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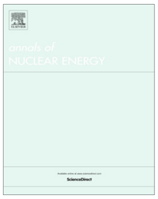

Effects of branch length and chamfer on flow-induced acoustic resonance in closed side branches

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ABSTRACT

The flow-induced acoustic resonance phenomenon may produce excessive vibrations of components in pipe systems. In this study, the effects of branch length and edge geometry on the acoustic resonance characteristics of closed side branches are investigated experimentally. Three different aspect ratios of L/d = 8, 10 and 12, where L is the branch length and d is the branch diameter, are investigated with Mach number up to 0.28. The results show that, for all the tested configurations, the second hydrodynamic mode only excites the first acoustic mode due to the small diameter of the side branches. The maximum normalized pulsation amplitude at the first acoustic mode decreases in branch length. The influence of branch length on the Strouhal numbers at onset of resonance is weak. It is about 0.55 for the first hydrodynamic mode in the case of sharp edge. The maximum normalized pulsation amplitudes are excited at a Strouhal number close to 0.4. Two different chamfers of angle 45° and C = 2.5 and 5 mm, where C is the width of the chamfered edge, are investigated. The results illustrate that the maximum normalized pulsation amplitude and the Strouhal number at onset of resonance both decrease significantly in chamfer width, which indicates chamfering is an effective method to attenuate undesirable acoustic resonance induced by closed side branches in pipe system.

1. Introduction

The flow-induced acoustic resonance phenomenon, which appears when one of the acoustic modes of a side branch is coupled with the flow oscillations, may produce excessive vibrations of components in pipe systems. In nuclear industry, extended power uprate of a nuclear power plant will increase the flow velocity of steam in the main steam lines, which may increase the flow-induced acoustic resonance in safety relief valve (SRV) stub pipes, a typical structure of closed side branches, and, subsequently, increases the pressure load of the steam dryer (Takahashi et al., 2016). Many investigations have confirmed this phenomenon based on experiments (DeBoo et al., 2006; Takahashi et al., 2010, 2016; Xiao et al., 2018; Ziada, 2010) and numerical analysis (Morita et al., 2011; Takahashi et al., 2008).

In the case of branches with sharp edges, Ziada and Shine (1999) developed a design chart to predict the critical St in the main pipe at which acoustic resonances are excited initially. They concluded that the ratio of the side branch pipe diameter to the main pipe diameter (d/D) and the shape of the velocity profile at the branch mouth both have significant influence on critical St. Besides, Graf and Ziada (2010) developed a semi-empirical method, considering the integrated effect of shear-layer excitation induced by a pressure difference across the shear layer, to predict the frequency and amplitude characteristics of acoustic resonance.

Chamfers are a kind of common transitional edge geometry. Investigations have demonstrated that the upstream edge geometry have remarkable influence on the acoustic resonance excitation in ducted shallow cavities (Amandolèse et al., 2004; Bolduc et al., 2013; Omer et al., 2016; Smith and Luloff, 2000). Smith and Luloff (2000) tested a lot of edge geometries and found that chamfering the upstream edge produces inconsistent results. The resonance in some cases is suppressed but not in others. Bolduc et al. (2013) investigated the effect of chamfers, with an angle of 17° and two widths of C = 4.9 and 9.8 mm, on the acoustic resonance in axisymmetric-ducted cavities. The results showed that chamfering the upstream edge delays the onset of resonance in proportion to the length of the chamfer. But for the amplitude of the acoustic resonances, chamfer has little influence comparable with those observed for sharp edged cavities. Omer et al. (2016) investigated the effect of chamfers, with angle ranges from 107° to 150°, on the excitation of acoustic resonance in shallow rectangular cavities. The results also showed that adding a chamfer can delay the onset of acoustic resonance.

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Nomenclature

c	velocity of sound (m/s)	Ma	Mach number
C	width of chamfer (m)	n	order of the acoustic mode
d	diameter of branch (m)	P	root mean square amplitude of acoustic pressure (Pa)
D	diameter of main pipe (m)	$\overset{*}{P}$	dimensionless pressure pulsation ($2P/\rho V^2$)
f	frequency (Hz)	SPL	sound pressure level (dB), P0 = 20 μPa
L	length of branch (m)	St	Strouhal number
Le	end correction (m)	V	velocity (m/s)
m	order of the hydrodynamic mode	ρ	density (kg/m^3)

But for the amplitude, the results showed that, when resonance is materialized, chamfer may increase the amplitude compare with the original cavity with sharp edges.

