Triangular cross section duct for ultrasonic flow rate measurement

A. Bagdonas, G. Daubaris, V. Petkus, A. Ragauskas

Telematics Science Laboratory
Kaunas University of Technology

Introduction

Liquid flow measurements are widely used to control cooling and heating systems. Flow sensor systems based on ultrasonic time-of-flight technology provide a reliable, rugged, and easy to integrate solution. Most important, ultrasound is also a cost – effective long term solution for flow problems.

Short ultrasonic wave pulses [1, 2] and the time-of-flight method are used for probing of the liquid. The flowing liquid causes time differences, frequency variations and phase shifts in ultrasonic signals, which are subsequently digitally evaluated by a flow meter electronics.

The principle behind the measurement is that sound waves traveling with the flow of liquid will travel faster than those traveling against it. The difference in the time-of-flight of the signals is an indication for the flow rate of the fluid.

Most flow meters are designed to measure a flow that follows a certain flow velocity profile. The exact behavior of the velocity profile will depend on many factors such as meter installation effects [4, 5], inlet pipe wall roughness [6], flow rate and viscosity of the fluid [7].

Prior art

The information about the flow profile in a measurement duct is critically important when developing a flow meter. Many authors have analysed various meter optimisation strategies. The first strategy is to improve meter accuracy even when flow profiles are unstable or unknown by increasing the number of ultrasound signal paths or using curved paths. The path weight factors (Fig. 1) are optimized to improve meter performance for a set of velocity profiles. Using only one ultrasound signal path (Fig. 1, a)) it is possible to achieve approximately 10% of measurement uncertainty, and by employing 18 paths the uncertainty could be reduced to 0.2% [8].

The second strategy is to optimise duct configuration by means of flow conditioners or by changing and stabilizing the flow profile [9,12]. The flow profile is changed to turbulent flow by increasing a pressure loss in the duct [9]. This has two advantages: a - the transitional flow regime is moved to low flows; b - the flow profile is less depending on the inlet flow profile.

The last, third optimization strategy is based on a complex ultrasound beam propagation in the duct. The goal in this case is to achieve the beam path location close to the turbulent and laminar flow profile crossing. This minimizes the influence of the different flow profiles on the measuring accuracy and also expands a dynamic range of the device [10, 11, 13, 14].

The main disadvantage of the helical beam propagations (Fig. 3) up to now has been that the duct construction was very complex for manufacturing and it was impossible to optimize the ultrasound path location.

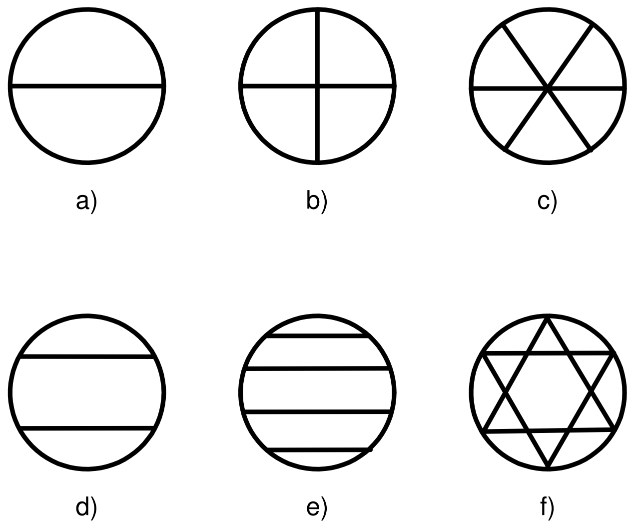

Fig. 1. **Most common ultrasound beam path configurations in time-of-flight flow meters**

