The challenge of correct flow sensor installation with respect to flow disturbances

In the field of water and heat/cooling meters, it is well known that the accuracy of the flow measurement can be compromised by elements like pipe bends and edges, pumps, valves, etc. in the installation, which are mounted in close proximity to the flow sensor.

These installation elements influence the flow velocity distribution inside the pipeline, mainly downstream but also upstream. This can, depending on the measurement technology, have an influence on the accuracy of the flow sensor. However, theoretical predictions of how these elements will actually disturb the flow are often inaccurate or simply do not exist for all possible cases. Systematic knowledge about how all the various flow velocity distributions will affect the measurement accuracy of the flow sensor can be considered as even more rare. The influence of flow disturbances on the accuracy of a flow sensor is typically only tested for a limited number of flow disturbing installation elements or standardized flow disturbers.

This guideline is therefore for you who would like to know more about the following:

- What are flow disturbances?
- How does Kamstrup by design ensure measurement accuracy of its flow sensors upon flow disturbances?
- How does Kamstrup test its flow sensors with respect to flow disturbances?
- What experiences does Kamstrup have regarding accuracy of its flow sensors and flow disturbances, beyond general recommendations found in Kamstrup's technical documentation?

Definition of flow disturbances

The water flow through a pipe system quantified by an average flow rate given e.g. in l/h or m³/h does not tell us anything about the actual inhomogeneity of the flow velocity distribution in the pipe. Theoretical flow velocity distributions are according to EN 1434 the HAGEN-POISEULLE distribution for laminar flow and GERSTEN&HERWIG/SCHLICHTING for turbulent flow. Thus, flow is characterized by flow profiles and is thus a 3-dimensional phenomenon. As an example, the flow velocity along the center of the pipe of both laminar and turbulent flow will be maximum, whereas the flow velocity at the pipe walls will be zero. The mentioned reference profiles for so-called fully developed flow are observed in long straight pipes with a homogenous temperature distribution in the pipe. Any deviation from these conditions will generate distorted flow profiles.

As an example, [1] shows that the swirling flow downstream of the symmetric swirl generator according to EN 1434:2015 will need about 100xD to have a homogeneous distribution again. Flow profiles can be characterized by values like a profile asymmetry and turbulence factor as well as a swirl angle [2], which can also be determined experimentally with e.g. laser optical methods. Any deviations from the characteristic values of the fully developed flow can be considered as a flow disturbance. Swirl and asymmetry can hereby be considered as two main types of flow disturbances.

Kamstrup investigates the flow profiles and their effect on the measurement accuracy both numerically and experimentally. Figure 1 below shows an example of in-house velocity measurements performed at various distances 10D, 50D and 100D downstream of an out-of-plane double bend. The flow along the pipe axis is presented in the first row (primary flow), while the in-plane flow is presented in the second row (secondary flow). Arrows indicate the flow structure of the secondary flow.

