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Ugotavljanje občutljivosti ultrazvočnega toplotnega merilnika s programskim paketom ANSYS

Determining the Sensitivity of an Ultrasonic Heat Meter Using the ANSYS Analysis Tool

Marko Boltežar

V prispevku prikazujemo način in rezultate raziskave merilne občutljivosti ultrazvočnega (UZ) toplotnega merilnika. Namen raziskave je bil ugotoviti, kakšna naj bo oblika pretočne merilne celice, da bo zagotovila ustrezno merilno občutljivost. Pri tem smo uporabili simuliranje s programskim paketom ANSYS, ki temelji na metodi končnih elementov (MKE). Z meritvami smo analize z MKE tudi potrdili. Izkazalo se je, da smo s simulacijami dovolj blizu dejanskim razmeram v pretočnem delu toplotnega merilnika, saj so se rezultati dobro ujemali. Končni rezultat izvedenih meritev in simulacij z MKE je prototip merilne celice, ki zagotavlja ustrezno merilno občutljivost toplotnega merilnika oz. toplotnega merilnika.

(Ključne besede: merilniki ultrazvočni, merilniki toplote, občutljivost, paketi programski, ANSYS)

In this paper an investigation of the sensitivity of an ultrasonic heat meter is presented. The goal of the investigation was to determine the shape of the flow measuring cell that gives the maximum sensitivity. The simulation involved the program package ANSYS, which is based on the finite-element method (FEM). The FEM results were experimentally verified. The simulations turned out to be very close to the actual flow conditions within the flow unit of the heat meter. The experimental results agree well with theory. The final result of the FEM analysis and the experimental measurements is a prototype of the measuring cell that ensures the required sensitivity of the heat meter.

(Keywords: ultrasonic heat meters, sesitivity, software packages, ANSYS)

0 UVOD

Energija postaja dandanes v vseh svojih pojavnih oblikah vedno bolj dragocena. Celoten svetovni razvoj sili k varčevanju energije in k iskanju novih alternativnih virov. Porabnik ima namreč pravico, da plača le tisto energijo, ki jo je dejansko porabil. Vse to terja sistemski postopek tako načrtovanja in izdelave merilnikov porabljene energije kakor tudi krmiljenja in vzdrževanja. Ena od naprav, ki je namenjena merjenju rabe toplotne energije, je toplotni merilnik, ki je namenjen merjenju porabljene toplotne energije v stanovanjih, enodružinskih hišah, stanovanjskih blokih itn.

Toplotni merilniki lahko delujejo po različnih načelih. Prevladujejo še vedno mehanski merilniki, med statične merilnike brez gibajočih se mehanskih delov pa spadajo ultrazvočni in induktivni toplotni merilniki.

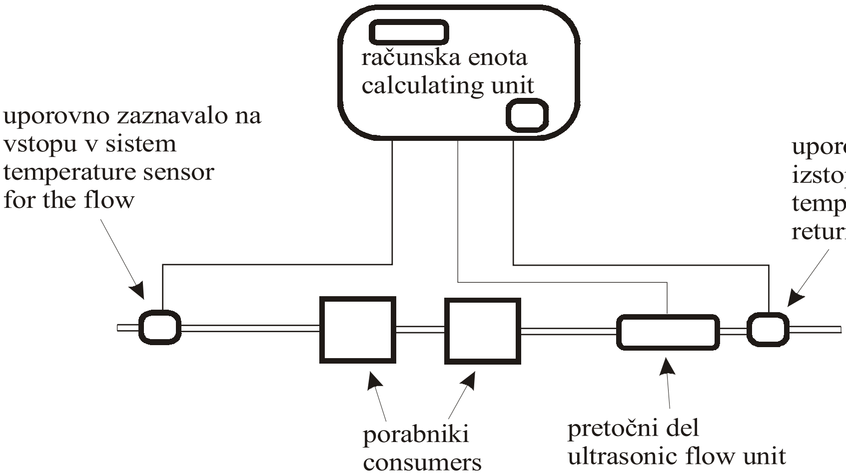
Ultrazvočni toplotni merilnik je sestavljen iz pretočnega dela, dveh uporovnih temperaturnih

0 INTRODUCTION

Energy, in all its forms, is becoming an increasingly valuable commodity. The world is developing in the direction of energy saving and the search for new, alternative sources of energy, regardless of its nature. A consumer has the right to pay only for the amount of energy that he/she has actually consumed. This concept requires a system approach to the design and development of new energy meters. One such device is a heat meter, which serves to measure the consumed heating energy in apartments, family houses and blocks of flats etc.

Heat meters operate on different principles, among which classical mechanical principles still prevail. Modern static heat meters, for example, magnetic inductive or ultrasonic meters have no moving mechanical parts.

An ultrasonic heat meter consists of an ultrasonic flow unit, two temperature sensors for the



Sl. 1. *Vezalna shema toplotnega merilnika*
Fig. 1. *Schematic drawing of a heat meter*

zaznaval in baterijsko napajane računske enote s prikazovalnikom (sl.1)

Pretočni del je sestavljen iz merilne cevi in dveh ultrazvočnih zaznaval. Ta sklop imenujemo tudi pretočna merilna celica.

