EFFECT OF THE FLOW REGIME ON FLUTTER IN COLLAPSIBLE TUBES

Julia Zayko*[1], Vladimir Yushutin[2]&Vasily Vedeneev[1]
[1]*Faculty of Mechanics and Mathematics, Lomonosov Moscow State University, Moscow, Russia*
[2]*Institute of Mechanics, Lomonosov Moscow State University, Moscow, Russia*

Summary We study the stability of elastic tubes conveying fluids. An apparatus for investigations of self-exciting oscillations of the elastic Penrose tubes was created. The effect of the flow regime (laminar vs turbulent) on the limit cycle oscillations and the stability boundary is experimentally analyzed. The influence of the fluid viscosity on the limit cycle oscillations is studied. Maps of regimes are obtained.

INTRODUCTION

Self-exciting oscillations of elastic tubes conveying fluid have been extensively studied during last 50 years in the context of biological applications, including blood vessel vibrations [1 – 4]. Although biofluid flows are generally laminar, most experimental studies deal with turbulent flows. In this investigation we find the stability boundary for different regimes, analyze the effect of the flow regime (laminar vs turbulent) on the limit cycle properties, the flow rate limitation and the influence of the fluid viscosity on these characteristics at the turbulent regimes.

EXPERIMENTAL APPARATUS

The apparatus used is shown in the Fig. 1. An elastic Penrose tube is attached at each end to a rigid tube of the same diameter. The external pressure p_e in the chamber is constant. The fluid flows through the elastic tube under the pressure drop $\Delta p = p_1 - p_2$, where p_1 and p_2 are the upstream and downstream pressures. The pressure drop is changed by the flow rate Q or downstream pressure p_2. The flow rate Q may by controlled by the adjustable resistance and is measured by flowmeter, p_2 may by controlled by the position of draining hose.

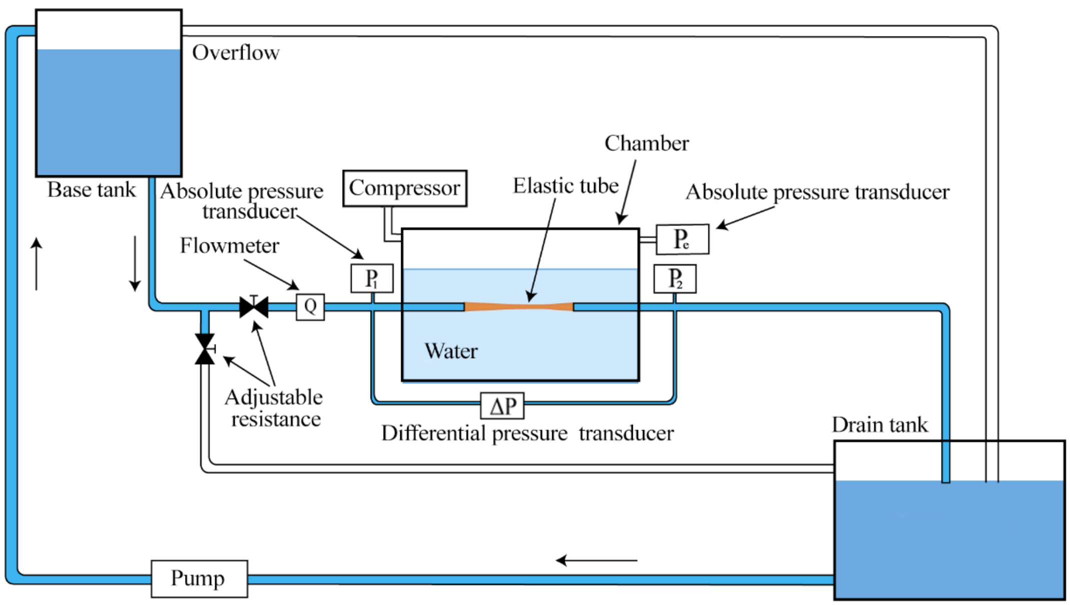

Figure 1: An apparatus for investigations of self-exciting oscillations of elastic tubes conveying fluid.

RESULTS OF EXPERIMENTS

Glycerin solutions of different concentrations and water were used at the experiments. Viscosities of the solutions provided laminar or turbulent flow regimes with the same pressure drops.

The first series of experiments was conducted for fluids with various viscosities corresponding to turbulent regimes. Reynolds number based on the Penrose tube diameter was varied in the range 2500<Re<16000. Results showed that the stability boundary and the character of limit cycle oscillations do not significantly depend on the fluid viscosity. This is explained by the fact that the molecular viscosity is negligible compared to the turbulent viscosity. When the stability was lost while keeping $p_1 - p_e$ constant and increasing $\Delta p = p_1 - p_2$, the tube first oscillates in the following manner: two

*Corresponding author. Email:juliazaiko@yandex.ru.

collapses followed by a delay in the stable state, then again two collapses, etc. For higher Δp, the tube collapsed three times followed by a delay; then four, five, and up to eleven times. As a rule, for higher Δp single-frequency oscillations were finally established and locked the tube, i.e. neither frequency nor flow rate are changed when Δp is increased more. The map of the regimes is shown in the Fig. 2a. In all the regimes the frequency representing consecutive collapses was not changed much when changing Δp.

