Direct Drive Valve Model for Use as an Acoustic Source in a Network Model

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Direct Drive Valves (DDVs) can be used as acoustic actuators in duct systems when requirements on mechanical or thermal robustness are high, e.g., for the active control of aerodynamic or combustion instabilities. This paper presents a model of a DDV that is used as an active element in an acoustic network model. In acoustic network modelling tools, acoustic sources are often implemented as simple velocity or mass flow boundary conditions. In practice, however, DDVs are not necessarily situated at the boundary of the system and the throughflow depends on the fluctuating pressure drop over the valve. This paper presents an acoustically compact model, based on mass conservation and a time-varying hydraulic resistance. The resistance depends on the fluctuating valve opening. The results are compared to the experiment in terms of acoustic wave transfer function.

NOMENCLATURE

A	Area $[\mathrm{m}^2]$
C_d	Discharge coefficient $[-]$
D	Transmission coefficient of an acoustic delay $[-]$
L	Length $[\mathrm{m}]$
M	Mach number $[-]$
Q	Gas flow rate in norm litre per minute $[\mathrm{NLPM}]$
R	Reflection coefficient $[-]$
$\mathcal{R}_{\mathrm{sys}}$	Combined reflection coefficient of an acoustic system $[-]$
Re	Reynolds number $[-]$
S	Source coefficient $[(\mathrm{m/s})\,/\%]$
$\mathcal{S}_{\mathrm{sys}}$	Combined source coefficient of an acoustic system $[(\mathrm{m/s})\,/\%]$
T	Transmission coefficient $[-]$
V	Volume $[\mathrm{m}^3]$
c	Speed of sound $[\mathrm{m/s}]$
$\tilde{f}$	Downstream characteristic wave amplitude $[\mathrm{m/s}]$
$\tilde{g}$	Upstream characteristic wave amplitude $[\mathrm{m/s}]$
p	Pressure $[\mathrm{Pa}]$
p_0	Total (stagnation) pressure $[\mathrm{Pa}]$
r	Radius $[\mathrm{m}]$
t	Time $[\mathrm{s}]$
u	Velocity $[\mathrm{m/s}]$
x, y, z	Coordinates $[\mathrm{m}]$
x_{sp}	Valve (spool) opening $[\%]$
ζ	Hydraulic loss coefficient $[-]$
ρ	Density $[\mathrm{kg/m}^3]$
$\bar{\circ}$	Time-averaged quantity
$\circ'$	Perturbation on time-averaged quantity
$\dot{\circ}$	Rate of change / flow$[\circ/\mathrm{s}]$

1. INTRODUCTION

DDVs are generally used as hydraulic (oil flow) actuators. For this application, they need to be stiff and precise, but their range of operation is restricted to low frequencies. Recently, they have been used as acoustic (gas flow) actuators, such as for the active suppression of combustion instabilities or dynamic compressor stall.[1–3]

Combustion instabilities arise when there is a positive feedback between a fluctuating heat release and the combustor acoustics. These instabilities can quickly grow to great amplitudes, and in worst case, lead to severe hardware damage. Dampers, such as Helmholtz resonators, are often used to damp combustion instabilities, but for low frequencies (e.g. $< 500\,\mathrm{Hz}$) the size of these dampers can get impractically large.

Active control by modulation of the fuel flow, is a commercial solution for these low-frequent instabilities.[2] Compared to passive measures, active control on combustion and flow dynamics has the advantage of being more flexible. Different frequencies can be damped without hardware modification, and several modes of instability can be dealt with simultaneously. For a thorough overview on active and passive control on combustion instabilities, the reader is referred to Zinn[4] and Culic.[5]

In these applications, valves, such as DDVs, have the advantage over loudspeakers that valves are very robust to thermal and mechanical influences. The volume flow modulated by a loudspeaker is limited by its geometry, while the modulated volume for a valve is limited by the throughflow. For the applications mentioned above, this is usually to the advantage of the valve.

The implementation of control systems as described before is not trivial; better tools are needed to predict the control authority a priori.[6] Network models are a popular tool to analyse 1-D acoustics and could be a valuable aid for setting up new systems. However, until now, there has been no description of a valve being used for this type of model.

No truly acoustical description of how such a valve would need to be modelled was found in the literature. Annaswamy and Ghoniem,[7] for instance, simply stated that the through-