

EXPERIENCES OF CLAMP-ON ULTRASONIC FLOWMETERS IN SMALL PIPES

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Abstract: Two commercially available clamp-on ultrasonic flowmeters were tested in the Laboratory of Measurement and Information Technology at Tampere University of Technology. In these tests two different pipe sizes, four different pipe materials and several sensor setups were used. The results show that it is very difficult to make accurate measurements in small pipes, because several factors have quite large effect on the meter performance. The measurement method, error in measured wall thickness, pipe material and the quality of the material are examples of these factors.

Keywords: Clamp-on, Ultrasonic flowmeter, Water meter

1 INTRODUCTION

There are about 550 000 domestic water meters in use in Finland. Most of them are very small in size and some of them have never been tested after the installation. In principle, water meters could be tested easily with clamp-on ultrasonic flowmeters and that was the main reason to make several tests in small pipes and in different conditions with clamp-on ultrasonic flowmeters.

Several problems exist, when water meters are tested on site with clamp-on flowmeters. Water meters are usually located so that flow conditions are not very good. Quite often water pipelines are constructed so that the water meter is in a very tight place. The result is that water meters are often installed too near elbows, elbow combinations, valves etc.

One problem is that water pipelines are made of several materials, which gives more requirements for the used clamp-on ultrasonic flowmeters, because they are sensitive to the quality of pipe material. One of the parameters is the wall thickness of the pipe. Cairney [1] has found that when the ratio between the outside diameter of the pipe and the wall thickness is smaller than 10, the error increases significantly.

Other parameter is the inner diameter of the pipe. A small error in the inner diameter can cause rather large errors in the flowrate. For example, an error of one millimeter in the diameter of a 25,4 mm pipe corresponds to an error of about 8 % in the flowrate [2].

The aim of this study was to test the practical usability of commercial clamp-on ultrasonic flowmeters in normal use in water flow. The following aspects were in mind in the tests:

- reproducibility by removing and reinstalling the ultrasonic transducers on the same spot on the pipe
- repeatability
- the effect of different ultrasonic transducer placings
- the effect of wall thickness
- the effect of selecting wrong pipe material in the flowmeter setup
- the effect of different pipe materials.

2 EQUIPMENT

The usability of clamp-on ultrasonic flowmeters in small pipes was tested in the Laboratory of Measurement and Information Technology. In the tests two commercially available clamp-on ultrasonic flowmeters, two different pipe sizes, four different pipe materials and several different transducer placings were used.

The reference meter in the measurements was a coriolis mass flowmeter. The used clamp-on ultrasonic flowmeters are denoted by 'meter A' and 'meter B', and the corresponding transducer pairs are A1, A2, B1 and B2. The intended applications of the transducers are:

- A1, transducer pair for pipe sizes 19...125 mm.
- A2, transducer pair for pipe sizes 51...305 mm.
- B1, 4 MHz transducer pair for pipe sizes 12...50 mm.
- B2, 2 MHz transducer pair for pipe sizes larger than 50 mm.

Flying start and stop calibration method was used in the tests. Pulse counting was used to determine the measurement results indicated by the meters. The measurement time was selected so that at least 10 000 pulses were counted from the reference meter.

Used piping configurations are shown in Figure 1 and Figure 2 seen from above.

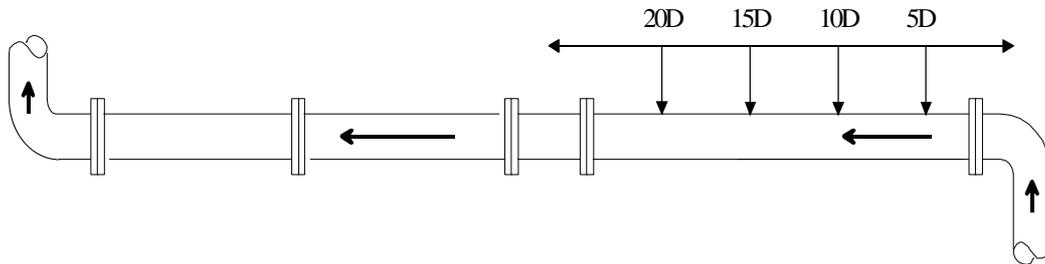


Figure 1. Used DN50 stainless steel piping configuration.

