

CFD analysis of the ultrasonic gas meter channel

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Abstract. This paper describes a process of numerical testing and optimization of the ultrasonic gas meter channel. A conventional ultrasonic flowmeter requires a large installation space due to the quality and stability of the velocity profile. Previously, the shape of the inner gas meter channel was optimized to reach a suitable flow field for ultrasonic measurement. The goal of this work is to find an optimal design of reduced size gas meter to achieve a stable velocity profile with minimum disturbances regardless of the entry conditions in the smallest possible space. Flow characteristics for volume flow rate in the range (1 to 250) m³/h were tested and the parameters of the gas meter were adjusted. Obtained results show good match with the requirements. Future work should aim to the measurement of transit time and the stability of measured values on the optimized design. Finally, it will enable to create the analogy between numerically obtained velocity fields and real transit time measurement.

1 Introduction

Ultrasonic (US) flow meters are devices for the fluid flow measurement using the ultrasonic principle. The flow rate is related to the fluid velocity. When the pressure disturbances are propagated at the speed of sound and the fluid also has a velocity, the absolute velocity of the pressure disturbance propagation is the algebraic sum of them [1]. A simple transit time flowmeter configuration is illustrated in Fig. 1.

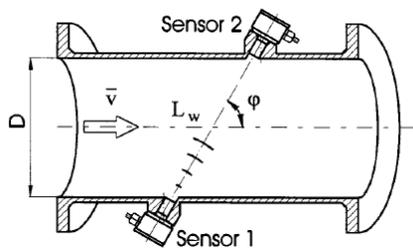


Fig. 1 Ultrasonic flowmeter – principle [2].

The transit time flowmeters evaluates the transit time following eq. (1) in the downstream (t_{12}) and upstream (t_{21}) direction [2]:

$$t_{12} = \frac{L_w}{c+v_a \cos \varphi} \text{ and } t_{21} = \frac{L_w}{c-v_a \cos \varphi}, \quad (1)$$

where L_w (m) is the distance in fluid between two transducers, c (m/s) the speed of sound at the operating conditions, φ the angle between pipe axis and the acoustic (US) path and v_a (m/s) is the axial velocity averaged along the acoustic path.

When the configuration with two transducers used both as transmitters and receivers, the time difference could be evaluated directly by the same pair.

Then, the mean axial velocity along the US path in a circular pipe is given by

$$v_a = \frac{L_w}{2 \cos \varphi} \left(\frac{1}{t_{21}} - \frac{1}{t_{12}} \right) = \frac{D}{2 \cos \varphi \sin \varphi} \left(\frac{1}{t_{21}} - \frac{1}{t_{12}} \right) \quad (1)$$

where D (m) is a pipe diameter.

A disturbance element a deformation of the velocity field as wakes, vortex structures etc. Therefore, the sufficient length of a straight pipe, shown in Fig. 2, before/after the ultrasonic flowmeter is required to achieve optimal performance and accuracy [2].

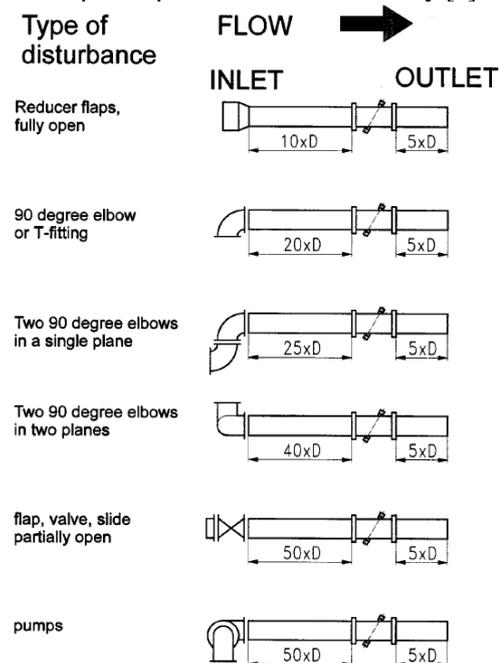


Fig. 2 Minimum straight pipe length for 1% accuracy of a single path transit time flowmeter [2].