Kakor bomo videli kasneje, je merilna občutljivost toplotnega merilnika odvisna od dolžine poti med oddajnikom in sprejemnikom in hitrosti vode pri imenskem pretoku. Pri razvoju novega pretočnega dela s krajšimi priključnimi merami ali pretočnega dela, namenjenega drugim pretokom, moramo biti pozorni na ustrezno merilno občutljivost. Pri krajši priključni meri je pot med oddajnikom in sprejemnikom krajša in je zato tudi občutljivost manjša. Tudi hitrosti vode pri imenskem pretoku ne smemo pretirano večati, saj bi s tem presegli dopustni padec tlaka. Občutljivost merilnika, oziroma merilne celice, bomo opazovali s pomočjo povprečne hitrosti vode pri imenskem pretoku v smeri UZ poti ($\bar{v}$) in dolžini UZ poti L. Hkrati lahko opazujemo tudi razliko časov preleta zvočnega signala v in proti smeri toka vode. Pri enem od naših sedanjih merilnikov iz družine UTM-2, s priključno mero 190 mm, ta čas znaša $\Delta t = 240$ ns, zmnožek $\bar{v} \cdot L$, pa znaša 0,260 m^2/s. V tem prispevku se ukvarjamo z načrtovanjem toplotnega merilnika s skrajšano priključno mero 110 mm, pri čemer mora biti občutljivost merilne celice enaka ali pa večja od zgoraj omenjene vrednosti.

1 TEORIJA

1.1 Prenosni učinek

Prenosni učinek [6], po katerem deluje merilnik, sodi med najbolj uporabljene postopke za izvedbo industrijskih merilnikov pretoka. Upošteva spremembo potovalnega časa ultrazvočnega signala v pretočnem sredstvu med točkama A in B, če se ta signal razprostira v smeri ali proti smeri pretoka. Če v pretočno sredstvo

flow and return and a battery-powered calculating unit with a display (Fig. 1).

The flow unit consists of a special measuring pipe and two ultrasonic transducers. This unit is usually known as the flow measuring cell.

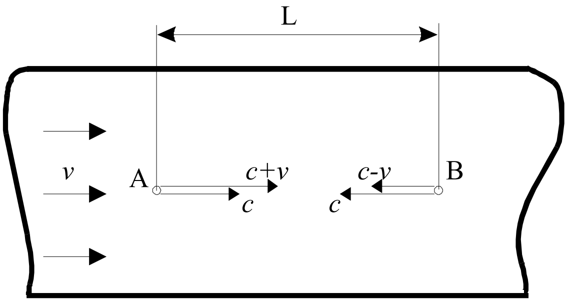
As will be shown later, the sensitivity of the heat meter depends on the length of the sound path between the two transducers and on the fluid velocity at the nominal flow rate. When constructing flow measuring units with either different overall lengths or for different flow rates care must be taken to maintain the meter's sensitivity. With a shorter overall length, the sound path between the transducers is shorter and the sensitivity is therefore lower. As for the fluid velocity at the nominal flow rate, it must be kept within limits so as not to cause an excessive pressure drop. The sensitivity of the heat meter, i.e., of the measuring cell, will be observed on the basis of the mean fluid velocity $\bar{v}$ along the sound path at the nominal flow rate and the length of the sound path L. We can also observe the difference in the transit times for the ultrasonic signals propagating with and against the flow. With one of our existing heat meters from the product family UTM-2 (ultrasonic heat meter) with an overall length of 190 mm the time difference is $\Delta t = 240$ ns and the product of $\bar{v} \cdot L = 0.260$ m^2/s. In this paper the procedure for designing heat meters with a reduced overall length of 110 mm, but where the sensitivity of the measuring cell will be kept at the required value, will be described.

1 THEORY

1.1 Transit time principle

The ultrasonic heat meters of Iskraemeco are based on the well-known transit-time principle [6], which has found broad application in the field of industrial ultrasonic flow meters. The basic idea behind this principle is to take into account the difference in the transit times of an ultrasonic signal odpošljemo ultrazvočni signal iz točke A proti točki B (sl. 2), potem pri mirujočem merjenem sredstvu potuje zvočni signal med točkama z zvočno hitrostjo c. Če pa se pretočno sredstvo premika v isti smeri s hitrostjo v, dobi zvočni signal rezultirajočo hitrost $(c+v)$, kar pomeni, da bo signal dosegel pri gibajočem se sredstvu točko B v krajšem času t_+, kakor pri mirujočem merilnem sredstvu. Če pa sedaj pošljemo signal od točke B k točki A, torej v smeri nasproti gibanju merjenega sredstva, bo rezultirajoča hitrost $(c - v)$, in signal potrebuje daljši čas t_- da prepotuje enako razdaljo v merjenem sredstvu. Časovna razlika $\Delta t = t_- - t_+$ je merilo hitrosti pretočnega sredstva. Tako lahko določimo hitrost vode in pretok prek razlike časov in konstrukcijskih lastnosti pretočnega dela.

traveling between two points, A and B, when the signal travels alternately with and against the flow of the fluid. With a stationary fluid an ultrasonic signal emitted from point A will propagate towards point B with a sound velocity c (Fig. 2). If the fluid is moving in the same direction with a velocity v, then the velocity of the ultrasonic signal will be $(c+v)$, thus resulting in a shorter transit time t_+. If, however, the signal is sent in the opposite direction, its velocity will be reduced to c-v, leading to a longer transit time t_-. The difference in transit times $\Delta t = t_- - t_+$ is proportional to the flow velocity. We can therefore deduce the flow velocity and the flow rate from the transit-time difference and the constructional properties of the flow unit.