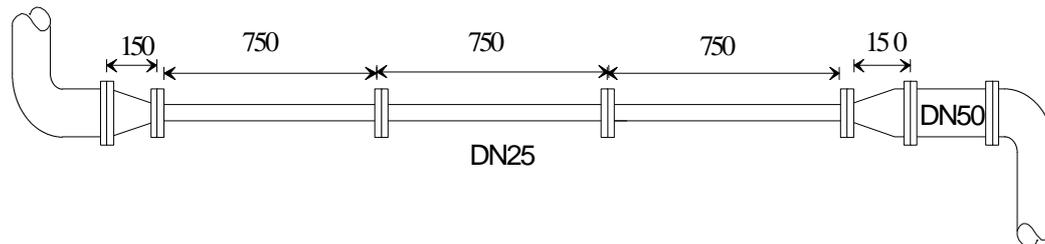


Figure 2. Used DN25 piping configuration.

In the measurements three different measurement modes were used. The modes were direct, two traverses and four traverses. Also four different orientation angles were used for transducer placing. Measurement modes are shown in Figure 3 and the orientation angles in Figure 4.

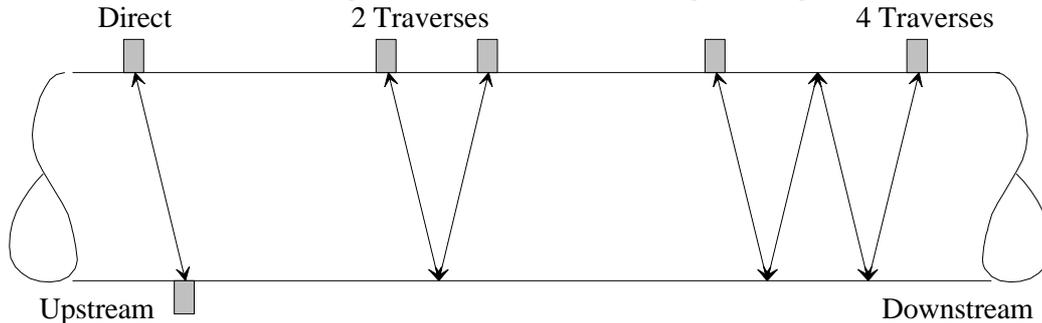


Figure 3. Used measurement modes.

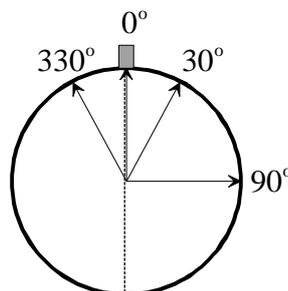


Figure 4. Orientation angles for the transducers looking upstream.

3 RESULTS

3.1 Reproducibility and repeatability

The first task was to test, how different measurement modes, different transducer pairs and the removal and reinstallation of the ultrasonic transducers affect measurement results. Measurements were made in DN50 stainless steel pipe 20D downstream of a single elbow in perpendicular plane to the elbow (0°). There were six series of measurements and each of the series consisted of six

individual measurements. Reynolds number was 22500. Results of these measurements are presented in Figure 5.

