INVESTIGATION OF OPTIMAL CHORD TOPOLOGY FOR MULTIPATH ULTRASONIC FLOW METERS IN DISTORTED FLOWS

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Abstract

In this study a theoretical investigation of performance of multipath ultrasonic flow meters under distorted flow profiles is proposed.
The velocity distribution depends on the pipe configuration, which will produce an asymmetric flow profile and as a result will affect the accuracy of measurement. So, we discover how to minimize the effect of distorted flows on measuring process of ultrasonic flow meters due to number of chords and their arrangement.
In order to evaluate the performance of the multipath ultrasonic flow meters the measurement error is determined for various asymmetric flow profiles with different chord configurations. As a part of the work it was obtained strategy that can reduce the error associated with different flow disturbances. Using CFD analysis interesting conclusions have been derived. These conclusions can be applied to specific individual situations and a significant reduction in error can be achieved.

Introduction

Ultrasonic flow measurement is a well-known and widely applied technology. Today there are a lot of ultrasonic flow meters with different number of acoustic paths. Single path meters are less expensive and commonly used but having not-enough straight pipe sections they can't provide highly accurate measurements. They are very sensitive to non-ideal flow profiles. Basicaly installation effects downstream of contraction, expansion, bend are studied. It is known that measurement errors of ultrasonic flowmeters with single diametric path are larger than for the meter with dual paths and more. To eliminate this problem multipath meters with different chord topology are applied. Practically all methods realized in multipath meters are based on velocity distribution. There are two methods of calculation, which are used to derive the mean velocity of a multipath ultrasonic meter, namely, averaged and integrated methods. The latter involves a weighted sum of the velocities along the individual paths while the former involves an equally weighted average of the path velocities.
For multipath meter numerical integration method gives position of each acoustic path together with weighting factor. Quadrature methods were introduced and compared by many researchers. These methods are pretty good discussed in literature[1-3] but we would like to pay more attention to averaged methods.

Objectives

In this paper the following objectives were represented:
1. Discovering of the impact of flow in different installation effects on meter's performance basing on mathematical model for multipath ultrasonic flow meter.
2. Optimization of topology of acoustic paths in ultrasonic meters.

Investigation of flow profiles caused by numerous installation effects is still very important. Every manufacturer of ultrasonic meters gives its own recommendations regarding necessary length of straight pipe sections before and after meter and there are no general recommendations.
Typical configurations for assessment of flow profiles after single 90^0 bend and spatial bend demonstrate that even 20 and 30 diameters (DN) are not enough for complete flow stabilization.
But it doesn't mean that such conditions are critical and absolutely non-appropriate for installation of ultrasonic flow meters.
To eliminate errors caused by flow disturbances there are 2 methods :
- To calibrate the meter in a piping arrangement similar to that in which it will be installed
- To add more paths to the flowmeter

Let's analyze what impact has a chord location on the performance of ultrasonic flowmeters.
For this purpose we propose the set of following configurations:

Chords schemes and parameters of their arrangement

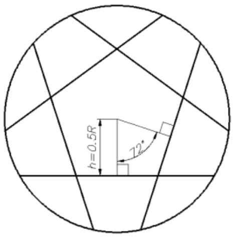

Fig. 1. 5S Scheme
Parameters of chords arrangement
$h_i = 0.5 \cdot R, \varphi_i = 72^0 \cdot i, i = \overrightarrow{1,5}$

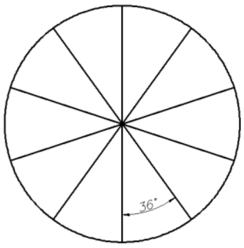

Fig. 2. 5C Scheme
Parameters of chords arrangement
$h_i = 0, \varphi_i = 36^0 \cdot i, i = \overrightarrow{1,5}$

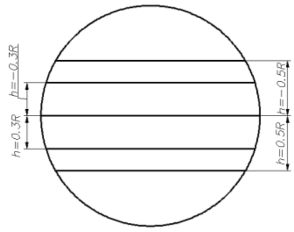

Fig. 3. 5P Scheme
Parameters of chords arrangement
$h_1 = 0.5 \cdot R, h_2 = 0.3 \cdot R, h_3 = 0, h_4 = -0.3 \cdot R,$
$h_5 = -0.5 \cdot R, \varphi_i = 0^0 \cdot i, i = \overrightarrow{1,5}$

