Applied Thermal Engineering 115 (2017) 463–476

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Influence of a circular strainer on unsteady flow behavior in steam turbine control valves

Peng Wang, Yingzheng Liu *

Key Lab of Education Ministry for Power Machinery and Engineering, School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China
Gas Turbine Research Institute, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China

HIGHLIGHTS

- Influence of strainer on unsteady flow dynamics in control valves was studied.
- A porous-medium model of strainer was established and experimentally validated.
- Oscillation of the annual flow around main valve's seat was attenuated by strainer.
- Continuous flow impingement onto the throttle valve's cavity wall was found.

ARTICLE INFO

Article history:
Received 21 September 2016
Revised 13 December 2016
Accepted 16 December 2016
Available online 4 January 2017

Keywords:
Valve
Strainer
CFD
Porous model
Steam flow

ABSTRACT

The influence of a circular strainer on unsteady flow behavior in steam turbine control valves, which are commonly placed between an intermediate-pressure turbine and a boiler in thermal power plants, was numerically studied. A porous-medium model, which established the dependencies of the pressure drop through the strainer on the magnitude and direction of the fluid flow's velocity, was validated by experimental measurements in a water flow test rig. As the benchmark configuration, a valve without a strainer was used for comparison. The turbulent steam flow in the complex serpentine channel was simulated with the implementation of the proposed porous model for the strainer. The numerical results demonstrated that placing the strainer in the main valve resulted in dramatic changes of the flow patterns in the main valve's chamber and its diffuser, and even in the downstream throttle valve. The complex steam flow in the main valve was efficiently managed by the circular strainer, significantly reducing the cross-sectional force on the main valve's spindle; this is attributed to attenuated oscillation of the annular flow around the main valve's seat. As for the downstream throttle valve, the pressure drop and the fluctuating lateral force on the spindle were intensified, which was shown to be closely related to the continuous impingement of the flow onto the throttle valve's cavity wall. In comparison with the configuration without a strainer, the placement of the strainer in the main valve gave rise to a pair of intensified secondary vortices in the diffuser section behind the throttle valve.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

As the major flow control unit in thermal power plants, steam turbine control valves are commonly integrated by the sequential placement of a main valve and a throttle valve; the main valve alerts to severe malfunction of the steam turbine by rapidly cutting off the steam supply, and the throttle valve operates in response to the required power output. In practice, the closely spaced configuration of these two valves creates a complicated serpentine channel, giving rise to a highly three-dimensional flow pattern. Previous studies have identified various unsteady flow behaviors inside control valves, for example, the impingement of shear flow [16], rotating pressure fluctuations [8], wall-attached jet flow and wall-detached jet flow [4]; these behaviors can have many cause-and-effect consequences, such as intensified noise [7], structural vibration [9] or even operational risk [10]. However, placing a circular strainer around the main valve which is commonly performed to prevent impurities coming from the boiler from reaching the downstream turbine stages, was found to considerably change the flow pattern [1,2]. Consequently, unsteady flow behaviors inside steam turbine control valves tend to show distinctly

---

* Corresponding author at: Key Lab of Education Ministry for Power Machinery and Engineering, School of Mechanical Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China.

E-mail address: yzliu@sjtu.edu.cn (Y. Liu).

http://dx.doi.org/10.1016/j.applthermaleng.2016.12.073
1359-4311/© 2017 Elsevier Ltd. All rights reserved.

Nomenclature

Main symbols

p^{*}_{in}	stagnation pressure of valve inlet
V_{in}	velocity of valve inlet
y^{+}	non-dimensional wall distance
ΔP	pressure drop
V	velocity in strainer
μ	viscosity
D	thickness of strainer
K_{perm}	permeability of strainer
K_{loss}	quadratic loss coefficient of strainer
$\tilde{F}_L$	normalized lateral force on valve's spindle
$\tilde{F}_A$	normalized axial force on valve's spindle
F_L	actual lateral force on valve's spindle
F_A	actual axial force on valve's spindle

Greek Symbols

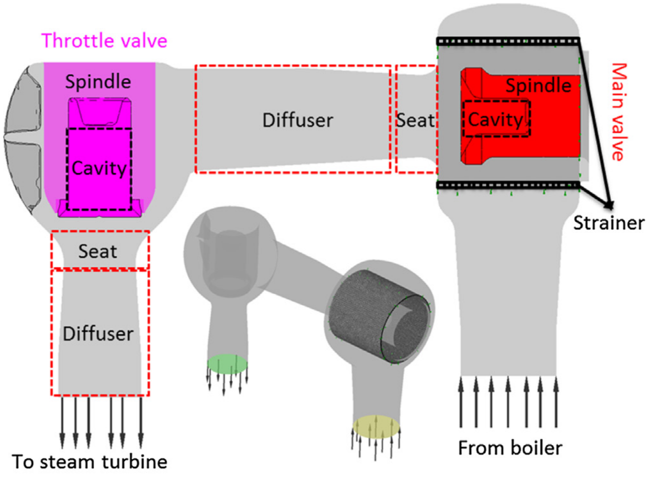
θ	incident angle
ξ	pressure drop coefficient