Sl. 2. *Širjenje ultrazvočnega signala med točkama A in B v gibajoči se kapljevini - prenosni učinek*
Fig. 2. *Propagation of an ultrasonic signal between points A and B in a moving fluid - the transit-time principle*

Preprost izračun pokaže, da je časovna razlika Δt enaka:

A simple equation shows that the transit-time difference Δt equals

$$\Delta t = \frac{2vL}{c^2} \qquad (1).$$

Pri tem je L razdalja med točkama A in B. V splošnem primeru, ko ultrazvočni snop ni preprosto vzporeden s smerjo gibanja kapljevine, in v primeru, ko porazdelitev hitrosti v cevi ni homogena, pa je enačbo (1) treba zapisati v obliki:

where L is the distance between the points A and B. In a more general case, when the ultrasonic beam is not in parallel with the direction of the flow and when the velocity distribution within the pipe is not uniform, Equation (1) should be rewritten as

$$\Delta t = \frac{2\bar{v}L}{c^2} \qquad (2).$$

Pri tem je $\bar{v}$ povprečna hitrost kapljevine vzdolž zvočne poti med točkama A in B. Časovna razlika Δt je tem večja, čim večji je zmnožek $\bar{v} \cdot L$, to pa pomeni, da je tudi ločljivost toplotnega merilnika, glede na dano rešitev elektronskega vezja, večja. Definirajmo zmnožek $\bar{v} \cdot L$ pri imenskem pretoku, kot mero občutljivosti toplotnega merilnika.

where $\bar{v}$ is the mean fluid velocity along the sound path between the points A and B. The transit-time difference at a given flow rate is proportional to the product $\bar{v} \cdot L$, which also means that the measuring resolution of the heat meter, taking into account the characteristics of the electronic circuitry, increases with increasing $\bar{v} \cdot L$. We therefore define the product $\bar{v} \cdot L$ at the nominal flow rate as a measure of the sensitivity of the heat meter.

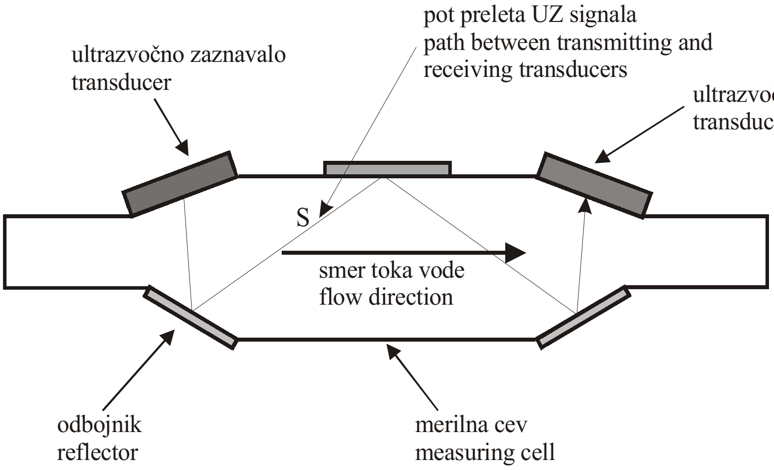
1.2 Prikaz problematike občutljivosti toplotnega merilnika

Občutljivost smo torej definirali kot zmnožek dolžine poti preleta signala L in povprečne hitrosti vode v smeri širjenja zvoka ($\bar{v}$) pri

1.2 Flow-unit sensitivity issues

The heat-meter sensitivity has been defined as the product of the flow path L between the transmitting and the receiving ultrasonic transducers imenskem pretoku merilnika. Pri tem smo pri širjenju ultrazvoka vzeli kar načela geometrijske optike, saj so vzdolžne in prečne izmere merilne cevi mnogo večje od valovne dolžine valovanja UZ, ki znaša približno pol milimetra. Model merilne celice našega toplotnega merilnika je razviden s slike 3. Vidimo, da se zvok širi skozi merilno celico pod različnimi koti glede na smer toka vode. Poglavitna težava pri določitvi občutljivosti merilnika je torej izračun povprečne hitrosti kapljevine vzdolž širjenja ultrazvoka skozi cev.

and the mean fluid velocity $\bar{v}$ along this path. Here, we have assumed that with ultrasonic propagation in the pipe the principles of geometrical optics apply. This assumption is valid as long as the relevant dimensions of the measuring-pipe section are bigger than the wavelength of the ultrasound, which is in our case approximately 0.5 mm. The model of the measuring cell of our heat meter is shown in Fig. 3. Along the flow path the ultrasonic signal propagates at different angles relative to the flow direction. The main problem in determining the sensitivity of the meter is therefore to calculate the mean fluid velocity along the sound path.