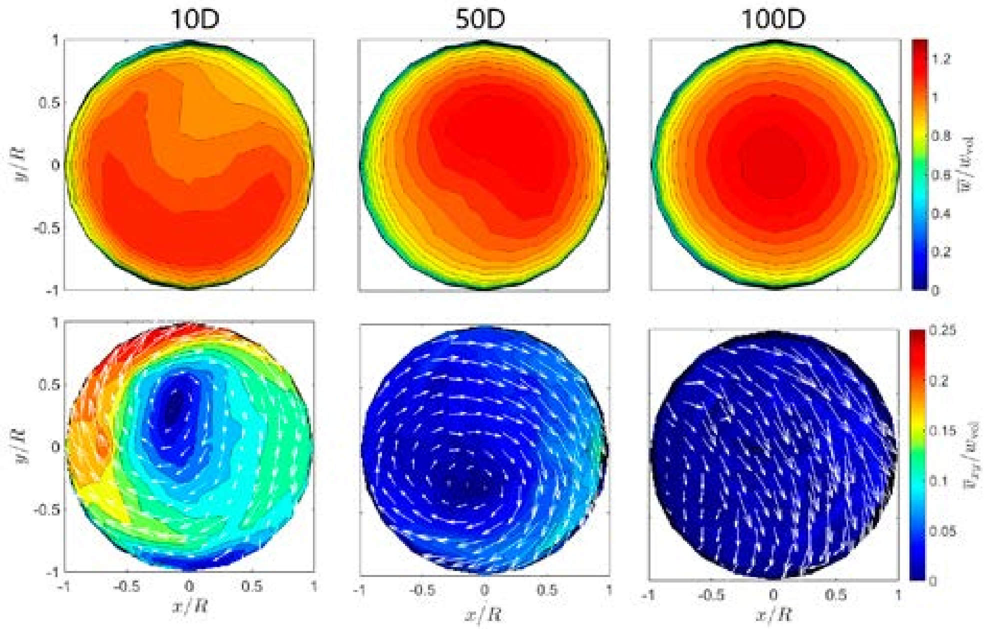


Figure 1. Average velocity profiles of the axial (first row) and in-plane (second row) fluid velocities measured with laser doppler velocimetry (LDV) at Kamstrup, in planes at various distances (given as a function of the tube diameter D at the top of each pair of figures) downstream of a out-of-plane double bend. The color represents values of velocity magnitude as a function of the average axial velocity, the white arrows (in-plane measurements only) show the flow structure

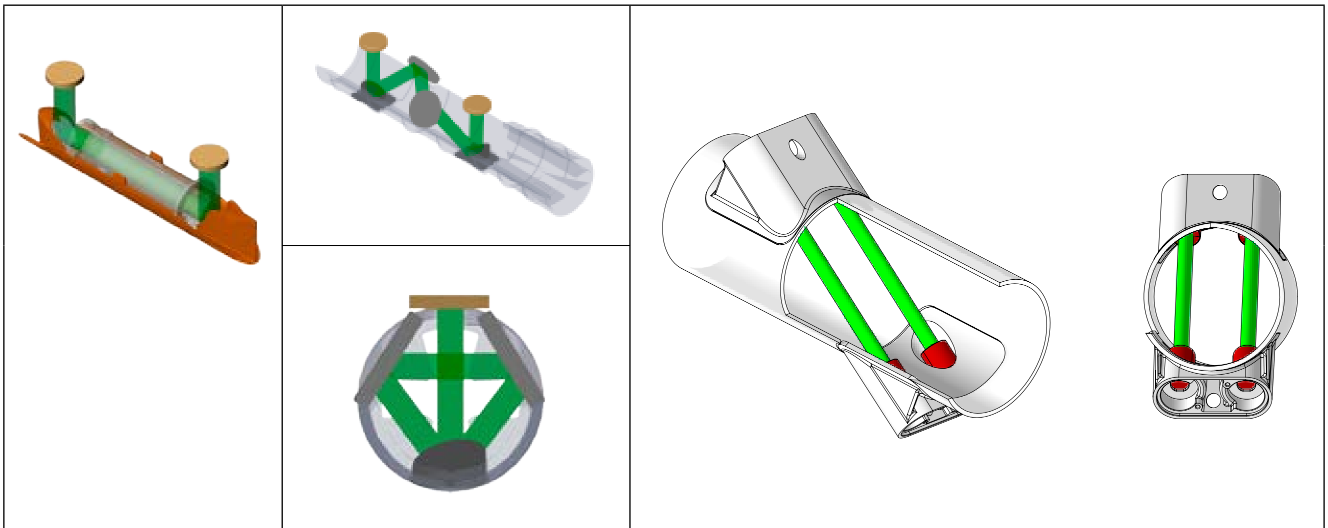
[1] Th. Eichler, Th. Lederer; Flow Measurement and Instrumentation 42, 2015, 89-97

[2] Guidelines for the Fluid Mechanical Validation of Calibration Test-Benches in the Framework of EN 1434 (March 2007). Task force Laseroptical FLOW DIAGNOSTICS PTB-METAS-BEV-OPTOLUTION-ILA

Design of Kamstrup flow sensors with regard to flow disturbances

Ultrasonic flow sensors from Kamstrup are based on the transit time method, i.e. we measure the difference of the transit time of an ultrasonic signal with and against the flow to determine an averaged flow velocity and by time integration the volume, which has passed through the flow sensor at a given time. The detected transit time difference is a result of the superposition of the ultrasonic wave and the flow velocity along the whole ultrasonic path. Depending on the chosen ultrasonic path, as given by the respective design of the flow sensor, different flow velocity distributions in the measuring section might theoretically lead to different results of the transit time and thereby of the measured volume. However, to ensure the accuracy of its flow sensors, Kamstrup utilizes different design principles. Flow conditioners are e.g. used to provide sufficiently reproducible flow profiles in the measuring section at a given average flow. In addition, the ultrasonic path covers as large parts of the flow profile in the measuring section as possible with a given number of transducers.

