Measurement of turbulent flow upstream and downstream of a bend in a round pipe

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Keywords: Stereo-PIV, turbulent pipe flow, bend, Dean vortex

Purpose

The flow in a pipe with a 90-degree bend has been paid particular attention because of the complex feature of the spatially evolving flow structure downstream from the bend. While the flow at small Dean numbers with a laminar inlet condition consists of a pair of steady counter-rotating vortices, the flow at larger Dean numbers with turbulence exhibits unsteady and anti-symmetric behavior of the secondary flow. The unsteadiness is typically characterized by the temporal variation of the position of the stagnation point, designated in Fig.1, where the azimuthal velocity is zero near the wall. We motivated finding structure existing in the upstream tangent of the bend that is responsible for the unsteady motion of the stagnation point.

Method

Experiment was performed in a facility of Plexiglas water pipe having diameter of d=50 mm. Reynolds number was fixed at Re=27000, and radius of curvature of the pipe at bend was identical to d. Temporally varying stagnation point is identified from the velocity vector field measured at a cross-section of the pipe downstream the bend by use of single-camera PIV, and time-resolved velocity vector field upstream the bend was measured simultaneously by additional stereo-PIV, as shown in Fig.2.

Result

Linear Stochastic Estimation (LSE) was applied to capture the upstream flow field conditioned by the azimuthal location of the stagnation point downstream the bend. Figure 3 shows the streamwise component of conditional fluctuating velocity vectors at 3.1d upstream the bend. The event was set at which the stagnation point locates below the symmetry plane. Based on Taylor’s frozen turbulence hypothesis, time lag between event and conditional field was converted into the streamwise distance z where the convection velocity of eddies was assumed to be identical to the bulk velocity. It is clear that the high (low) speed streaks extended in a quasi streamwise direction are found at outer side, i.e. x > 0, above (below) the symmetry plane. The most significant streaks are appeared first at z~7d, which is comparable to a distance measured from the upstream to downstream location of the measurement along the centerline of the pipe. The streaks have slight inclination respect to the x-z plane and gets closer downstream. The streamwise extension of the streaks is approximately 5d. The magnitude of conditional streamwise velocity of the streaks reaches approximately 1% of the bulk velocity.

Conclusion

We measured velocity distribution in cross sections of a fully developed turbulent pipe flow upstream and downstream of a 90-degree bend simultaneously by use of synchronizing two sets of PIV system. Linear Stochastic Estimation (LSE) was applied to capture the upstream flow field conditioned by the azimuthal location of the stagnation point downstream the bend. Under condition where the inner side stagnation point stays below the symmetry plane, the conditional streamwise velocity upstream the bend exhibited a high (low) speed streak above (below) the plane on the outer side. Such a structure is possibly responsible to the azimuthal arrangement of the stagnation point downstream the bend.

Fig.1 Typical instantaneous velocity vectors downstream the bend. Color contour represent streamwise, i.e. out-of-plane, velocity components.

Fig.2 Arrangement of two sets of PIV system

Fig.3 Isosurface of streamwise component of conditional fluctuating velocity vectors earned by LSE. The event was set at which the stagnation point locates below the symmetry plane.