Sl. 3. *Model merilne celice toplotnega merilnika*
Fig. 3. *Measuring-cell model of the heat meter*

Interakcija polja UZ s turbulentnim hitrostnim poljem v merilni cevi je v splošnem zelo zapleten pojav. V modelu, prikazanem na sliki 4, izračunamo preletna časa t_+ in t_- z enačbama:

The interaction of the ultrasonic field within the pipe with the turbulent velocity field is generally a very complicated phenomenon. In the simplified model shown in Fig. 4, the transit times t_+ and t_- can be calculated with equations:

$$t_+ = \int_0^s \frac{ds}{c+v(s)} \qquad (3)$$

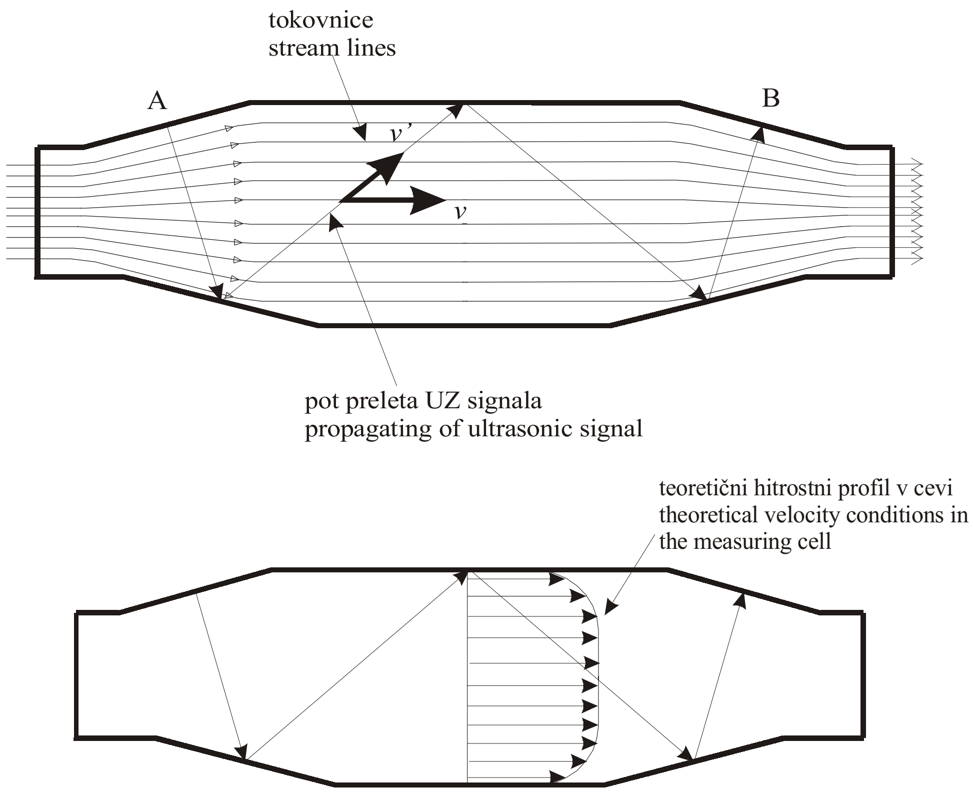
$$t_- = \int_0^s \frac{ds}{c-v(s)} \qquad (4).$$

Pri tem je treba poznati porazdelitev hitrosti vzdolž poti *v(s)*. Model je dvorazsežen v prvem približku, saj trirazsežna analiza, ob poprej omenjeni poenostavitvi širjenja zvočnega curka, ne bi bila primerna.

Iz povedanega izhaja, da je izračun dejanske porazdelitve hitrosti dokaj zapleten problem in ga analitično ni mogoče rešiti. Zato smo se tega problema lotili s programskim paketom ANSYS, ki problem reši z uporabo metode končnih elementov.

where the integration is taken along the sound path *s*. This model is a two-dimensional one and requires a knowledge of the fluid velocity distribution *v(s)* along the path *s*. In this first approximation a 3D analysis was not taken into consideration in view of the previous simplifications related to the ultrasonic propagation within the pipe.

The calculation of the exact velocity distribution within the pipe is a complex problem that cannot be dealt with analytically. We have therefore solved the problem with the use of the finite-element method and the program package ANSYS.



Sl. 4. *Hitrostne razmere v merilni celici*
Fig. 4. *Velocity conditions within the measuring cell*

2 IZDELAVA MODELA IN IZRAČUN POVPREČNE HITROSTI

Programski paket ANSYS ([1] do [3]) je eno od orodij za simuliranje in analizo različnih fizikalnih pojavov in tehničnih sistemov. Reševanje teh poteka preko uporabe metode končnih elementov. V splošnem se delo s tem programom deli v tri dele, in sicer :

- priprava
- rešitev
- obravnava.

V prvem delu pripravimo model. V drugem koraku sledi definiranje robnih pogojev in izračun, v tretjem delu pa lahko na različne načine opazujemo in analiziramo dobljene rezultate.

V prvem koraku je treba definirati obliko modela merilne celice in ga omrežiti z dvorazsežnimi elementi s prostostnimi stopnjami hitrosti, tlaka in temperature.