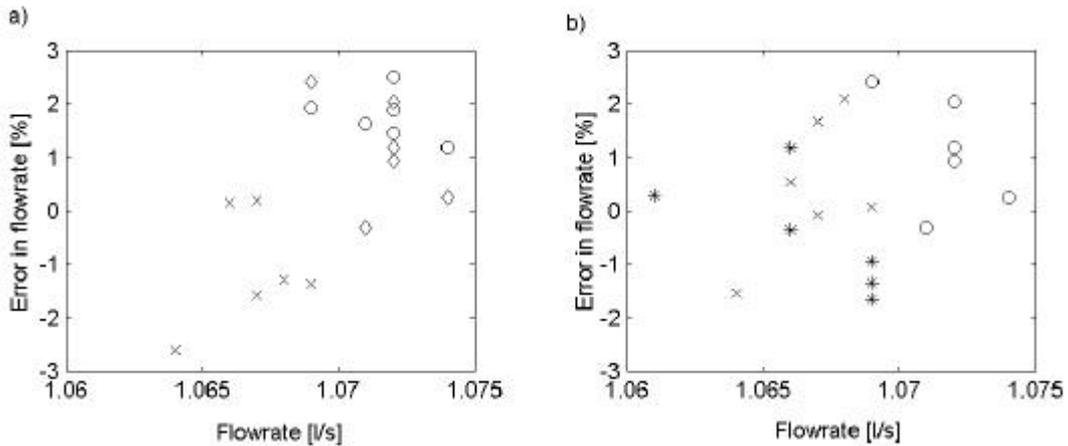


Figure 5. Errors when removal and reinstallation of the ultrasonic transducers was used.

- a) The removal and reinstallation of the ultrasonic transducers using different measurement methods. \circ direct mode, meter A with transducer pair A2, \times two traverses, meter A with transducer pair A2 and \bullet four traverses, meter B with transducer pair B2.
- b) The removal and reinstallation of the ultrasonic transducers when using different transducer pairs in two traverse measurement mode. \bullet meter A with transducer pair A2, $*$ meter A with transducer pair A1 and \times meter B with transducer pair B1.

In Table 1 are presented the deviations of the mean flowrate for the ultrasonic clamp-on flowmeters, when the reproducibility was tested in different installations of the transducers.

Table 1. Deviations in reproducibility testing.

Transducer/ mode	A2/ Direct	A2/ 2 traverses	A1/ 2 traverses	B1/ 2 traverses	B2/ 4 traverses
Deviation of the mean	0,47 %	0,37 %	0,38 %	0,58 %	0,17 %

In Table 2 are presented the results of repeatability testing in different installations. Also these measurements were made in series of six measurements and each of the series consisted of six individual measurements. The meters were installed on a DN50 stainless steel pipe 20D downstream of a single elbow.

Table 2. Results of repeatability testing.

Transducer/ mode	A1/ 2 traverses	A1/ 2 traverses	B2/ 4 traverses	B2/ 4 traverses
Angle	0°	90°	0°	0°
Reynolds number	167 000	167 000	167 000	22 500
Mean standard deviation	0,09 %	0,12 %	0,08 %	0,36 %
Relative error	-2,7 %	-5,5 %	-2,5 %	2,3 %

The results show that there are differences in deviations between the modes and transducer pairs in reproducibility testing. One reason for the differences is that the used pipe size, DN50 is at the upper limit of the transducer pair B1.

Repeatability tests show quite acceptable standard deviations but the errors are too big for calibration purposes.

When comparing the effect of different orientation angles in transducer placing on the standard deviations, the results show insignificant differences (0,09 % and 0,12 %), but the difference in errors is quite large (-2,7 % and -5,5 %).

3.2 The effect of ultrasonic transducer placing on the flowrate

In the tests both flowmeter A and flowmeter B and four different orientation angles in transducer placing were used. The used ultrasonic transducer pairs were A1 and B2. Also four different locations downstream of a single elbow were used. In Figure 6 are presented the results for the orientation angles 0° and 90° and in Figure 7 the results for the angles 30° and 330° .

