Vortices in turbulent curved pipe flow-rocking, rolling and pulsating motions

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Abstract

This thesis is motivated by the necessity to understand the flow structure of turbulent flows in bends encountered in many technical applications such as heat exchangers, nuclear reactors and internal combustion engines. Flows in bends are characterised by strong secondary motions in terms of counter-rotating vortices (Dean cells) set up by a centrifugal instability. Specifically the thesis deals with turbulent flows in 90° curved pipes of circular cross-section with and without an additional motion, swirling or pulsatile, superposed on the primary flow. The aim of the present thesis is to study these complex flows in detail by using time-resolved stereoscopic particle image velocimetry to obtain the three-dimensional velocity field, with complementary hot-wire anemometry and laser Doppler velocimetry measurements.

In order to analyse the vortical flow field proper orthogonal decomposition (POD) is used. The so called "swirl-switching" is identified and it is shown that the vortices instantaneously, "rock" between three states, viz. a pair of symmetric vortices or a dominant clockwise or counter-clockwise Dean cell. The most energetic mode exhibits a single cell spanning the whole cross-section and "rolling" (counter-)clockwise in time. However, when a honeycomb is mounted at the inlet of the bend, the Dean vortices break down and there is strong indication that the "swirl-switching" is hindered.

When a swirling motion is superimposed on the incoming flow, the Dean vortices show a tendency to merge into a single cell with increasing swirl intensity. POD analysis show vortices which closely resemble the Dean cells, indicating that these structures co-exist with the swirling motion. In highly pulsating turbulent flow at the exit of a curved pipe, the vortical pattern is diminished or even eliminated during the acceleration phase and then re-established during the deceleration.

In order to investigate the effect of pulsations and curvature on the performance of a turbocharger turbine, highly pulsating turbulent flow through a sharp bend is fed into the turbine. Time-resolved pressure and mass-flow rate measurements show that the hysteresis loop in the pressure-ratio-mass-flow plane, may differ significantly between straight and curved inlets, however the mean operating point is only slightly affected.

Key Words
Turbulence, curved pipes, swirling flow, pulsatile flow, time-resolved stereoscopic particle image velocimetry, hot-wire anemometry, proper orthogonal decomposition, turbocharger