For the effects of chamfer on the flow-induced acoustic resonance in closed side branches, which is a kind of typical deep cavity structure, the influence rule is still not illustrated. In this study, the effects of branch length and edge geometry on the acoustic resonance characteristics of closed side branches are investigated experimentally. Three different aspect ratios of L/d = 8, 10 and 12, where L is the branch length and d is the branch diameter, are investigated with Mach number up to 0.28. The effects of the branch length on the pulsation amplitude at resonance and Strouhal numbers at onset of resonance are discussed. The Strouhal numbers at where the maximum normalized pressures excited are obtained. Two different chamfers of angle 45° and C = 2.5 and 5 mm, where C is the width of the chamfered edge, are investigated. The effects of the chamfer width on the pulsation amplitude at resonance and Strouhal numbers at onset of resonance are discussed in detail.

Table 1
Dimensions of the test section.

Parameters	Symbol	Values	Units
Diameter of main pipe	D	0.05	m
Diameter of branch	d	0.025	m
Length of branch	L/d	0.2, 0.25, 0.3	m
Width of chamfer	C	0, 0.0025, 0.005	m
Length of inlet and outlet developing sections	L_d	1.5	m

2. Experimental apparatus and test sections

Fig. 1 shows a schematic diagram of the pressurized-air test facility at Shanghai Jiao Tong University (Xiao et al., 2018), which was used to carry out the tests. As shown in Fig. 1, the facility is equipped with a screw air compressor, two regulating valves, two absorption silencers, and a turbine flowmeter to measure the volume flow rate. All pipes of the facility were made of stainless steel and firmly fixed to the ground to prevent structure vibration.

The test sections were also made of stainless steel and the edge geometries of the branches were processed accurately. Table 1 shows the dimensions of the test sections in detail. The inner diameter of the main pipe was 50 mm. Three side branches with diameter ratio 0.5 were studied. The length of the branches was ranged from 200 mm to 300 mm, which was varied by means of changing the connecting pipe as shown in Fig. 2. The chamfers of the branches had two widths, 2.5 and 5 mm, which were varied by means of changing the T-joint (Fig. 2). The chamfer was cone-like and the angles of the chamfered edges are both 45° due to it is the most common angle in industries. As shown in Fig. 3, the T-joints with sharp edge and 5 mm chamfer are presented. All flanges of the test section were tongue and groove connection to guarantee the smoothness of the flow channels.

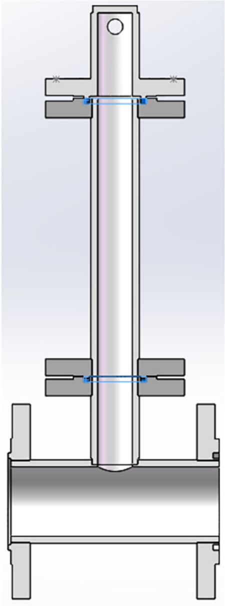

Fig. 2. Scheme of the closed side branch test sections.

The static pressure and flow rate were regulated cooperatively by the compressor, the pressure regulating valve and the flow

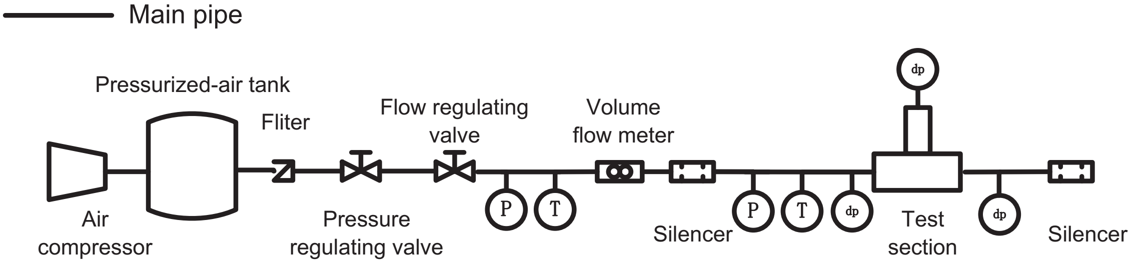

Fig. 1. Scheme of the experimental system of acoustic resonance.