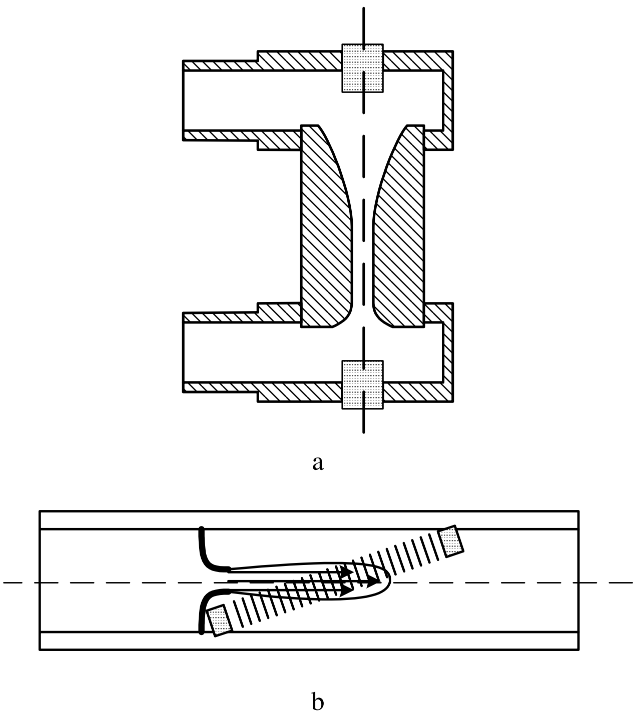

Fig.2. **Measurement uncertainty optimisation by increasing a pressure loss in the duct. Special duct configuration (a) increases velocity speed with minimal pressure losses [9], and cost optimised solution (b) [12]**

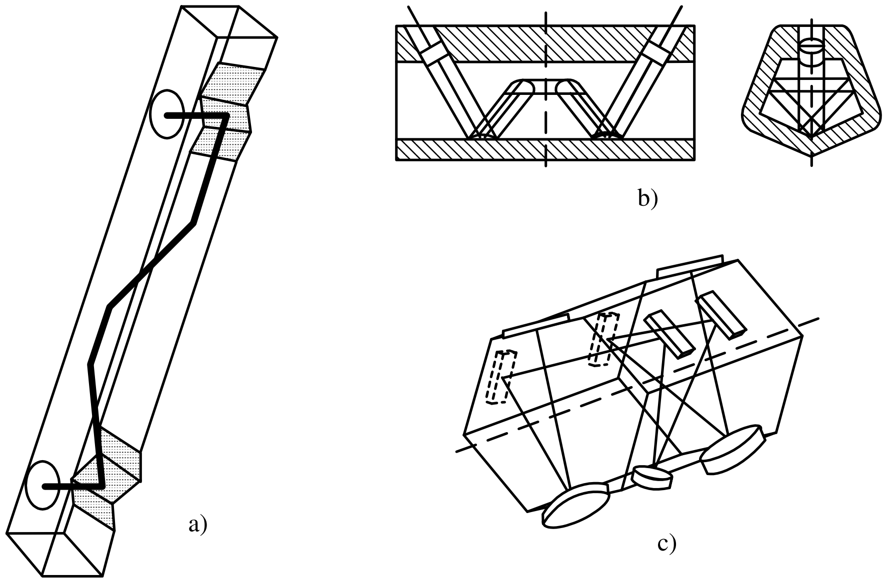

Fig. 3. **Helical beam propagation in ducts: (a) [10], (b) [13], (c) [14]**

Duct with triangular cross section

We have found that the triangular duct [3] has many advantages over another types of ducts (round, quadratic and more complex cross sections). We carried out flow simulations on triangular and rectangular ducts to verify our assumptions. The results have shown that the turbulent and laminar flow profile crossing curve in the triangular duct is more linear (Fig. 4 a), Fig. 5, Fig. 6 a)). The measurement error is significantly reduced over a wide measurement dynamic range applying the triangular duct [3] (Fig. 7).

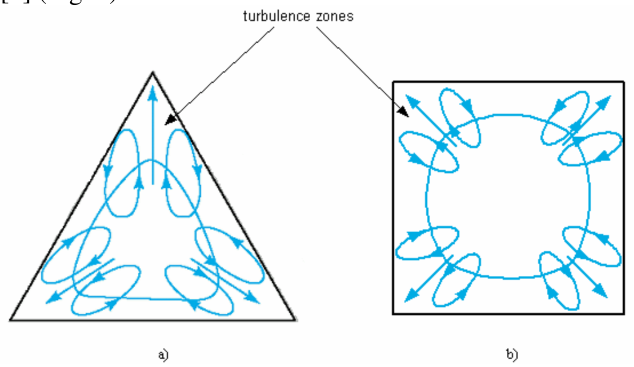

Fig. 4. **Turbulent flow zones in triangular and rectangular ducts [7]**

It is well known [7, 15] that turbulence zones are drastically reducing measurement uncertainty. The flow in turbulent zones is unstable and it depends on the inlet flow profile. The duct with a triangular cross section (Fig. 7) has an advantage against the rectangular cross section (Fig. 4 b)). It is possible to arrange the ultrasound beam so that its path avoids these zones (Fig. 4 a)).