Figure 2 illustrates representative examples of measuring tube assemblies for Kamstrup flow sensors qp 0.6…2.5 m^3/h, qp 3.5…100 m^3/h and qp 150…1000 m^3/h. Flow sensors qp 0.6…100 m^3/h include flow conditioners and the measuring pipes have a conical shape. For flow sensors qp 0.6…2.5 m^3/h, a single ultrasonic path has proven to be sufficient for the required accuracy. For the larger flow sensors with qp 3.5…100 m^3/h, one ultrasonic path is still guided by reflectors along a triangle to cover major parts of the 3-dimensional flow velocity distribution. The big flow sensors from Kamstrup with qp 150…1000 m^3/h utilize 4 transducers resulting in two separate ultrasonic paths. Both ultrasonic transducer pairs are positioned in the flow to provide diagonal paths across the measuring section. The results of measurements from both transducer pairs are taken into account for the final flow calculation.



qp 0.6…2.5 m^3/h	qp 3.5…100 m^3/h	qp 150…1000 m^3/h

Figure 2: Representative measuring tube assemblies for flow sensors qp 0.6…2.5 m^3/h, qp 3.5…100 m^3/h and qp 150…1000 m^3/h. Flow conditioners and the signal paths are indicated.

Testing of Kamstrup flow sensors with respect to flow disturbances

Type testing – flow disturbances upstream (by out-of-plane double bend)

Kamstrup flow sensors for heat and cooling meters are type-tested according to EN 1434:2015 and FprEN 1434:2022 from 04-2022 with respect to flow disturbances. Based on this test "Kamstrup's flow sensors (are qualified to) require neither straight inlet nor straight outlet to meet the Measuring Instruments Directive (MID) 2014/32/EU, OIML R75:2002 and EN 1434:2015" as outlined in the technical documentation from Kamstrup. The type tests are supposed to emulate an installation directly behind a double bend out of two planes.

However, the test according to FprEN 1434:2022 from 04-2022 utilizes an asymmetric swirl generator (ASG), which appears to emulate flow downstream a real double bend even better than the symmetrical swirl generator. In general the ASG exposes the flow sensor with a combination of swirl and asymmetric flow. Different relative orientations and additional flow are tested. From this perspective the new test can be considered as even more severe. Kamstrup can provide flow sensors from qp 0.6 to 1000 m^3/h, which already have passed this new test.

"The background for the CEN/TC176/WG2 working group behind EN 1434 to include a flow disturbance test in the type test of flow sensors for heat meters was the fact that tube bends before the meter are the only obstacles that cannot be avoided in real life. Most other obstacles just before the meter can be avoided (move obstacles from before the meter to after the meter) under installation and valves before the meter can be sealed in fully open position to avoid the severe flow disturbances that may occur from partly opened valves. [3]."

Type testing – flow disturbances downstream (e.g. through mounted temperature sensors)

Kamstrup's flow sensors with qp 0.6…10 m^3/h often have the possibility to directly mount a temperature sensor in the outlet (M10x1 connection). Thereby they are potentially exposed to flow disturbances, which might be generated upstream of the mounted temperature sensor. However, comparative tests during type approval with and without a mounted temperature sensor in the outlet of the flow sensor did not show noticable differences in the error of the respective flow sensor. Note that external installation elements will be mounted further away from the measuring section, i.e. close to the flow sensor but not as part of the flow sensor. This shows in summary that installations mounted downstream of the flow sensor will have an even minor effect on the measurement accuracy of the flow sensor.

Additional testing (e.g. out-of-plane double bends, single bends, partly open valves, mixing zones)

In addition to (mandatory) type approval tests, in particular our flow sensors from the group qp 0.6…2.5 m^3/h have been tested thoroughly with success both at Kamstrup [4] and at a highly reputed German flow laboratory (MID-Cert) with respect to flow disturbances of different kinds. The results are partly published in [4] and upon request, Kamstrup can provide you with the test results from MID-Cert. In summary, they show that the observed errors were always within the maximum permissible error of the metrological class 2. Our flow sensors are therefore fairly robust with respect to many severe flow disturbances generated by different kinds of installation elements mounted upstream the flow sensors like e.g. out-of-plane double bends, single bends, partly open valves and mixing zones supplied from two fitted pipes. This makes these flow sensors particularly suitable for installation in compact district heating/cooling substations where room for long straight inlet or outlet sections is often limited.

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[3] Short summary of the discussions in the CEN/TC176/WG2 working group, made by Kamstrup's participant in this group.

[4] EuroHeat&Power English Edition Vol. 15 III/2018.

Experiences with flow disturbances

Many aspects of flow sensor installation including considerations with respect to flow disturbances are addressed e.g. in EN 1434-6:2015, "Heat meters – Parts 6: Installation, commissioning operational monitoring and maintenance" and CEN CR 13582, "Heat meter installation. Instructions in selection, installation and use of heat meters".