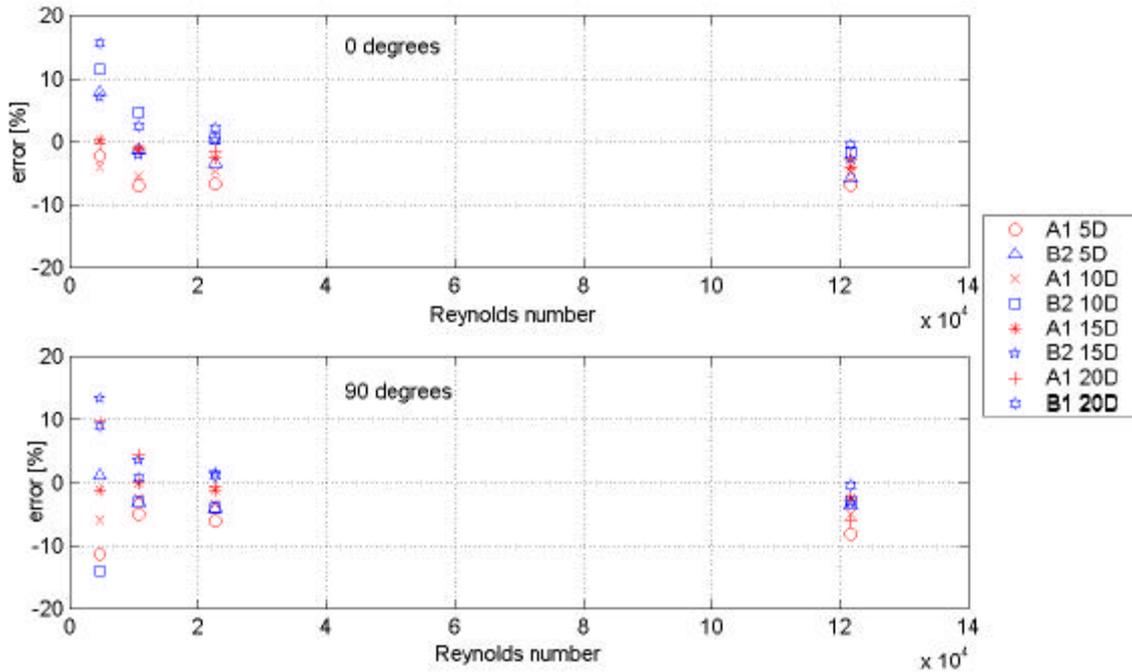


Figure 6. Relative errors in flowrate as a function of Reynolds number, when the orientation angles in transducer placing were 0° and 90° at the distances of 5D, 10D, 15D and 20D downstream of a single elbow.

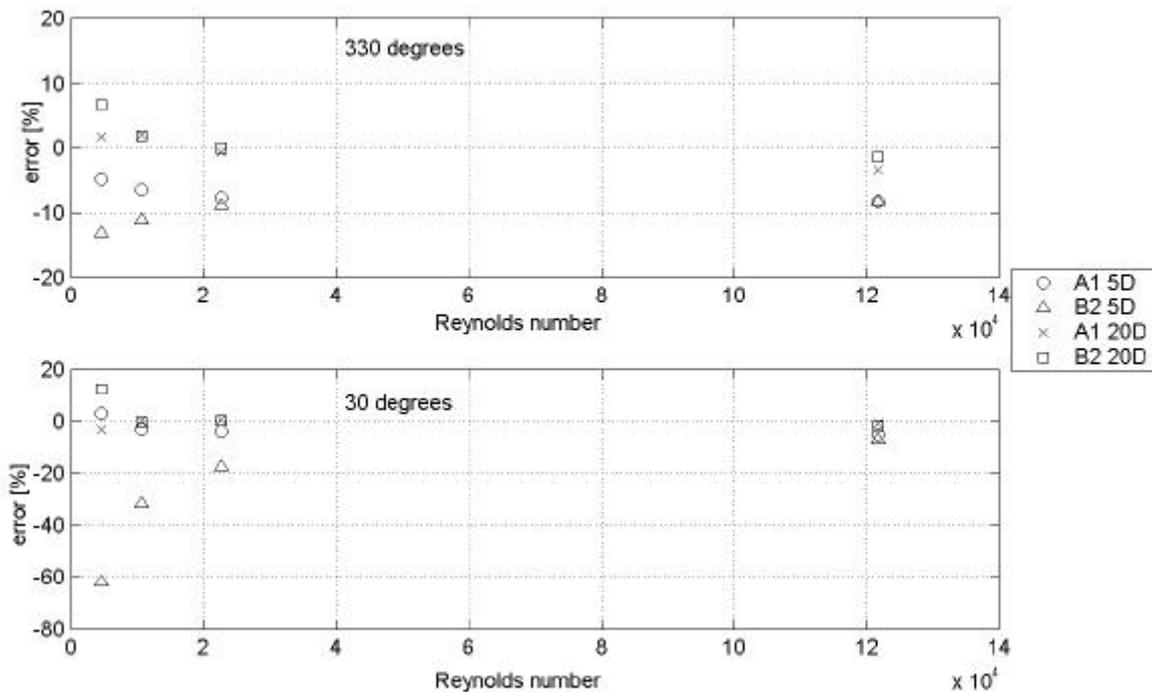


Figure 7. Relative errors in flowrate as a function of Reynolds number, when the orientation angles in transducer placing were 30° and 330° at the distances of 5D and 20D downstream of a single elbow.