This is limited in the rectangular cross section because the location of the beam path is only one and it is fixed (Fig. 6 b))

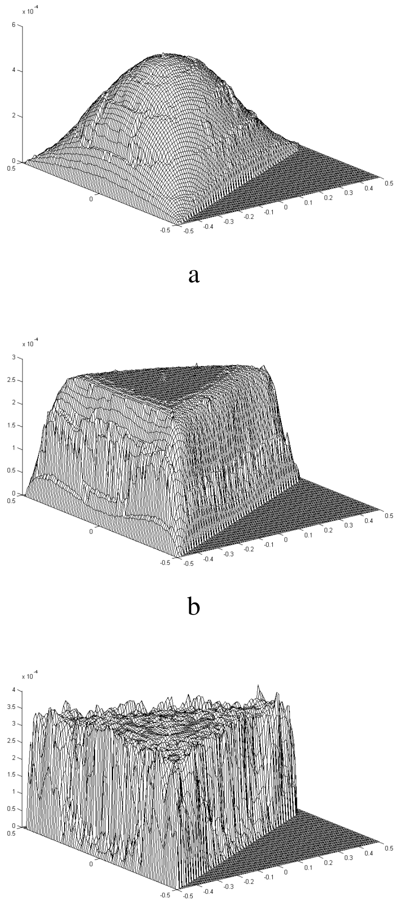

Fig.5. **Flow profiles in the duct with a triangular cross section: a) laminar (Re ≈ 50), b) transitional (Re ≈ 1000), c) turbulent (Re ≈ 10000)**

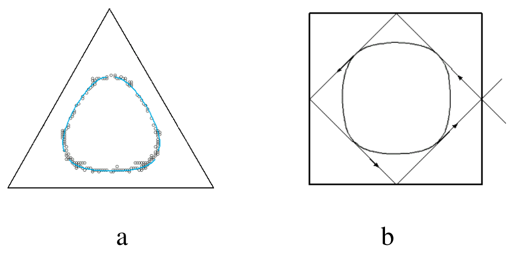

Fig. 6. **Crossing lines between laminar and turbulent flow profiles for triangular (a) and rectangular (b) ducts' cross sections**

in space without possibility of changes of path location in order to optimize the location.

And the last advantage of the triangular cross section against other known cross sections used for helical beam forming is the presence of V-notch at a disturbing wave reflection point (Fig. 7), thus providing a better condition for absorption and deflection of a parasitic wave energy than in the case of the tube having the rectangular cross-section. This effect was largely analysed in [16] works.

Experimental studies of the innovative ultrasonic time-of-flight flow meter [3] have been performed in a wide flow Q range and also in wide temperature range T=20C ... 120C. It has been shown (Fig. 8) that such innovative ultrasonic flow meter fits the accuracy requirements of European standard EN1434-1 (Fig. 8).

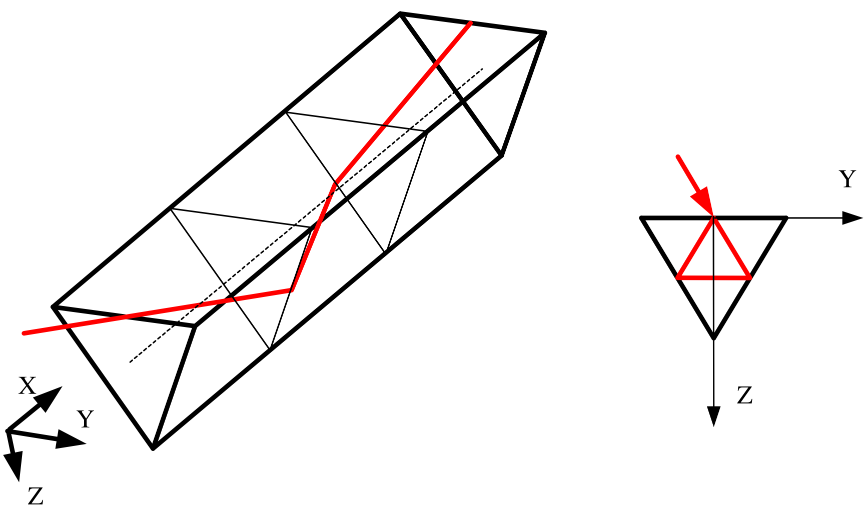

Fig. 7**. Beam (bold internal line) path arrangement optimized for secondary turbulent flow**

