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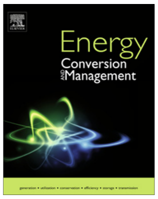

Transmission loss analysis of thick perforated plates for valve contained pipelines

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ABSTRACT

Valve contained pipelines have witnessed a great growth and there exists a lot of noise caused by valves. Thick perforated plates are especially used is valve contained pipelines for the noise control, but there are limited literatures about its noise control performances under different structural parameter of thick perforated plates, which limits its popularization and application. In this paper, transmission loss (TL) predictions of various thick perforated plates are carried out to analyze the noise control performances. Finite element method (FEM) is implemented to simulate the acoustic response, and TL is achieved by the sound pressure of four points on both sides of the thick perforated plates. Adopted numerical method shows good agreements with the existing research works and the results indicate that reducing the margin of the plates can enhance TL of some frequencies. Similar to chamber mufflers, the maximum TL depends on the area ratio and the frequency range with the best noise control performance is related to the plate thickness. Meanwhile, the low velocity flow does not affect the TL curve so much and in the situation of supersonic flow, and the TL curve turns into a periodic shape, which may weaken the effects of noise control. Besides, based on the analytical solution of TL for the chamber muffler, a linear correction formula of maximum TL is proposed for the thick perforated plate. This work can give several advices for similar perforated plates design works and someone who are dealing with decreasing the noise effects from the valves in pipelines.

1. Introduction

With the widely used of valves in industries, valve contained pipelines have witnessed a great growth. Due to the change of flow channel caused by valves, fluid flow in pipelines changes a lot and turns out a lot of noise and vibration, which means a lot of energy waste and harms to both valves and pipelines. Taking these into accounting, research on the noise performances in valve contained pipelines is meaningful.

Nowadays, in the valve contained piping system, many researchers mainly focus on the structure of the valve in order to reduce noise, pressure loss, vibration and cavitation. Chern et al. research on the design work of cages in globe valve in order to improve the control capability of the globe valve [1]. Rao et al. [2] and Song et al. [3] both pay attention to the optimization work of butterfly valves. Ye et al. also analyze the effects of groove shape of notch on the flow characteristics of spool valve [4], and Xu et al. mainly focus on the structural optimization of a downhole float valve in order to reduce erosion and performance failure [5]. Meanwhile, many other researchers also concern about flow characteristics inside the valve a lot and they have achieved a lot of progresses. Focusing on the flow forces and cavitation characteristics of a hydraulic directional proportional valve by numerical and experimental methods, Amirante et al. have achieved many useful results [6–8]. Aung et al. also analyze the flow forces, energy loss characteristics and cavitation phenomenon in an electrohydraulic servo-valve with an innovative flapper shape [9,10]. At the same time, Lisowski et al. also take a three dimensional computational fluid dynamics (CFD) analysis on the flow force and pressure loss of logic valves with some experimental tests [11–13]. Liu et al. also investigate the operation performance of parameters of the integrated valve under the high temperature condition by numerical method [14]. Wu et al. carry out a numerical invetstigation on a pressure control valve which is used for automotive fuel supply system [15]. Furthermore, Song et al. [16,17] and Yuan et al. [18] take a research on the dynamic analysis of a safety relief valve using CFD method, while Valdés et al. also take numerical and experimental methods to check the cavitation flow through a ball check valve [19] and flow coefficients in hydraulic valves [20].

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For other researchers, they also have recognized the importance of the noise control technologies in pipelines by dealing with the transmission loss (TL), which is the main characteristic parameter of noise control components. Guo et al. mainly analyze the absence of magnetic state dependent low-frequency noise in spin-valve systems [21] and Zeng et al. pay attention to the flow-induced vibration and noise in a control valve [22]. At the same time, Sekhar et al. research on the enhanced stability against spin torque noise of a spin valves [23]. Furthermore, Phong et al. [24] and Mendez et al. [25] both express the useful functions of the orifices and perforated plates which have simple structures and effective noise reduction features, in pipelines, especially at the end of valves. Antebas et al. [26] and Mimani and Munjal [27,28] also study the noise control components with complex geometries, such as TL prediction of expansion chamber mufflers by finite element method (FEM).