As can be seen from Figure 6 and Figure 7, the absolute value of the error increases significantly when the Reynolds number is below 10 000. The used angle in transducer placing does not have much effect on the error, when distance from the single elbow is 20D, which means that the velocity profile must be well developed and/or the profile correction procedure of the meter works correctly. Also the standard deviation increases significantly when the Reynolds number is below 10000.

In table 3 are presented the standard deviations in the measurements 5D and 20D downstream of a single elbow.

Table 3. Standard deviations of the measurement results in different installations.

Transducer pair Orientation angle		Clamp-on flowmeter A				Clamp-on flowmeter B			
		A1 0°	A1 30°	A1 90°	A1 330°	B2 0°	B2 30°	B2 90°	B2 330°
Distance	Re	Standard deviation [%]							
5D	4500	0,14	0,53	0,25	0,19	0,76	0,73	0,59	0,21
	10500	0,09	0,05	0,02	0,09	0,17	0,36	0,18	0,38
	22500	0,08	0,05	0,04	0,09	0,17	0,08	0,05	0,22
	121500	0,03	0,07	0,06	0,03	0,16	0,02	0,02	0,23
20D	4500	0,10	0,12	0,70	0,45	0,21	0,19	0,48	0,14
	10500	0,06	0,15	0,19	0,07	0,08	0,07	0,07	0,10
	22500	0,05	0,04	0,19	0,03	0,05	0,09	0,13	0,08
	121500	0,06	0,08	0,06	0,04	0,04	0,09	0,05	0,06

3.3 The effect of the error in measured wall thickness on the flowrate

The effect of the error in measured wall thickness A was measured in two different pipes. The first pipe was DN25 stainless steel pipe and the other DN25 copper pipe.

