Frequency-dependent damping model for the hydroacoustic finite element analysis of fluid-filled pipes with diameter changes

Jan Herrmann a,*, Jürgen Koreck b, Matthias Maess b, Lothar Gaul a, Otto von Estorff c

a Institute of Applied and Experimental Mechanics, University of Stuttgart, Pfaffenwaldring 9, 70550 Stuttgart, Germany
b Robert Bosch GmbH, Robert-Bosch-Straße 2, 71701 Schwieberdingen, Germany
c Institute of Modelling and Computation, Hamburg University of Technology, Denickestraße 17, 21073 Hamburg, Germany

A R T I C L E   I N F O

Article history:
Received 18 December 2009
Received in revised form
11 June 2010
Accepted 30 September 2010
Available online 8 October 2010

Keywords:
Fluid damping
Complex circular wave number
Fluid-filled pipes
Substructuring
FEM
Acoustic fluid-structure interaction

A B S T R A C T

The integration of a model for longitudinal hydroacoustic fluid damping in thin hydraulic pipes in 3D finite element models is presented in this paper. In order to perform quantitative prediction of the vibroacoustic behavior and resulting noise levels of such fluid–structure coupled system due to hydraulic excitation, an accurate frequency-dependent fluid damping model including friction effects near the pipe wall is required. This step is achieved by matching complex wave numbers from analytical derivation into a parameterized damped wave equation and consecutive translation into finite element modeling.

Since the friction effect close to the pipe wall changes locally with the inner pipe radius, the fluid damping model is applied segment-wise in order to model the influence of cross-sectional discontinuity, such as orifices, on the oscillating pressure pulsations. A component synthesis approach, which uses pipe segments as substructures, allows a simple model generation and fast computation times.

The numerical harmonic results are compared to experimental frequency response functions, which are performed on a hydraulic test bench driven by a dynamic pressure source in the kHz-range.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

Thin hydraulic pipes in automotive applications undergo oscillating pressure pulsations due to pump and valve operation. As a result, pressure waves propagate along the pipes, and are transmitted to attached structures. Finally, undesired noise is radiated from vibrating panels at the full range of audible frequencies. Common application fields are found in brake-pipe systems or fuel injection systems, where hydroacoustic wave propagation via pipes may lead to sound radiation from floor panels or cylinder heads.

In order to quantitatively predict noise levels, the modeling of damping is an important step, which is often not treated sufficiently. Whereas the structural and noise path is modeled well by convenient finite element techniques in 3D, including the hydroacoustic fluid domain and acoustic-structure two-field coupling, predictive fluid damping models for wave propagation in thin pipes are often missing – although friction effects close to the pipe wall are known to be the dominant damping mechanism in thin fluid-filled pipes with circular cross section [1,2]. A corresponding analytical model