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Technical applications of the gas meter follow the International recommendation OIML R137 [3]. These rules contain the specification of performance testing using different pipeline configuration in front of the flowmeter to test the stability of measured values. Fig. 3 illustrates two cases with a straight pipe as a reference case and disturbance OIML d+ as the worst case in terms of the flow disturbance.

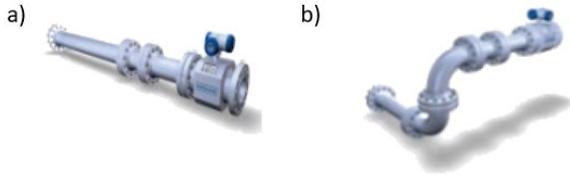


Fig. 3 Piping configurations for flow disturbances [3]: a) straight pipe (reference conditions), b) double elbow with a half-moon plate (OIML d+).

Our team investigates a new gas meter type with no required straight runs upstream. Previously, the disturbance testing of the gas meter with innovative channel shape [4] have been studied numerically. The results published in [5] shows that the disturbance does not affect the velocity field in the US measurement area. For the final prototype the dimensions were reduced so the inner shape had to be modified. These modifications have to be tested numerically to find the solution suitable for the US flow measurement.

2 CFD setup and results assessment

Based on the CAD model of the DN80 gas meter the computational grid and simulation setup was prepared in ANSYS Fluent [6]. Computational grid created in Fluent Meshing contains 2.3 million polyhedral elements. The near wall area is covered by the prism polyhedral elements with respect to the application of wall function models.

2.1 CFD setup

Boundary conditions were applied on the inlet and outlet boundaries. At the inlet cross section (see the green area with blue arrows in Fig. 4) the velocity corresponding to the flow rate Q01-Q06 was applied. Then, the pressure outlet boundary condition with $p = 0$ Pa was defined. Flow conditions are listed in Table 1.

Table 1 Simulated flow rates.

Label	Flow rate (m ³ /h)	Velocity (m/s)	Re (1)
Q01	1	0.055	293
Q02	5	0.276	1463
Q03	10	0.553	2926
Q04	30	1.658	8778
Q05	65	3.592	19018
Q06	250	13.816	73146

Viscous forces are modelled using the two equation turbulence model SST $k-\omega$ model. Standard air considered as a gas with constant properties at 20°C and atmospheric pressure 10^5 Pa have been used as a working fluid.

Computation was set as steady state using the coupled scheme with the second order discretization for pressure, momentum and QUICK for turbulence quantities.

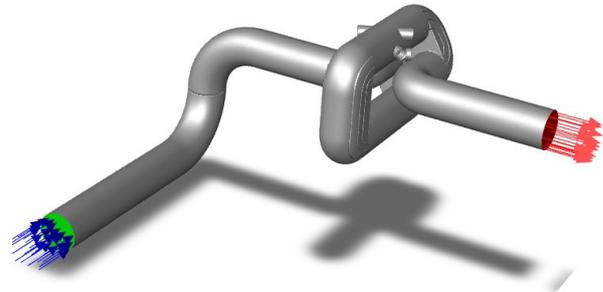


Fig. 4 Case with OIML d+ disturbance – BCs.

2.2 Results assessment

In Fig. 5 there is a sketch of the area of interest for results assessment. These area covers a space in which the ultrasonic measurement is realized. Two sets of cross-sections were defined and labelled as lineZ and lineY. Depending on the x-coordinate, velocity profiles in both directions were observed (labelled as section01 to section09).

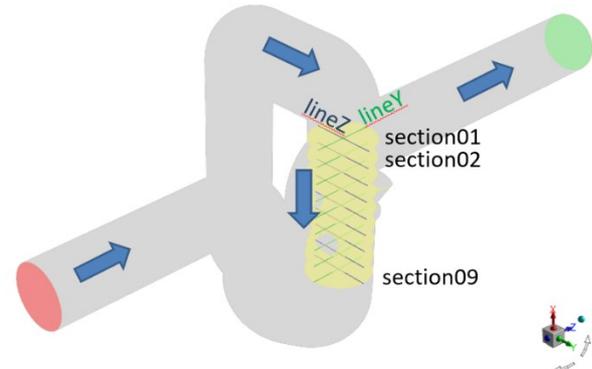


Fig. 5 Cross-section planes – sketch.