Due to copyrights, Kamstrup cannot provide you directly with these documents. To acquire CEN CR 13582 (and other EN standards), please refer, for example, to the Danish Standard organization's web shop here.

Alternatively, you can find your national standardization organization here.

However, Kamstrup's technical documentation complies with these general recommendations and suitable guidelines for installation can be found there.

By the mentioned facts that flow characterization itself as well as knowledge about the interaction of specific flow profiles with different flow conditioners and signal paths, precise predictions and categorization of flow disturbances are a complex matter. Recommendations are therefore often given qualitatively only and can also be based more on common agreements motivated by the wish for a minimum requirement formulation for all flow sensors in the field than on actual knowledge. Quantitative recommendations shall therefore be considered as a guideline based on many years of experiences like e.g. the recommendation that "a straight inlet pipe of at least 5 × diameter and an outlet pipe of 2 × diameter in the same dimensions as the flow sensor" will reduce "any effect on the measurement deviation caused by the flow profile." [5].

The following rules of thumb apply:

- Straight long inlets and outlets are in general always recommended where possible.
- Installation elements mounted downstream of the flow sensor can be considered as less critical compared to installations mounted upstream at the same distance to the flow sensor. Conclusively, a straight inlet shall normally be longer than a straight outlet.
- "Heavy flow disturbances" can in particular be expected after an out-of-plane double bend and in the proximity of regulation valves and pumps. For valves and pumps, Kamstrup has the recommendations for its flow sensors described in Table 1 on the next page. For further general installation recommendations, please consider relevant paragraphs of Kamstrup's technical documentation.
- EN 1434 suggests a flow conditioner package consisting of a flow straightener of the NEL (Spearman) type followed by a straight pipe section of 5D upstream the flow sensor and a straight pipe section of 3D downstream the flow sensor. This package will help to reduce heavy flow disturbances and might be helpful in installations, where place for long straight pipes is limited.

In case that you utilize our flow sensors for leak surveillance and permanent performance monitoring (PPM), i.e. in a situation where you want to compare the results of two separate flow sensors in a common line, requirements with respect to straight inlet are more strict to limit any influences from flow disturbances on the result of the separate flow sensors as much as possible. It is particular important that the installation conditions for both flow sensors are as similar as possible.

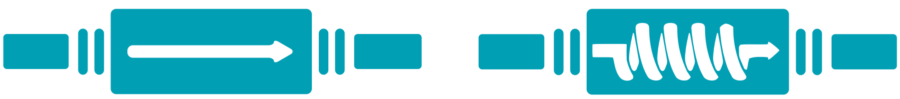
For specific requirements, see the respective technical documentation.

[5] CEN CR 13582, 8.3.2 Inlet and outlet pipes

	Flow sensors DN15...80	Flow sensors DN100...300
Min. pipe distance from out-of-plane double bends mounted upstream	0 x DN [1]	0 x DN [1]
Min. pipe distance from out-of-plane double bends mounted downstream	0 x DN	0 x DN
Min. pipe distance from partly open valves mounted upstream	20 x DN	40 x DN
Min. pipe distance from partly open valves mounted downstream	10 x DN [4]	10 x DN [4]
Min. pipe distance from the pressure side of pumps (pump mounted upstream)	20 x DN	20 x DN
Min. pipe distance from the suction side of pumps [2] (pump mounted downstream)	3 x DN	3 x DN
Min. pipe distance after "any kind of a strand formation caused by the combination of two flow circuits with different fluid temperatures" [6]	10 x DN	10 x DN
Min distance between 2 flow sensors (measuring reverse flow) [3]	0 x DN	0 x DN

Table 1: Recommendations for minimum straight inlet and outlet at a double bend out of two planes, regulation valves and pumps.

1) According to EN 1434:2015 and FprEN 1434:2022 from 04-2022. If possible, a straight inlet is in general recommended.
2) Be aware of the minimum required static pressure (static pressure at the outlet of the flow sensor).
3) Kamstrup flow sensors do not measure reverse flow. However, with 2 flow sensors, where one is always mounted in flow direction, reverse flow can still be measured.
4) The minimum distance to flow disturbing obstacles in the installation depends on, whether the obstacle is mounted upstream or downstream the flow sensor. For downstream installation the minimum distance can be smaller than for upstream installation.



[6] CEN CR 13582, 8.3.3 Influence of insufficient temperature mixing on measuring accuracy

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Kamstrup A/S
Industrivej 28, Stilling
DK-8660 Skanderborg
T: +45 89 93 10 00
info@kamstrup.com
kamstrup.com