Naslednji korak je določitev robnih pogojev. Ti so prikazani na sliki 5. Vsi izračuni se nanašajo na imenski pretok. Za to smo na vstopu v merilno celico definirali vstopno hitrost pri imenskem pretoku v smeri X (ν_{xo}), medtem ko je hitrost v smeri Y (ν_{yo}) na vstopu enaka nič. Ob stenah celice je hitrost v obeh smereh (ν_x, ν_y) enaka nič. Na izstopu pa smo definirali tlak p = 0 bar.

2 BUILDING THE FEM MODEL AND THE DETERMINATION OF THE MEAN FLUID VELOCITY

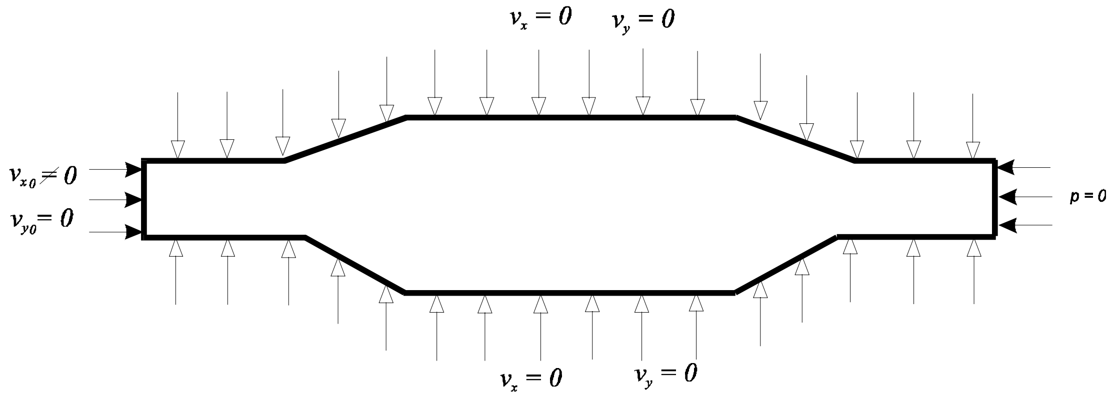
The program package ANSYS ([1] to [3]) is a tool for the analysis and simulation of different physical phenomena and technical systems. The problem solving is carried out with the help of the finite-element method. Generally, a typical procedure can be divided into three steps:

- preprocessing,
- solution,
- postprocessing.

In the first step a problem model is prepared. In the second step, boundary conditions are applied and the numerical solution is carried out. In the third step, the obtained results can be observed in many different ways and further analyzed.

In the first step we defined a model of the measuring cell with a mesh of 2D finite elements with velocity, pressure and temperature degrees of freedom.

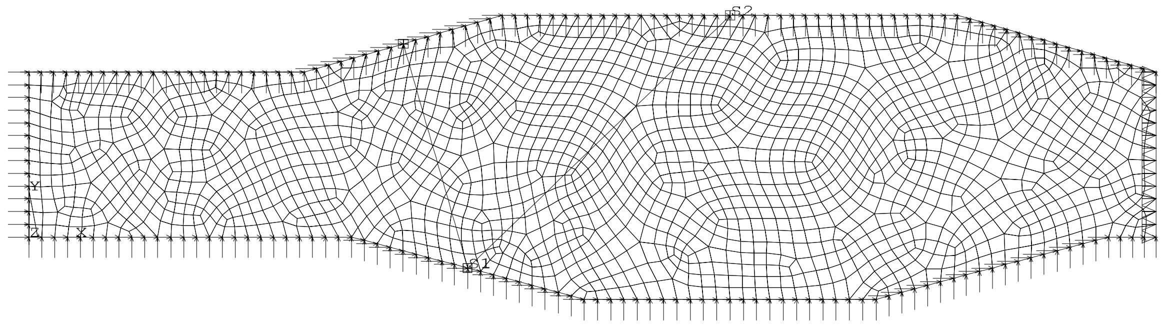
In the second step we applied the appropriate boundary conditions, as shown in Fig. 5. All the calculations were performed at the nominal flow rate. We therefore specified, at the measuring-cell inlet, the corresponding fluid velocity in the X direction (ν_{xo}), whereas the velocity component in the Y direction (ν_{yo}) at the inlet was set to zero. The velocity components ν_x and ν_y on the walls of the cell were set to zero. At the outlet the pressure was set to a value of p = 0 bar.



Sl. 5. *Definirani robni pogoji*
Fig. 5. *The applied boundary conditions*

Na sliki 6 je prikazan končni model MKE. Vstopni del celice smo podaljšali, da bi s tem zagotovili veljavnost robnih pogojev ($\nu_{xo} \neq 0$ in $\nu_{yo} = 0$).

In Fig. 6. the complete FE model can be seen. The inlet section of the cell was extended in order to ensure the validity of the boundary conditions ($\nu_{xo} \neq 0$ and $\nu_{yo} = 0$).