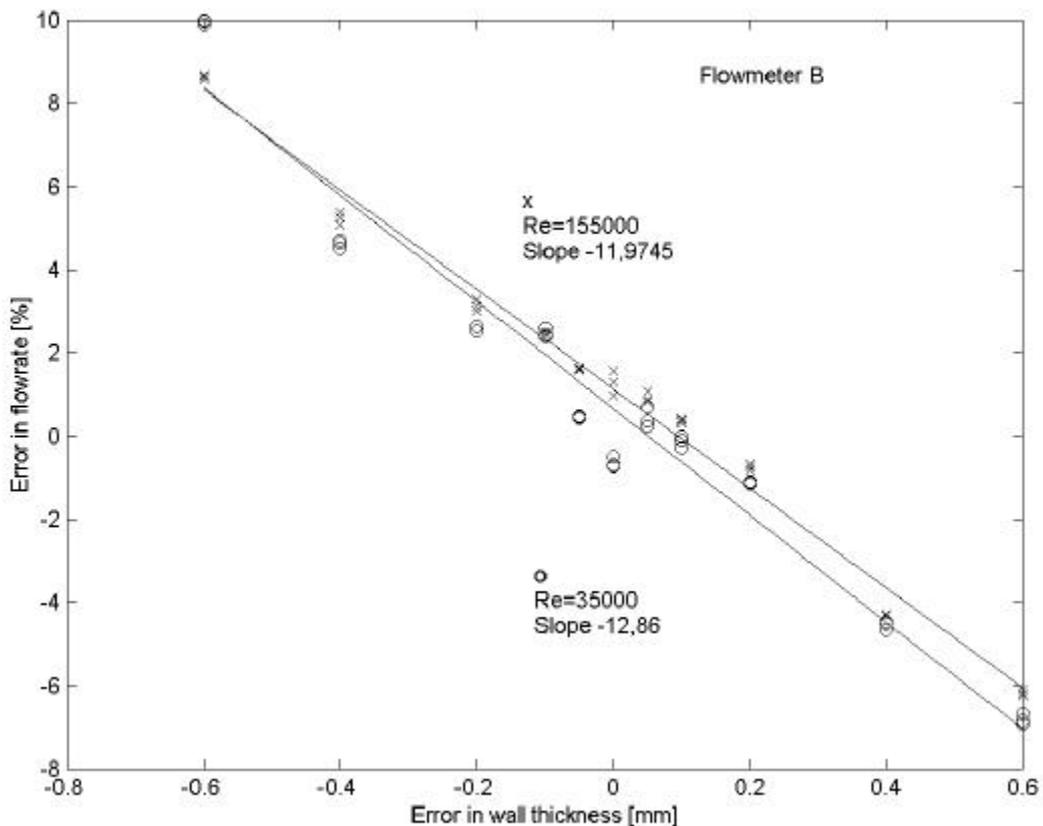


Figure 8. The effect of the error in measured wall thickness in DN25 stainless steel pipe on the flowrate, flowmeter B, 60D downstream of the contraction, orientation angle 0°, two traverses.

In Figure 8 are shown the measured errors for different errors in wall thickness. An error of 0,1 mm in wall thickness of the DN25 stainless steel pipe means an error of 3,2 % of the actual wall thickness. This 0,1 mm error in the wall thickness causes an error of 1,1 % in flowrate at Reynolds number 35 000 and an error of 1,3 % at Reynolds number 155 000. The straight lines shown in Figure 8 and Figure 9 have been fitted to the data using the method of least squares.

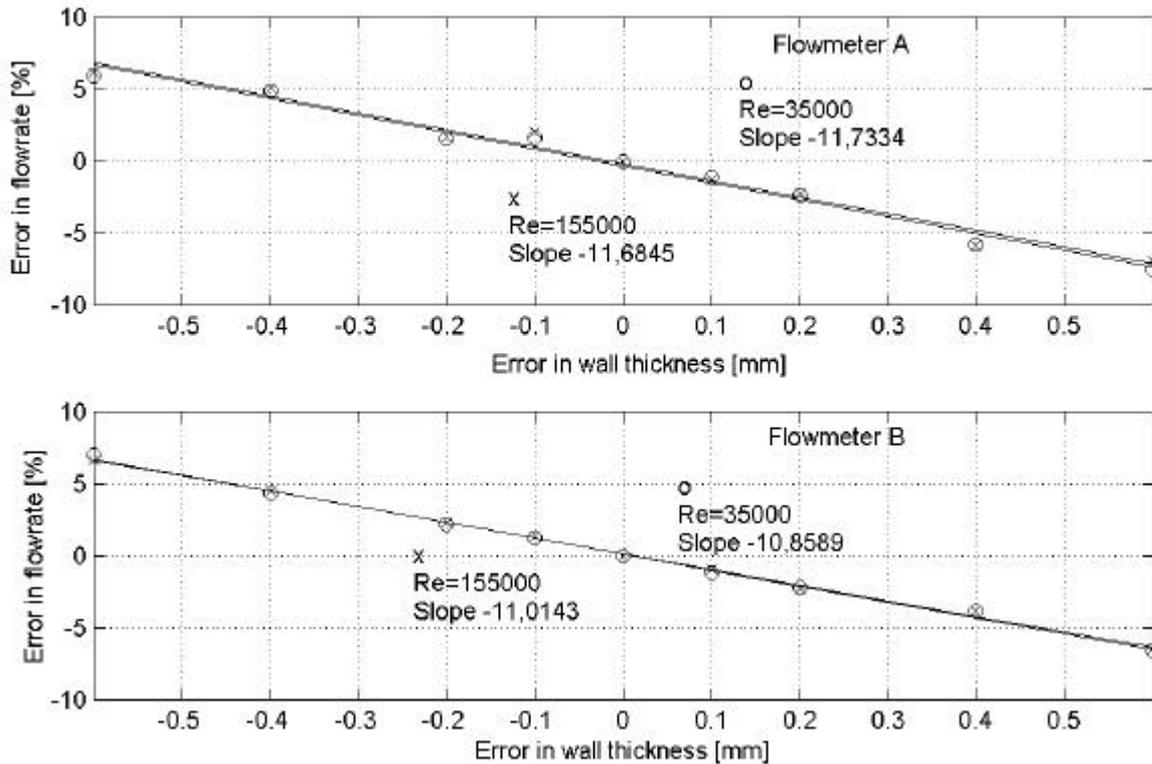


Figure 9. The effect of an error in measured wall thickness in DN25 copper pipe on the flowrate. Flowmeters installed 60D downstream of the contraction, orientation angle 0° , two traverses.