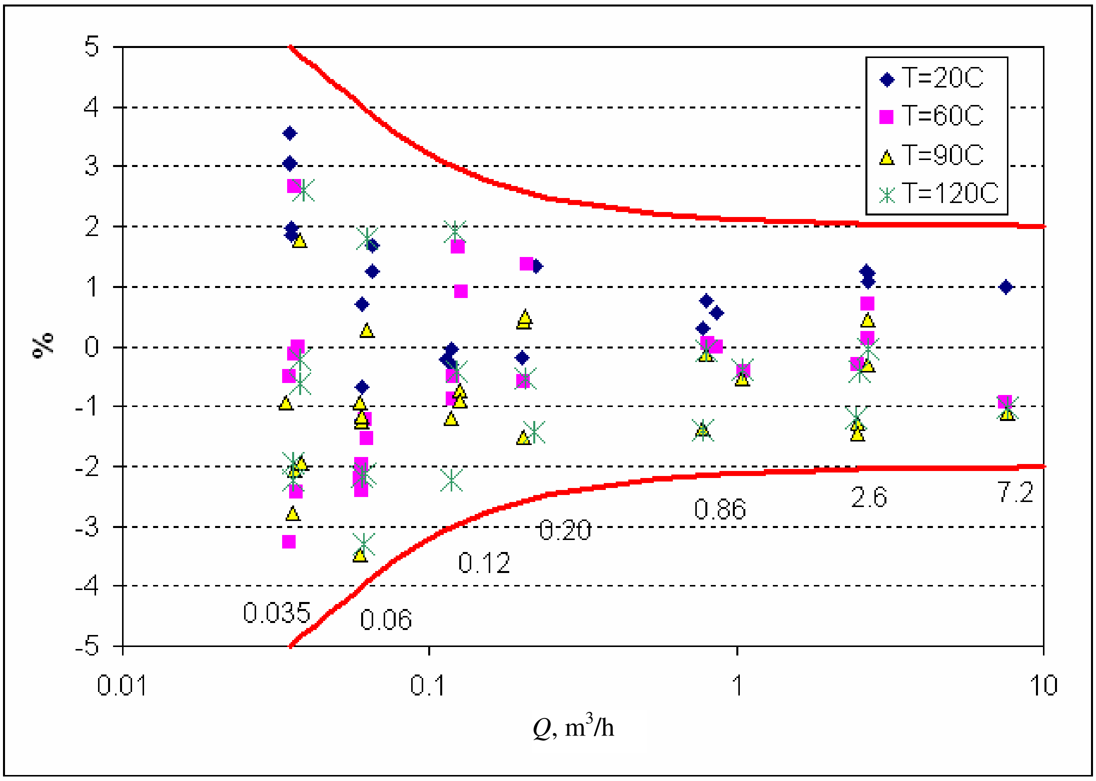

Fig. 8. **Experimental measurements at various temperatures and the error curve limits (bold lines) required by EN1434-1**

Conclusions

We have shown that the duct with a new triangular cross section has the following advantages over another known cross sections:

- turbulent and laminar flow velocity profile crossing curve is more flat that in other ducts,

- it is possible to arrange a more optimal location of the ultrasound beam path which is closer to the crossing line of laminar and turbulent flow profiles and as a result it is possible to achieve a much wider dynamic range and better accuracy of such ultrasonic flow meter,

- comparing with the duct with the rectangular cross section the innovative solution provides the possibility to reduce the influence of turbulent flow zones for the measurement accuracy,

- V shape notch in the triangular duct reduces the amplitude of parasitic ultrasonic signals reflected by the internal surfaces of triangular duct. This is impossible to achieve in the duct with the rectangular cross section.

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A. Bagdonas, G. Daubaris, V. Petkus, A. Ragauskas

Ultragarsinio debito matuoklio trikampio pjūvio matavimų ruožas

Reziumė

Ultragarsinių debito matuoklių metrologinės charakteristikos priklauso nuo daugelio veiksnių: instaliavimo efektų, įeinančiojo srauto profilio, srauto ir aplinkos temperatūrų ir kt. Straipsnyje siūlomas inovacinis trikampio formos pjūvio matavimų ruožas. Pateikiami srauto profilių modeliavimo tokiame ruože rezultatai. Parodyta, kad trikampio pjūvio ruožas turi daug pranašumų, palyginti su kitais žinomais ruožais. Tai įrodyta ultragarsinio debito matuoklio su trikampio pjūvio ruožu eksperimentiniais tyrimais. Jų rezultatai rodo, kad pasiūlytasis techninis sprendimas leidžia smarkiai išplėsti ultragarsinių debito matuoklių dinaminį diapazoną nesumažinant matavimo tikslumo. 2005 m. užregistruota straipsnio autorių paraiška siūlomo inovacinio techninio sprendimo Europos patentui gauti.

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