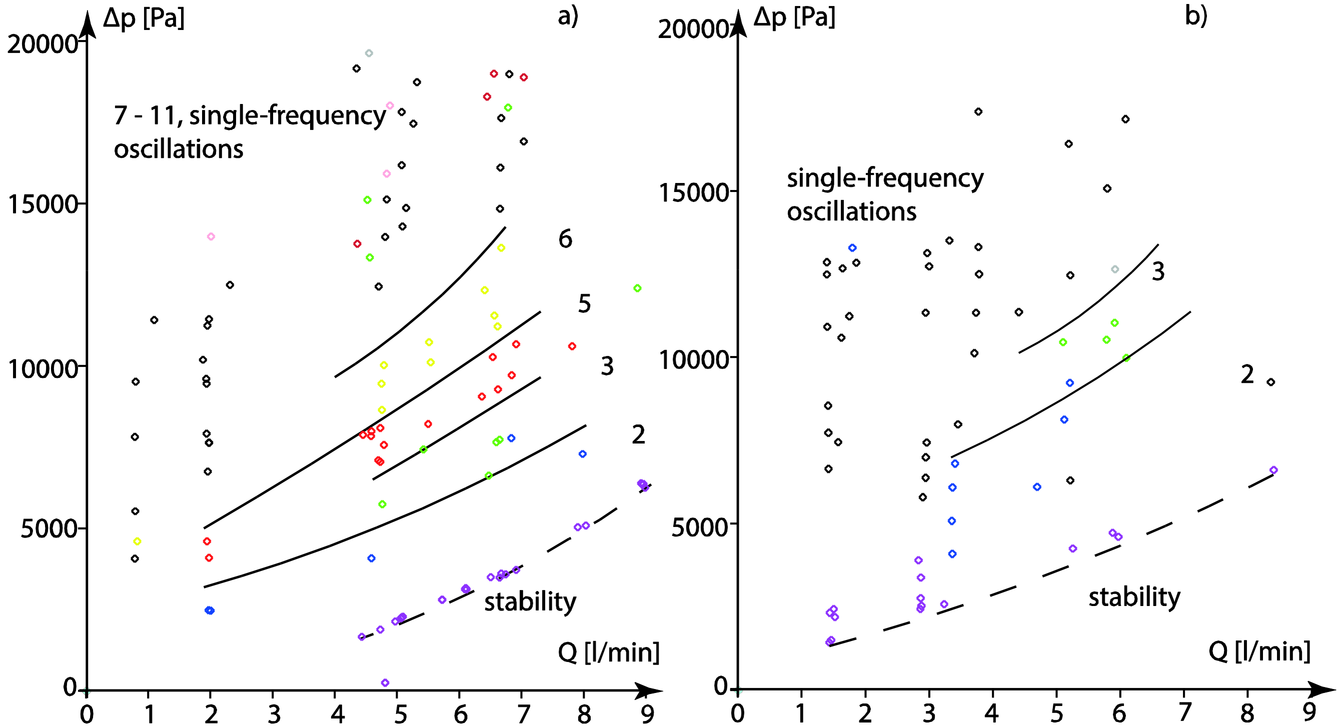

Figure 2: Map of the limit cycle oscillations for turbulent (a) and laminar (b) flow regimes. Number of consecutive tube collapses followed by a delay for each limit cycle type is marked by number and color. Dashed lines show the stability boundaries.

At the second series of tests a more viscous glycerine solution was used, which provides laminar flow at the unstable regimes with 100<Re<1000 with similar pressure drop along the Penrose tube. Unstable behaviour is quite different. For most flow rates, single-frequency oscillations developed almost immediately after the loss of stability (Fig. 2b). When increasing Δp, the regime does not change.

Oscillation amplitude at the laminar regime is essentially lower than at turbulent, so that the oscillations do not fully block the tube, that is why the oscillation frequency is more significantly affected by the pressure drop than at turbulent regimes.

The work is supported by grant MD-4544.2015.1.

References

[1] C.D. Bertram, C.J. Raymond, T.J. Pedley. Mapping of instabilities for flow through collapsed tubes of different length. Journal of Fluids and Structures. 1990. 4. P. 125 – 153.

[2] C.D. Bertram, J. Tscherry. The onset of flow-rate limitation and flow-induced oscillations in collapsible tubes. Journal of Fluids and Structures. 2006. 22. P. 1029 – 1045.

[3] James B. Grotberg, Oliver E. Jensen. Biofluid mechanics in flexible tubes. Annu. Rev. Fluid Mech. 2004. 36. P. 121 – 147.

[4] T.J. Pedley, X.Y. Luo. Modelling flow and oscillations in collapsible tubes. Theoret. Comput. Fluid Dynamics. 1998. 10. P. 277 – 294.