In Figure 9, a 0,1 mm error in the wall thickness of the DN25 copper pipe is about 6,2 % of the actual wall thickness. This 0,1 mm error in wall thickness causes an error of approximately 1,1 % in flowrate regardless of the used flowrate and flowmeter.

3.4 The effect of selecting wrong pipe material in flowmeter setup

Next test was made by selecting wrong parameters of the pipe material in the setup of the flowmeter. The real material of the pipe was stainless steel 304 and the used wrong materials were stainless steel 302, 410 and 430. The flowmeter B was installed 60D downstream of the contraction at the orientation angle 0° . The results of these measurements are shown in Figure 10.

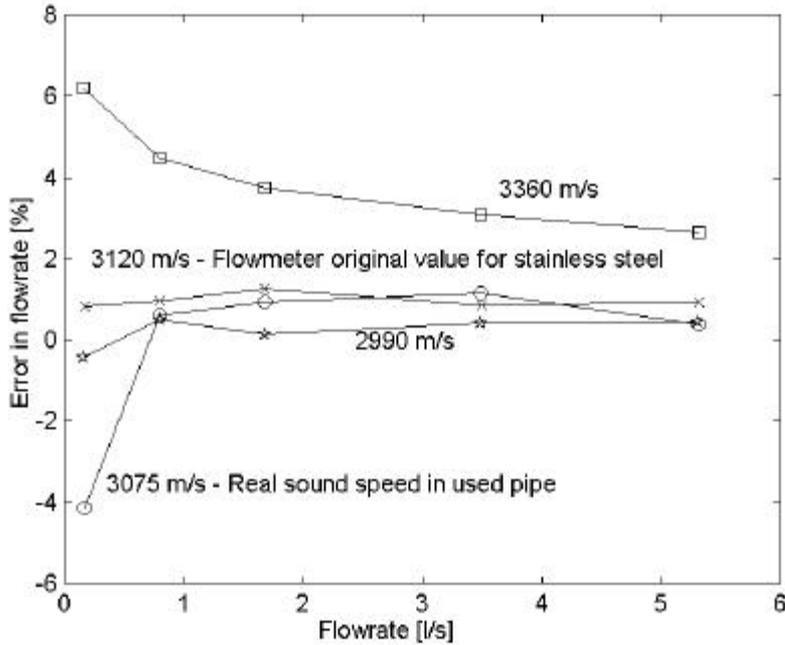


Figure 10. Effect of selecting wrong parameter in the setup procedure of flowmeter B.

As can be seen, in this pipe size a 100 m/s error in the sound speed of the used material causes a shift of about 1 % in flowrate.

3.5 The effect of different pipe materials

Four different materials were used in the measurements in DN25 pipes. The materials were copper, iron, stainless steel 304 and high-density (HD) polyethylene. Measurements done with copper and stainless steel 304 have been presented before in this paper. There were problems when using the two other materials. It was almost impossible to do any measurements in iron pipe, because it was hard to get good contact between transducers and the pipe wall. Reason for this is obviously the inhomogeneous nature of the pipe and the high frequency of the used ultrasonic transducer.

There were different problems with HD polyethylene. This material was not included in the flowmeters library of the pipe materials and it could not be added there. So some measurements were made using parameters of low-density (LD) polyethylene and as a result errors bigger than 5 % in flowrate was measured.

4 CONCLUSIONS

From the results several aspects can be found. Standard deviations can be very small, but at the same time the errors in flowrate can be quite large. A small error e.g. in wall thickness can cause relatively large errors in flowrate. There are some common materials, which are not included in the pipe material library of the clamp-on ultrasonic flowmeters and the measurements in those pipes cannot be made as routine work. The use of clamp-on ultrasonic flowmeters especially in small pipes depends on very many factors and it seems that using commercially available meters it is real hard to get reliable results. The need for reliable on-site, non-intrusive calibration method still exists.

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