Sl. 6. *Omreženi model v ANSYS-u*
Fig. 6. *The meshed model in ANSYS*

Ko imamo izračunano hitrostno polje v merilni celici, je treba iz dobljenih rezultatov izračunati povprečno hitrost v smeri poti UZ. Najprej je treba določiti povprečno hitrost v smeri *x* in *y,* vzdolž poti UZ. Skupno povprečno hitrost potem lahko določimo prek geometrijske oblike celice. Oblikovali smo dve poti (S_1 in S_2), ki sta označeni na sliki 7. Na teh poteh smo z enim od orodij v ANSYS-u po enačbah od (5) do (8), izračunali povprečne hitrosti:

After the fluid velocity field has been calculated we have to determine the mean fluid velocity along the path of the ultrasonic signal. To do so, we first determine the mean velocity components in the X and Y directions along the path. The mean fluid velocity can then be obtained using the geometrical properties of the measuring cell. We created the two paths, S_1 and S_2, given in Fig. 7. Along these two paths we then calculated, with one of the ANSYS tools, according to Equations (5) to (8) the corresponding mean velocities:

$$v_{x1} = \left[\int v_{XS1} dS_1 \right] / l_1 \qquad (5),$$

$$v_{y1} = \left[\int v_{YS1} dS_1 \right] / l_1 \qquad (6),$$

$$v_{x2} = \left[\int v_{XS2} dS_2 \right] / l_2 \qquad (7),$$

$$v_{y2} = \left[\int v_{YS2} dS_2 \right] / l_2 \qquad (8),$$

v_{x1}... povprečna hitrost v smeri *x* na poti S_1
v_{y1}... povprečna hitrost v smeri *y* na poti S_1
v_{x2}... povprečna hitrost v smeri *x* na poti S_2

v_{x1}.... mean fluid velocity component *X* along the path S_1
v_{y1}... mean fluid velocity component *Y* along the path S_1
v_{x2}.... mean fluid velocity component *X* along the path S_2

v_{y2}.... povprečna hitrost v smeri y na poti S_2
v_{XS1}....hitrosti v smeri x na poti S_1
v_{YS1}...hitrosti v smeri y na poti S_1
v_{XS2}...hitrosti v smeri x na poti S_2
v_{YS2}...hitrosti v smeri y na poti S_2
l_1... dolžina poti S_1
l_2... dolžina poti S_2.

Nadalje lahko izračunamo povprečno hitrost na poti UZ. Iz geometrijske oblike merilne celice (sl.7) dobimo enačbi:

v_{y2}... mean fluid velocity component Y along the path S_2
v_{XS1}...velocity component X along S_1
v_{YS1}... velocity component Y along S_1
v_{XS2}... velocity component X along S_2
v_{YS2}... velocity component Y along S_2
l_1... path S_1 length
l_2... path S_2 length

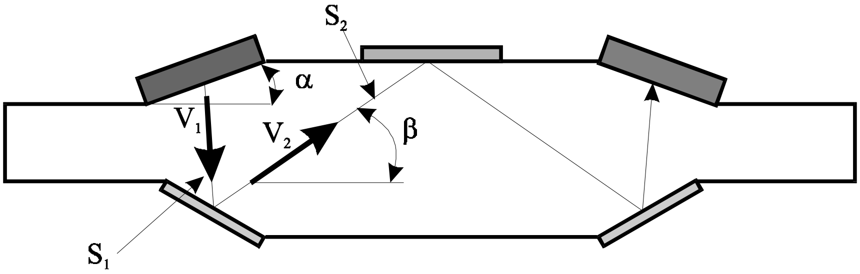
The final mean fluid velocity along the sound path can then be determined. With the use of the geometrical properties of the measuring cell (Fig. 7) we obtain equations:

$$v_1 = v_{x1} \cdot \cos(90\text{-}\alpha) + v_{y1} \cdot \cos\alpha \qquad (9),$$

$$v_2 = v_{x2} \cdot \cos(90\text{-}\beta) + v_{y2} \cdot \cos\beta \qquad (10),$$

v_1... povprečna hitrost vode na poti S_1
v_2... povprečna hitrost vode na poti S_2

v_1... mean fluid velocities along S_1
v_2... mean fluid velocities along S_2.



Sl. 7. *Geometrijska oblika merilne celice in prikaz poti* S_1 *in* S_2
Fig. 7. *Measuring-cell geometry and the paths* S_1 *and* S_2

Po enačbi (11), izračunamo povprečno hitrost vode ($\overline{v}$) na celotni ultrazvočni poti:

With Equation (11) we calculate the mean fluid velocity along the whole sound path:

$$\overline{v} = (l_1 \cdot v_1 + l_2 \cdot v_2)/(l_1 + l_2) \qquad (11).$$

Razlika časov Δt se izračuna po enačbi (2), kjer je L celotna dolžina zvočne poti, c pa hitrost zvoka v vodi (c = 1485 m/s pri 20 °C [5]). Dolžino celotne poti izračunamo po enačbi:

The difference Δt in the transit times for the signal propagating in the downward and upward directions can be calculated with Equation (2), where L is the overall sound-path length and c the sound velocity in water (c=1485 m/s, temperature 20°C [5]). The total path length can be determined with equation:

$$L = 2 \cdot (l_1 + l_2) \qquad (12).$$

3 TEORETIČNO UGOTAVLJANJE OBČUTLJIVOSTI IN POTRDITEV S PREIZKUSI PRI RAZLIČNIH IZVEDBAH MERILNIH CELIC

Za dano izvedbo elektronskega vezja toplotnega merilnika je zadovoljiva razlika časov Δt = 240 ns. Ta čas zagotovi ustrezno občutljivost merilnika. Pri razvoju merilnika s krajšimi priključnimi merami moramo torej zagotoviti vsaj to razliko v časih preleta, lahko pa tudi večjo.

