. (8) to (12). The resulting equation may take the following form;

$$\lfloor a_{ij} \rfloor \{c_j\} = 0 \qquad (13)$$

Where, $i, j = 1,2,3,......12$.

The frequency equation is a function of natural frequency, fluid velocity, mass ratio, angle between the Y-shape branches and length ratio, which can be written in an equation form as:

$$F\left(\Omega, \nu, \beta, \theta, (RL)_1, (RL)_2\right) = 0 \qquad (14)$$

Therefore the natural frequency (Ω) is calculated from Eq. (14) by setting the determinant of Eq. (13) equal to zero; i.e.

$$\left| a_{ij} \right| = 0 \qquad (15)$$

The procedure is executed by assigning an initial value for Ω then varying this value until reach a value which makes the determinant (Eq. (15)) to vanish. The value of Ω which vanishes the determinant represents the natural frequency.

5-Results and Discussion

The effect of flow velocity on natural frequency of a Y-shaped tube for the first two modes of vibration is given in Fig. (2). This figure compares the present results with those for straight tube and for Y-shaped tube presented by [13]. The general behavior of the results was elaborated by [1, 2, 3, 7, &12]. Figure (3) shows the variation of the dimensionless natural frequency with the angle between branches of a clamped-clamped Y-shaped tube conveying fluid. It seen that the first mode of vibration increased with increasing the angle between the Y branches then it begins to decrease. This behavior is attributed to the increase in stiffness of tube in the range of the angle between 0-40^o which gives high impedance to stresses then it decreased after 40^o. This behavior is no longer for the second mode because that the node of the second mode is at the junction between segments and in which the effect of bending components at this point will be minimum.

For simply supported Y-tube, the angle between the tube branches has the effect of decreasing the natural frequency as shown in Fig. (4). This behavior is due to the decrease in tube stiffness over all the range of the angle between the tube segments. The relation between dimensionless natural frequency of the Y-shaped tube simply supported at both ends with flow velocity is shown in Fig. (5). It is seen that the flow velocity has the effect of damping to the natural frequency. Figure (6) shows the effect of dimensionless mass ratio on dimensionless natural frequency for the first two modes. It is shown that the natural frequency increased with increasing the mass ratio for the first mode while it decreased for the second mode.

From the above results it can be concluded that the Y-shaped tube loses its stability at flow velocity higher than that for straight tube of the same characteristics.

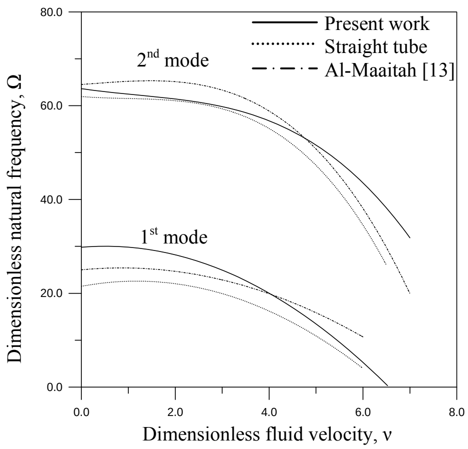

Fig. (2): Effect of dimensionless fluid velocity on natural frequency of clamped-clamped Y-shaped tube.

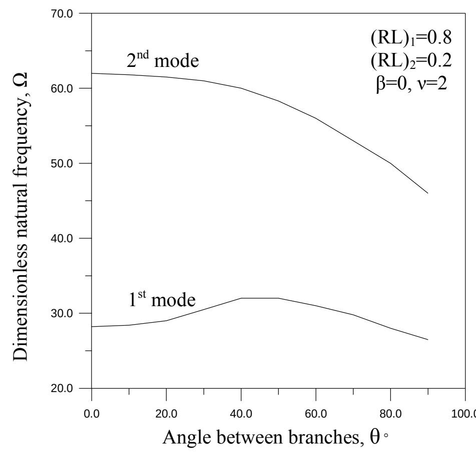

Fig. (3): Effect of angle between branches on dimensionless natural frequency of clamped-clamped Y-shaped tube.

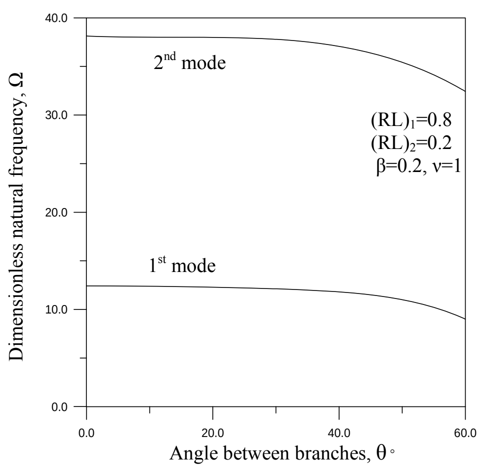

Fig. (4): Effect of angle between branches on dimensionless natural frequency of simply supported Y-shaped tube.

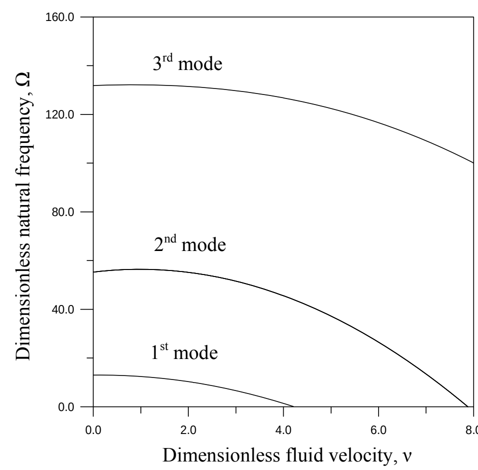

Fig. (5): Effect of dimensionless fluid velocity on natural frequency of simply supported Y-shaped tube (simply supported at both ends), θ = 0, β = 0.25.

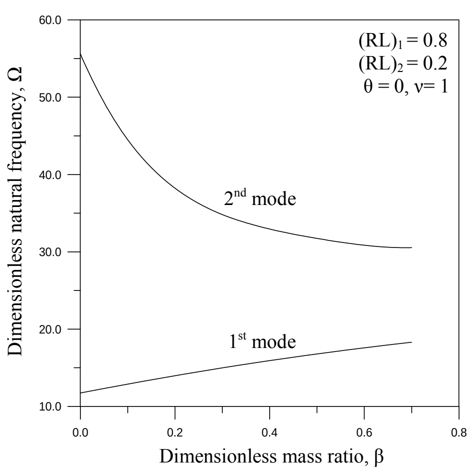

Fig. (6): Effect of dimensionless mass ratio on natural frequency of simply supported Y-shaped tube.

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