To compare the results for different flow rates, the dimensionless velocity U' have been evaluated as

$$U' = \frac{u}{U_{max}} \quad (1), \quad (1)$$

where U (m/s) is the velocity value in the axis direction at the specified point, U_{max} (m/s) the maximum velocity value on the evaluated line.

3 Results

The initial and optimized design have been analysed. The results shown the final design state. Fig. 6 shows results for the case with straight inlet pipe, Fig. 7 then the case with the disturbing element at the entrance. The horizontal axis symbolises the dimensionless coordinate where $\frac{r}{R} = 0$ means the axis of the pipe.

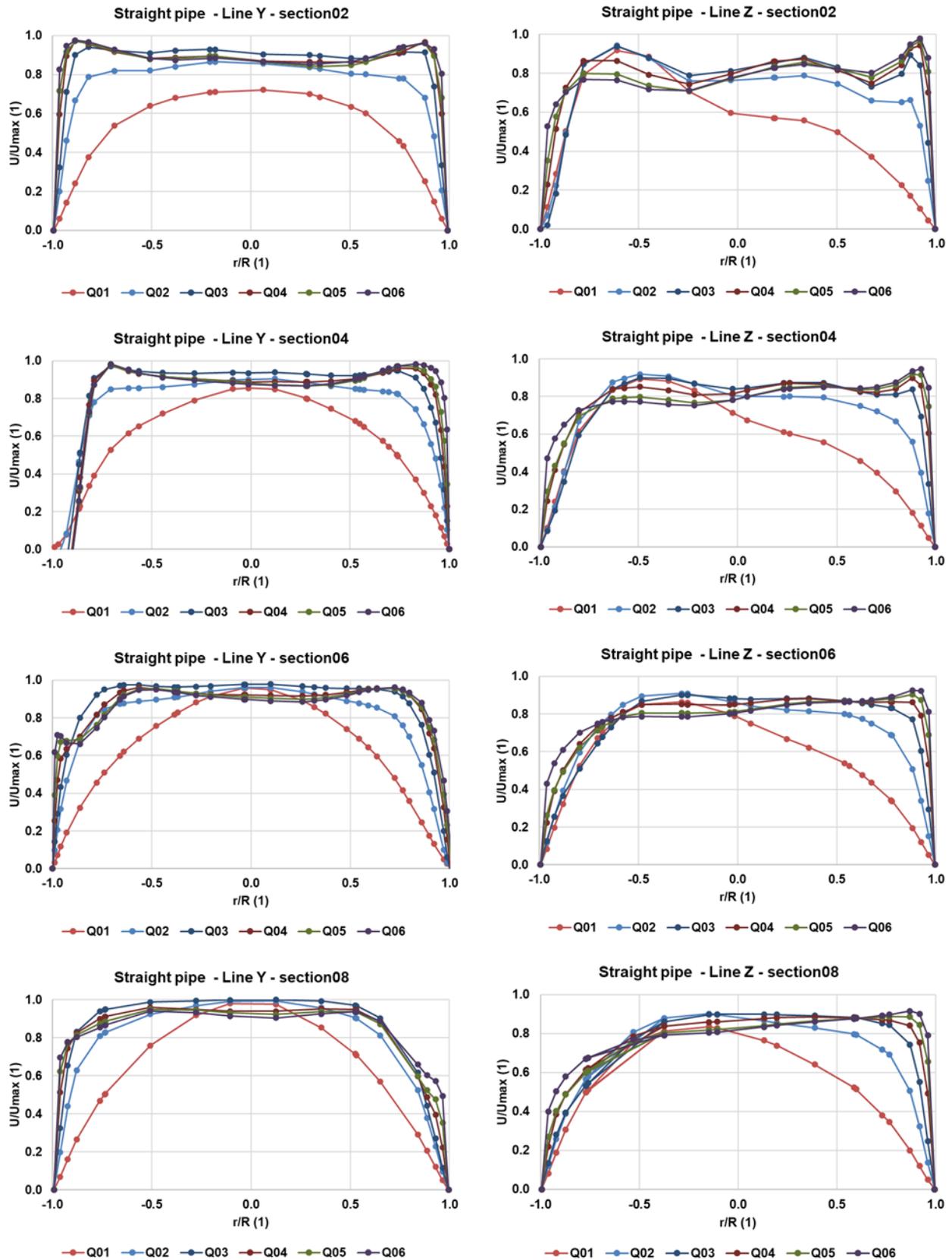


Fig. 6 Velocity profiles – straight pipe (no disturbance), selected sections.