3 THEORETICAL PREDICTION AND EXPERIMENTAL VERIFICATION OF THE PERFORMANCE OF SEVERAL MEASURING-CELL DESIGNS

Given the characteristics of the electronic circuit of the heat meter, a sufficient difference in the transit times to achieve the required resolution of the meter is approximately Δt = 240 ns. Therefore, when constructing an ultrasonic flow unit with shorter overall dimensions, care must be taken to achieve at least an equal or possibly a longer time difference.

Z osnovnim pretočnim delom, ki je v bistvu samo manjša različica že razvitega pretočnega dela, smo desegli Δt = 227 ns. Kasnejša analiza z metodo končnih elementov, pa je dala čas Δt = 222 ns, kar se dobro ujema s preizkusom. Ti rezultati nas pripeljejo do tega, da je treba narediti več simulacij in se ob ustreznih rezultatih odločiti za takšno merilno celico, ki bo zagotavljala ustrezno merilno občutljivost toplotnega merilnika.

Kakor že vemo, je občutljivost merilnika odvisna samo od povprečne hitrosti kapljevine v smeri poti UZ in od dolžine poti UZ. Vendar smo tako pri dolžini poti kakor tudi pri večanju hitrosti omejeni. Pri daljšanju poti smo omejeni s priključnimi merami pretočnega dela. Za povečanje hitrosti moramo zmanjšati pretočni prerez. Tu pa imamo zahteve za padec tlaka. Ta je namreč omejen, poleg tega pa ne smemo prekinjati pot signalu UZ, saj bi ga s tem oslabili.

Narediti je bilo torej treba več modelov merilne celice, ki so predstavljeni na slikah od 8 do 12. Najprej je bilo treba narediti analizo z MKE, potem pa rezultat preveriti na pretočni merilni progi pri imenskem pretoku. Te rezultate smo potem primerjali z osnovnim pretočnim delom s priključno mero 110 mm. Naredili smo naslednje primere:

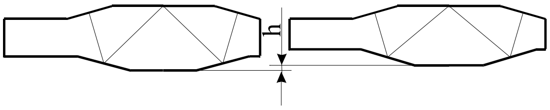
1. Zvišali dno celice, s čimer smo povečali hitrost kapljevine, a obenem tudi nekoliko skrajšali pot zvoka (sl.8).
2. Podaljšali celice do največje mogoče dolžine, pri čemer smo podaljšali tudi pot zvoka (sl 9).
3. Kombinirali 1. in 2. različico (sl.10).
4. Zvišali celice z oviro, kar povzroči povečanje hitrosti kapljevine, ne vpliva pa na dolžino poti zvoka (sl.11)
5. Kombinirali 2. in 4. različico (sl.12).

With the basic flow-unit model, which was a simple miniaturization of one of our previously designed flow units, the achieved transit time difference was Δt = 227 ns. A later finite-element analysis gave a value of Δt = 222 ns, which agreed well with the experiment. We therefore decided to make several additional FE calculations and choose from them the design with the required sensitivity.

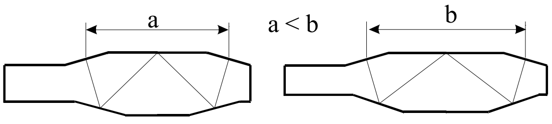
As explained, the sensitivity of the heat meter depends on the mean fluid velocity along the ultrasonic path and on the length of the path. However, with both parameters certain limitations exist. The path length is limited by the overall dimensions of the flow unit. The fluid velocity, on the other hand, can be increased by diminishing the inner cross-section; however, this may lead to an increase in the pressure drop or an obstruction of the propagated ultrasonic waves.

Several variations of the basic measuring cell, presented in Figs. 8 to 12 have been considered. The expected transit-time difference was first predicted with the FE method and then determined experimentally on a test flow rig at the nominal flow rate. These results were then compared to the basic version of the flow unit with the overall dimensions of 110 mm. The following models were made:

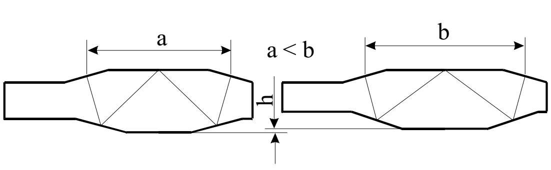
1. Cell with a raised bottom relative to the basic model - larger fluid speed but shorter sound-path length (Fig. 8)
2. Cell with a maximum overall length - maximum achievable sound-path length (Fig. 9)
3. Combination of 1. and 2. (Fig. 10)
4. Cell with a raised bottom with a protuberance - larger fluid speed but unaffected sound-path length (Fig.11)
5. Combination of the 2. and 4. point (Fig.12).