Abbreviations

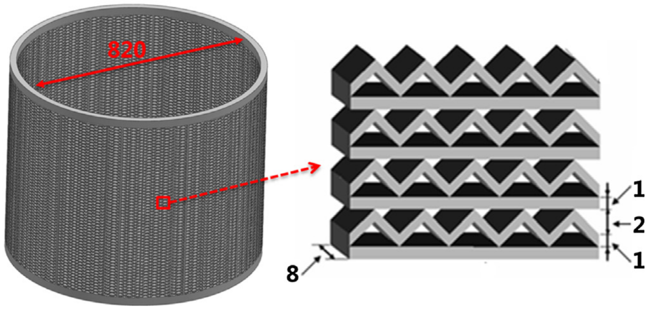
CFD	computational fluid dynamics
LES	large-eddy simulation
DES	detached-eddy simulation
SAS-F	scale-adaptive simulation with an embedded forcing zone
RANS	Reynolds-averaged Navier–Stokes
SST	shear stress transport
DEH	digital electric hydraulic control system
LIC	line-integral convolution
RMS	root mean square
FFT	fast Fourier transform
PSD	power-spectral density

different dynamics when a circular strainer is placed inside the main valve's chamber.

A literature survey shows that considerable efforts have been made to numerically determine the unsteady flow behaviors of various industrial valves [11,15]. A large-eddy simulation (LES) of the flow in a control valve by Morita et al. [8] revealed rotating pressure fluctuations caused by the asymmetric flow around the valve spindle, which was determined to be the excitation source of valve vibration. Detached-eddy simulations (DES) of unsteady flows in a steam turbine throttle valve by Zeng et al. [14] demonstrated that the alternating flow pattern induced a low-frequency intermittent vibration of the valve's spindle. Domnick et al. [4] numerically simulated the time-variant flow field of steam turbine control valves using a scale-adaptive simulation with an embedded forcing zone (SAS-F), identifying three different flow topologies in the valve's diffuser section: full diffuser flow, wall-attached jet flow and wall-detached jet flow. Unfortunately, numerical simulations using SAS-F, DES and LES are extremely computationally expensive for unsteady internal flows in complex valves at high Reynolds numbers; hence, the cost-effective prediction of strongly unsteady flows using unsteady Reynolds-averaged Navier–Stokes (RANS) simulations at an allowable discrepancy is highly desirable. Using the shear stress transport (SST) model, Tecza et al. [12] numerically analyzed the flow-induced vibration of a steam turbine control valve; the flow instability within the pressure-balanced valve plug was successfully predicted to be the cause of valve vibration, as the self-induced pressure oscillations locked onto the valve chamber's natural frequency. Clari et al. [3] also performed SST simulations of the flow in a control valve. These results, along with the measurement of the dominant frequency, elucidated the behaviors of three-dimensional flow separation in the valve's diffuser section. However, to the best of the authors' knowledge, no studies have been conducted to assess the influence of a strainer on unsteady flow behaviors in control valves.



(a) Steam turbine control valves



(b) Geometry of circular strainer (mm)

Fig. 1. Schematic illustration of steam turbine control valves and strainer.

In the present study, the main focus is the influence of a circular strainer, placed in the main valve, on unsteady flow behaviors in steam turbine control valves, as shown in Fig. 1. To this end, a porous model of the strainer was established, incorporating the directivity of the pressure loss and allowing variation of the approaching flow directions and flow speeds. For comparison, the same valves without the inclusion of the strainer were used as the benchmark configuration. SST simulations of the unsteady steam flow field in the valves were carried out. The influence of the strainer on the unsteady flow behaviors was discussed in terms of the fluctuating aerodynamic forces on the valve's spindle, the pressure fluctuations inside the valves, the annular flow oscillations around the main valve's seat and the impingement flow onto the throttle valve's cavity.

2. Numerical approach

2.1. Numerical setup

The configuration of the steam turbine control valves is shown in Fig. 1a, in which the different components, i.e., the valve's

Download English Version:

https://daneshyari.com/en/article/4991617

Download Persian Version:

https://daneshyari.com/article/4991617

Daneshyari.com