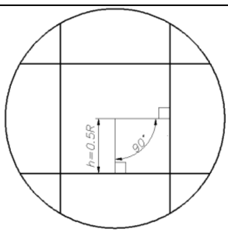

Fig.4. 4S Scheme
Parameters of chords arrangement
$h_i = 0.5 \cdot R, \varphi_i = 90^0 \cdot i, i = \overrightarrow{1,4}$

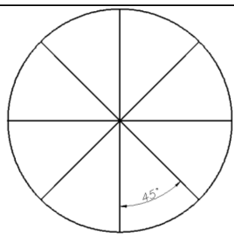

Fig. 5. 4C Scheme
Parameters of chords arrangement
$h_i = 0, \varphi_i = 45^0 \cdot i, i = \overrightarrow{1,4}$

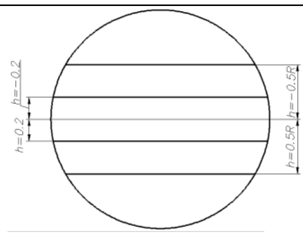

Fig. 6. 4P Scheme
Parameters of chords arrangement
$h_1 = 0.5 \cdot R, h_2 = 0.2 \cdot R, h_3 = -0.2R,$
$h_4 = -0.5 \cdot R, \varphi_i = 0^0 \cdot i, i = \overrightarrow{1,4}$

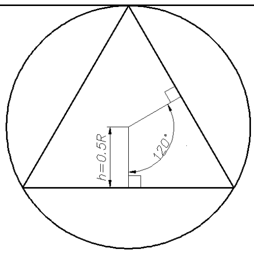

Fig. 7. 3S Scheme
Parameters of chords arrangement
$h_i = 0.5 \cdot R, \varphi_i = 120^0 \cdot i, i = \overrightarrow{1,3}$

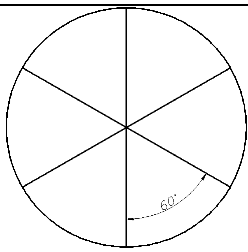

Fig. 8. 3C Scheme
Parameters of chords arrangement
$h_i = 0, \varphi_i = 60^0 \cdot i, i = \overrightarrow{1,3}$

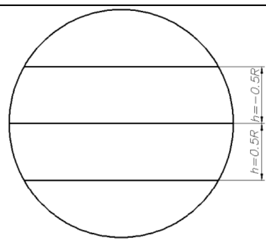

Fig. 9. 3P Scheme
Parameters of chords arrangement
$h_1 = 0.5 \cdot R, h_2 = 0 \cdot R,$
$h_3 = -0.5R, \varphi_i = 0^0 \cdot i, i = \overrightarrow{1,3}$

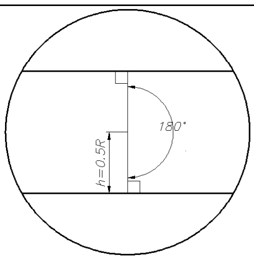

Fig. 10. 2S Scheme.
Parameters of chords arrangement
$h_i = 0.5 \cdot R, \varphi_i = 180^0 \cdot i, i = \overrightarrow{1,2}$

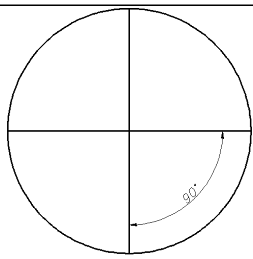

Fig. 11. 2P Scheme
$h_i = 0, \varphi_i = 90^0 \cdot i, i = \overrightarrow{1,2}$

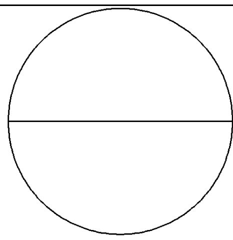

Fig. 12. 1C Scheme
Parameters of chords arrangement $h = 0, \varphi = 0^0$

The equally weighted method of calculation is applied to 2 to 5 ultrasonic paths configurations by implementation of equation for measured velocity

$$V = \frac{1}{n}\sum_{i=1}^{n}(Vpath_i)$$

where $Vpath_i$ is the mean velocity along path i.
For non-equal weighted method measured velocity can be presented as:

$$V = \frac{1}{n}\sum_{i=1}^{n} k_H(h_i, Re)\cdot \overline{v_h}(h_i, Re).$$

where n is number of chords; h_i is a distance from a chord to the center of flow metering section; k_H is a weighted factor.
Measurement error can be represented on plots on different distances from bend: 5DN (Fig. 13), 10DN (Fig. 14), 20DN (Fig. 15).