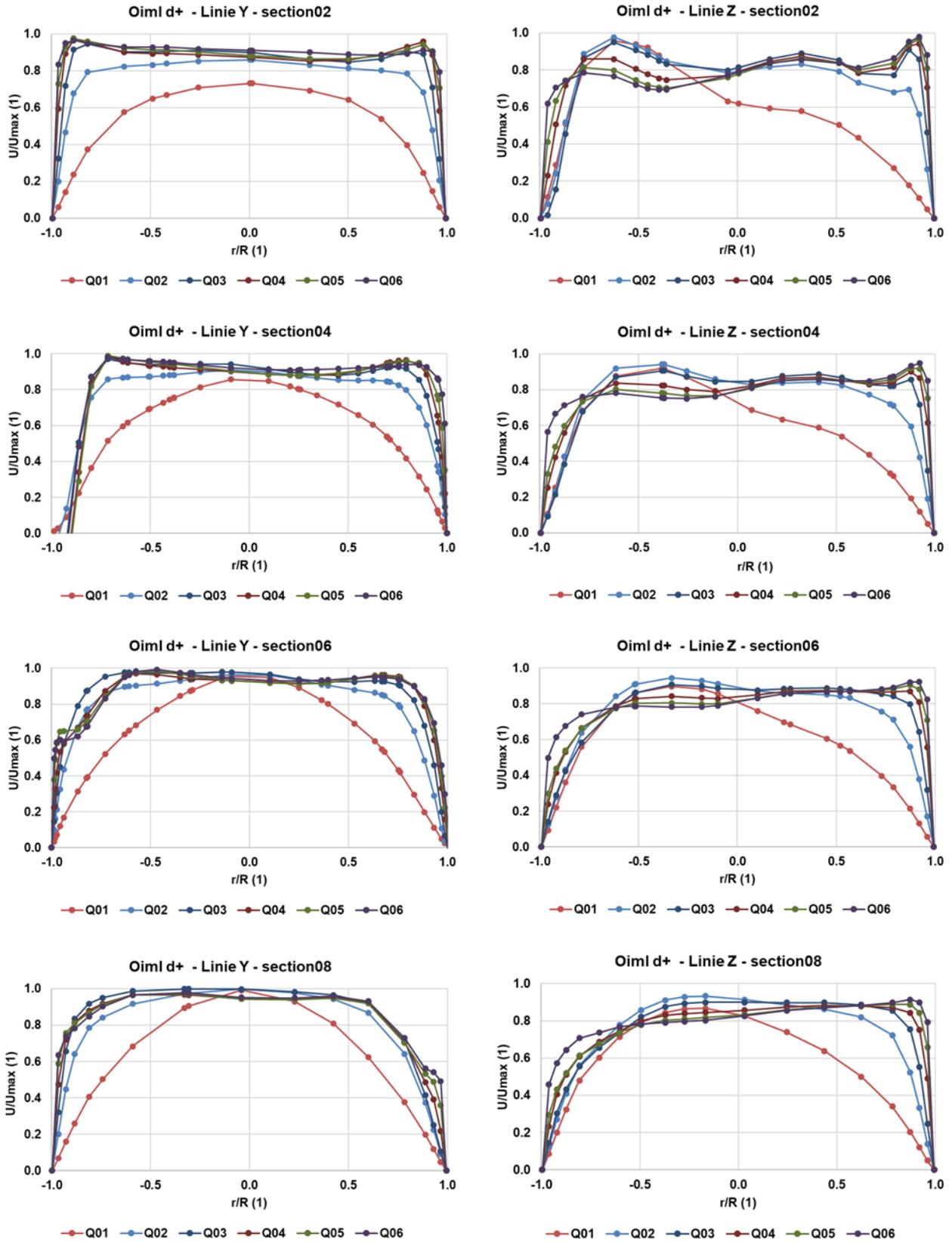


Fig. 7 Velocity profiles – straight pipe (no disturbance), selected sections.

The vertical axis follows the dimensionless velocity U/U_{\max} . The graphs are plotted for flows Q01 to Q06. Except the lowest flow rate, the profiles in line Y direction are independent on the flow rate and the installed disturbance except the lowest flow rate Q01. The change in profile shows the different flow character in laminar (Q01, Q02) and turbulent flow. All the velocity profiles could be considered as symmetrical along the pipe axis. Finally, the change of the profile in the regions $|r/R| > 0.6$ for section08 shows the influence of the downstream channel shape.

The profiles in the second direction (lines Z) exhibit the same behaviour against the flow disturbance. No significant difference have been found between straight pipe and double bend cases. However, the profiles are not symmetrical, when higher velocity values are situated for $\frac{r}{R} > +0.8$. This part is affected by the 3D shape of the upstream channel where the flow is more adjacent to the outer wall of the gas meter for turbulent flow. In laminar regime the flow behaves in the opposite way, when the main flow stream is located closer to the gas meter centre.

4 Conclusion

The current research project aims to the innovative gas meter channel. The main goal is the design optimization of the gas meter with limited dimension, actually. Secondly, the optimized design have to meet the OIML requirements, especially the stability of the velocity fields in the US measuring area.

Based on the previously proposed methodology for a numerical testing using CFD methods, the disturbance effect on the flow field inside the optimized channel have been studied. Several flow regimes have been analysed to find the stability of the flow field across the whole measuring range of the gas meter. The results were presented as the velocity profiles in predefined cross sections. These curves show the change of the profile depending on the flow rate (inlet velocity), as well as the comparison of both disturbance cases which have been taken into account. Generally, main goal was reached, so the profiles match well for both cases.

