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The asymmetric swirl disturbance generator: Towards a realistic and reproducible standard

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ABSTRACT

Flow sensors are exposed to very disparate and usually adverse flow conditions produced by the pipe configuration at the installation location. These so-called installation effects may affect the accuracy of the flow measurement. Within performance tests of water, heat, and cooling meters at flow laboratories, a selection of such installation effects are emulated by standardized disturbance generators. In particular, the standardized swirl disturbance generator is designed to reproduce the flow conditions downstream from a double-bend out of plane, a common installation in realistic pipe networks. However, recent studies suggest that tests with standardized swirl disturbance generators might not be sufficiently reproducible due to instabilities generating random flow patterns downstream. Here, we analyze the flow profile generated by a novel asymmetric swirl disturbance generator and a double-bend out of plane using laser-Doppler velocimetry. Our results suggest that the asymmetric swirl disturbance generator produces flow disturbances with similar features as those downstream from a double-bend out of plane. In consequence, the asymmetric flow disturbance generator is a good candidate for more reproducible and realistic tests of installation effects at flow laboratories and shall replace the current swirl generator in the standards.

1. Introduction

Smart water networks and district heating or cooling networks consist of kilometers of pipework where instrumentation such as flow sensors has a significant importance. For example, heat meters are installed at the consumption points for efficient and transparent billing but also at strategic points of the network like heat exchange stations or heat generation plants to monitor and optimize the efficiency of the distribution system.

Pipe networks for smart grids are complex systems with many installation elements including nozzles, diffusors, pumps, valves, and bends. All these singularities produce flow disturbances such that metering installations are exposed to a large variety of flow patterns besides the fully-developed reference profile. The term installation effects encompasses all flow disturbances generated by the layout of the pipe system that can affect the flow measurement accuracy. Conversely, the disturbances decay during straight pipe sections and the flow profile relaxes towards the fully-developed reference state. Hence, a long straight pipe section downstream from installation elements is needed for the disturbances to relax to the fully-developed reference state. However, in realistic installations, long straight pipe sections are usually not feasible. Consequently, flow sensors are optimized with respect to delivering reliable and robust measurements in a variety of flow conditions. Methods to systematically identify installation effects on flow sensors for water, heat and cooling meters are provided in the standards EN 1434, OIML R 49 and ISO 4064 [1–3]. For the worldwide acceptance of conformity assessments according to the EN 1434-4 standardized "Flow disturbances test" (subclause 7.22), i.e. for the avoidance of market distortions and for the safeguarding of the consumer protection, it is necessary to overwork this test instruction to include a better disturbance generator on the current state of knowledge. For testing purposes, flow laboratories are confronted with the challenge of emulating realistic and reproducible installation effects in testing facilities. The common installation elements producing disturbances, like bends and double-bends out of plane, require large three-dimensional installations that are inconvenient to realize in standard test facilities. Consequently, the approval tests for water, heat, and cooling meters (OIML R 49-2:2013 [3]) make use of standardized disturbance generators that are meant to emulate flow patterns from realistic installations including bends and double-bends. However,

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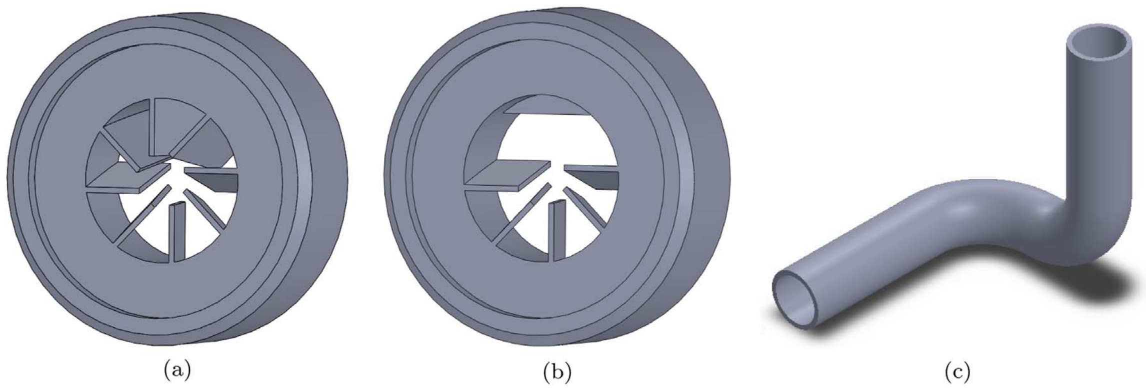

Fig. 1. (a) Standardized swirl disturbance generator according to EN ISO 4064-2:2014, OIML R 49-2:2013 and EN 1434-4:2007 [1–3]. (b) Asymmetric swirl disturbance generator [4]. (c) Double bend out of plane.