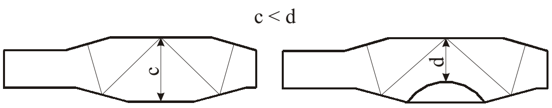
Sl. 8. *Zvišanje dna celice za povečanje hitrosti vode*
Fig. 8. *Cell with a raised bottom to increase the fluid speed*



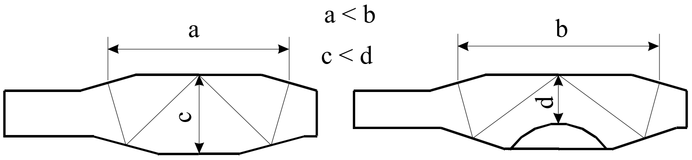
Sl. 9. *Podaljšanje celice za podaljšanje zvoka poti*
Fig. 9. *Cell and its sound path lengthened*



Sl. 10. *Zvišanje in hkrati podaljšanje celice*
Fig. 10. *Cell with a raised bottom and increased length*



Sl. 11. *Zvišanje celice z oviro, ki ne skrajša poti zvoka*
Fig. 11. *Cell with a part of the bottom raised with a protuberance leaving the sound path length unaffected*



Sl. 12. *Zvišanje celice z oviro, ki ne skrajša poti zvoka, in podaljšanje celice*
Fig. 12. *Cell lengthened and with a protuberance which doesn't shorten the sound path*

Rezultati, ki smo jih dobili z MKE in nekatere potem tudi s preizkusi potrdili, so prikazani v preglednici 1. Kakor lahko vidimo, se ne razlikujejo za več ko nekaj odstotkov. Opazimo tudi, da merilna celica z največjo merilno občutljivostjo (primer 5: $\bar{v}\cdot L = 0{,}291$) zagotavlja tudi največji Δt, kar potrjuje tudi teorija v poglavju 2.

The results obtained with the FE model and those obtained experimentally are shown in Table 1. As seen from the results the theoretically predicted time difference agrees, to within a few percent, with the experimentally obtained values. It can be seen that the measuring-cell design with the maximum sensitivity (case 5, $\bar{v}\cdot L = 0.267$ m^2/s) also exhibits the maximum transit-time difference Δt, which confirms the theory of Section 2.

Preglednica 1. *Rezultati simulacij in izvedenih meritev*
Table 1. *Simulated and measured results*

Primer **Case**	$\bar{v}\cdot L$ m^2/s MKE / FEM	Δt ns MKE / FEM	Δt ns meritev measured	Δt % napaka error
Osnovna kratka celica Basic measuring cell	0,245	222	227	2,2
Primer 1 - zvišanje dna celice Case 1- raised bottom	0,239	217	/	/
Primer 2 - podaljšanje celice Case 2 - lengthening	0,249	226	220	2,7
Primer 3 - podaljšanje in zvišanje celice Case 3 - raised bottom and lengthening	0,259	235	/	/
Primer 4 - zvišanje celice z oviro Case 4 - protuberance	0,262	238	259	8,1
Primer 5 - podaljšanje in zvišanje celice z oviro Case 5 - protuberance and lengthening	0,267	242	264	8,3

4 SKLEP

Z uporabo programskega paketa ANSYS smo analizirali različne modele ultrazvočnih merilnih celic. Tako smo s teoretičnih predvidevanj določili model, ki glede občutljivosti najbolj ustreza. Iz preglednice 1 lahko vidimo, da je razlika med rezultati, pridobljenimi s simulacijami, in rezultati, pridobljenimi z meritvami, dokaj majhna. Se pa poveča v primerih, ko imamo v celici vgrajeno oviro, za povečanje pretoka. Ta ovira očitno zelo spremeni razmere v merilni celici. Določena odstopanja pa so tudi posledica dvorazsežne analize in poenostavljenega modela širjenja valov ultrazvoka.

Izbrano merilno celico bo treba preveriti še s hidrodinamičnega vidika. Lahko se namreč tlak v celici preveč zniža, ta pa je s standardom omejen in ga

4 CONCLUSION

With the help of the ANSYS analysis package we analyzed several design models of an ultrasonic measuring cell. From the theoretical predictions we managed to select the design that yields the required cell sensitivity. The experimentally obtained values of the transit-time difference agree, to within a few percent, with the theoretically predicted values. The discrepancies become larger in cases where a protuberance to increase the fluid velocity is mounted in the measuring cell. This protuberance obviously changes the conditions within the cell considerably. Some discrepancies can also be attributed to the 2D fluid-velocity solution as well as to the simplified model of the propagation of the ultrasonic waves.

The selected measuring cell will have to be further verified with respect to its hydrodynamic properties. At the nominal flow rate an excessive ne smemo preseči. Poleg tega je pomembna tudi možnost izdelave izbrane oblike merilne celice.

Vidimo, da kljub različnim računalniškim orodjem, praktično ne moremo nekega izdelka razviti brez prototipa. Lahko le bistveno hitreje določimo prototip, potem pa ga je kljub vsemu treba izdelati in preveriti njegovo delovanje v dejanskih razmerah.

pressure drop in the cell can result; however, this drop is limited by standards and must not be exceeded. Also, manufacturing issues have to be considered.

In spite of advanced computer-design tools a product cannot be developed without a prototype. However, with the help of these tools, a prototype can be designed in a much shorter time and then be verified experimentally.

5 LITERATURA
5 REFERENCES

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