In recent years, our research group mainly focuses on the fluid flow inside valves [29,30] and the piping system. During the research work of analysis of flow characteristics inside valves, we find that noise control in the whole pipelines, especially after the valve, is very important. In our previous work, we mainly concern more about the flow-induced noise inside the valve by optimizing its structures or adding some other components [31,32]. In this paper, we carry out the thick perforated plates as the noise control components since it is very convenient and economical compared with changing the shape of the whole pipes or changing the physical properties of the fluids. However, there are limited literatures about its noise control performances under different structural parameter of thick perforated plates, which limits its popularization and application. TL is one of the most important parameters to characterization the mufflers' noise control performances, which is much more convenient to simulate in numerical method compare with other judging methods, so that here we use TL predictions of various thick perforated plates to analyze their noise control performances. Then, the FEM numerical model of thick perforated plate is developed and a four-point method is used to obtain TL curves, and the thick perforated plate is compared with the orifice with a single hole to further analyze the margin effects. Then a correction formula of maximum TL is carried out. Furthermore, the relationship between thickness and frequency is studied and the effects of mean flow are discussed. These works can give several advices for similar perforated plates design works and someone who are dealing with decreasing the noise effects from the valves in pipelines.

2. Numerical method

Nowadays, numerical method is widely used in dealing with engineering problems due to its obvious advantages of economy, efficiency and accuracy, especially for these complex models. For instance, Chau et al. develop an interesting CFD model to simulate the Pearl River Estuary, the pollutant transportation and the water quality rehabilitation with rainwater [33–35]. Meanwhile, Epely-Chauvin et al. pay attention to the plunge pool with its scour evolution under non-cohesive sediments [36], Liu et al. carry out an useful numerical model of water–air flow in the bottom spillway when the gate is opening [37], and Gholami et al. analyze the water surface profile in open channel bend numerically companied with experimental ways [38].

In this work, we use FEM to achieve the TL through the thick perforated plate, which is illustrated in Fig. 1. The holes on the plates are in rhomboidal arrangement. The height of the rhomboid is a, and the acute angle is 60°. The diameter d of holes is the same and the diameter of holes area is D' while the diameter of the plate is D. All the key parameters of the thick perforated plate are listed in Tables and different comparison with different parameters respectively.

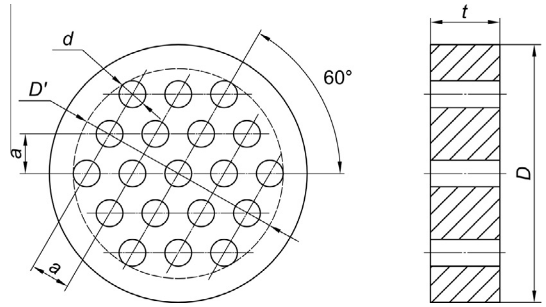

Fig. 1. Geometry of the perforated plate.

2.1. Finite element method

The numerical simulation software Virtual.lab used in this work can perform both FEM and boundary element method (BEM) computations. The region under analysis is divided into a number of elements. For a three-dimensional model, a tetrahedron element is associated with four nodes which are the corners of the element defining its shape due to its complex structure with several different models. The acoustic pressure within element e is approximated by the trail function, which leads to

$$p = \{N\}^T\{p_n\}, \tag{1}$$

where p is the acoustic pressure within an element; p_n is the nodal pressure and N is the shape function.

The algebraic equation for an element is

$$([K]^e + i\omega[C]^e - \omega^2[M]^e)\{p_n\} = \{F\}^e, \tag{2}$$

where $i = \sqrt{-1}$; ω is the radian frequency; $[K]^e$ is the stiffness matrix; $[C]^e$ is the damping matrix; $[M]^e$ is the mass matrix; and $\{F\}^e$ is the vector of acoustic forces.

Here, the matrices and vectors are given by

$$[K]^e = \int_{V^e} \{N\}\{N\}^T \mathrm{d}V^e, \tag{3}$$

$$[C]^e = \rho A_n \int_{S^e} \{N\}\{N\}^T \mathrm{d}S^e, \tag{4}$$

$$[M]^e = \frac{1}{c^2} \int_{V^e} [\nabla N][\nabla N]^T \mathrm{d}V^e, \tag{5}$$

$$\{F\}^e = -i\rho\omega \int_{S^e} u\{N\}\mathrm{d}S^e, \tag{6}$$

where V^e is the element volume; S^e is the element surface; A_n is the admittance; and u is the normal velocity and away from the surface.

For a rigid boundary and for internal elements, the forcing vector $\{F\}^e$ would reduce to a null vector. The algebraic equation for the overall finite elements system can be formed by assembling equations of all elements. When the flow effects are considered, the mean flow boundary condition is added to inlet. The potential flow is calculated through laplace's equation, the results of which are set as boundary conditions for solving acoustic response.

2.2. Prediction method of TL

The general expression for TL of silencers can be written as

$$\mathrm{TL} = 10\lg\frac{W_i}{W_t} = 20\lg\frac{p_i}{p_t}, \tag{7}$$

where W is the sound power; subscripts i and t represent incident and transmitted parameter, respectively.

Based on the work of Lee et al. [39], p_i and p_t are derived from pressure of measurement points shown in Fig. 2. The perforated