On the other hand, a few significant differences was found for specific conditions. The velocity profiles evolve gradually from the lowest velocity corresponding to laminar flow, when the increasing of velocity, i.e. the transition to turbulence, leads to the stabilization of the profiles. Then the geometry of the channel causes the nonsymmetric profiles in line Z. The asymmetry is similar for different cases and flow rates, but it is necessary to analyse that phenomena further for the influence on the US measurement.

Finally, the presented results are limited to the CFD methods only. The velocity fields have been analysed as the results. However the ultrasonic measurement is based on the transit time, which is affected by the axial velocity and the working fluid parameters. The future work should be aimed to the experiments for validation of numerical results, also. Then, finding a suitable analogy between

numerically obtained velocity fields, experimentally measured transit time and the stability of measured values will enable the interconnection of all partial activities in the design and optimization of the gas meter channel. It is planned to use the PIV (particle image velocimetry) method for validation of the numerical results.

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References

1. Doebelin E. O. Measurement Systems: Application and Design. McGraw-Hill Inc., 1990.
2. Webster, J. G. The Measurement, Instrumentation and Sensors Handbook. CRC Press, 1999. ISBN 0-8493-2145-X
3. International organization of legal metrology. Gas meters. OIML R 137-1 & 2 Edition 2012.
4. Mikan, J.: Compact Ultrasonic Flow Meter, Especially For Gas. Patent nr. 17/056784.
5. Vít, T., Novosád, J., Dančová, P.: International Journal on Engineering Technologies and Informatics, Volume 2 Issue 1- 2021.
6. Ansys Inc. Ansys Fluent User's guide. Release R2021R2.