recent studies suggest that the standardized swirl disturbance generator (Fig. 1 (a)) might not generate a reproducible flow pattern. Due to normal manufacturing tolerances, samples of the standardized swirl disturbance generator are not fully symmetric. Consequently, the generated flow field is not fully symmetric and small asymmetries generate instabilities that get amplified by the strong swirling component, as studied by Tawackolian [4] and Eichler [5]. Small geometrical differences within the angle of the blades, the cross-sectional diameter, or the centering of the device in the test-section result in asymmetrical flow patterns and, hence, instabilities that grow due to nonlinear interactions in the swirling flow. These instabilities are unique in position and intensity for each device and each realization of the experiment. Consequently, the flow pattern downstream from a standardized swirl disturbance generator is asymmetric and not reproducible.

However, flow patterns in realistic installations are not symmetric either. To address the reproducibility problems of the standardized device, Tawackolian [4] explored a novel device that enforces the flow asymmetry and thereby creates a more reproducible asymmetric flow field. The new asymmetric swirl disturbance generator consists of a combination of two standardized disturbance generators. The design includes five rotated blades to produce swirling flow combined with a disturbance plate that blocks 7.0% of the cross-section. In addition to the improved reproducibility, the asymmetric swirl disturbance generator is also expected to be more realistic in emulating the flow patterns downstream from a double-bend out of plane. This common pipe configuration, consisting of two 90° bends rotated by 90°, was investigated by several authors because of the adverse combination of asymmetric and swirling flow generated downstream from the bend [6–8].

In this article, we analyze the flow patterns downstream from the asymmetric swirl disturbance generator and a double-bend out of plane in DN15 (Fig. 1(b) and (c)). We collect LDV data of all three velocity components at various measurement sections downstream from the two devices and study the downstream development of the axial flow profile and swirl intensity using performance indicators. Further, we compare the flow characteristics downstream from the asymmetric swirl disturbance generator with references of the standardized swirl disturbance generator and the double-bend out of plane.

With the present project, we aim to elucidate if the novel asymmetric swirl disturbance generator can generate flow patterns that are more realistic for emulating the flow patterns of actual installations compared to flow patterns generated by the standard disturbance generators. The goal is to enable tests with realistic and reproducible installation effects in industrial test facilities. Such tests will provide valuable information to improve the robustness and accuracy of water, heat, and cooling meters.

2. Materials and methods

2.1. Experimental set-up

To visualize the flow patterns downstream from the asymmetric swirl disturbance generator and the double-bend out of plane (Fig. 1(b) and (c)), we use a commercial laser-Doppler velocimetry (LDV) probe from ILA GmbH/OPTOLUTION Messtechnik GmbH and measure the velocity components at different cross-sections downstream. The measurement procedure followed in this article is analogous to the one used for the measurements by Graner et al. [9] for the standardized swirl disturbance generator. A window chamber and transparent pipe are used to enable optical access for the laser and the water is seeded with neutrally-buoyant silver-coated tracer particles. The laser probe is mounted on a traversing system for automated displacement in a Cartesian coordinate system. The traversing system is installed on the side of the window chamber to measure the axial velocity component as well as the velocity component in y-direction, and on top to measure the velocity component in x-direction. Fig. 2 (a)–(c) illustrates the three positions of the LDV probe to measure the three velocity components. Fig. 2(d) shows the LDV probe ready to measure the axial velocity component.

The double-bend out of plane is realized with a diameter $D = 15.0$ mm and curvature ratio $r/D = 1.5$, with r the curvature radius of the bends. Fig. 2(f) shows the piping work solution designed to test a double-bend out of plane in a standard test bench. To ensure fully-developed flow entering the double-bend out of plane, we install a flow conditioner followed by $140.0D$ of straight pipe upstream from the double bend. An LDV measurement confirms the fully developed flow upstream from the double bend. We consider five cross-sections downstream from the double-bend out of plane with normalized distances $z/D = 11.0$, $z/D = 32.0$, $z/D = 49.0$, $z/D = 66.0$, and $z/D = 103.0$.

Similarly, the asymmetric disturbance generator is installed $100.0D$ downstream from the inlet of the test section to ensure fully-developed flow at the inlet of the disturbance generator (Fig. 2(a)–(c)). We collect LDV data at five cross-sections downstream from the asymmetric swirl disturbance generator. The normalized downstream distances are $z/D = 12.0$, $z/D = 30.0$, $z/D = 50.0$, $z/D = 70.0$, and $z/D = 105.0$.

From a perspective looking upstream, the asymmetric swirl disturbance generator provides counter-clockwise swirling flow. In contrast, due to the arbitrary choice of assembly in present experimental setup, the double-bend out of plane provides clockwise swirling flow. To facilitate a comparison, all measurements from the asymmetric swirl disturbance generator are mirrored accordingly.