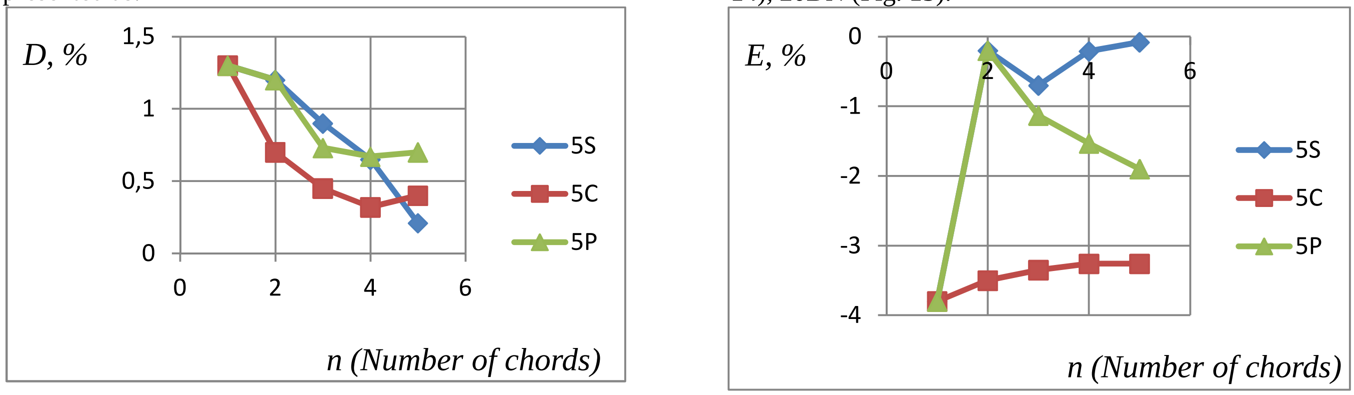

Fig. 13. $D = f(n)$ and $E = f(n)$ for 5DN

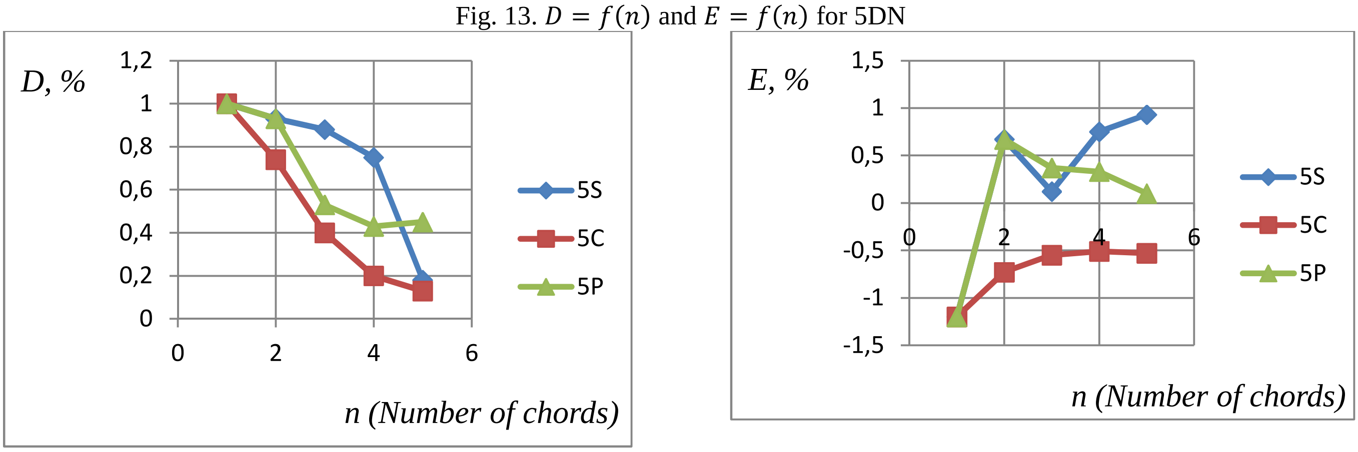

Fig. 14. $D = f(n)$ and $E = f(n)$ for 10DN

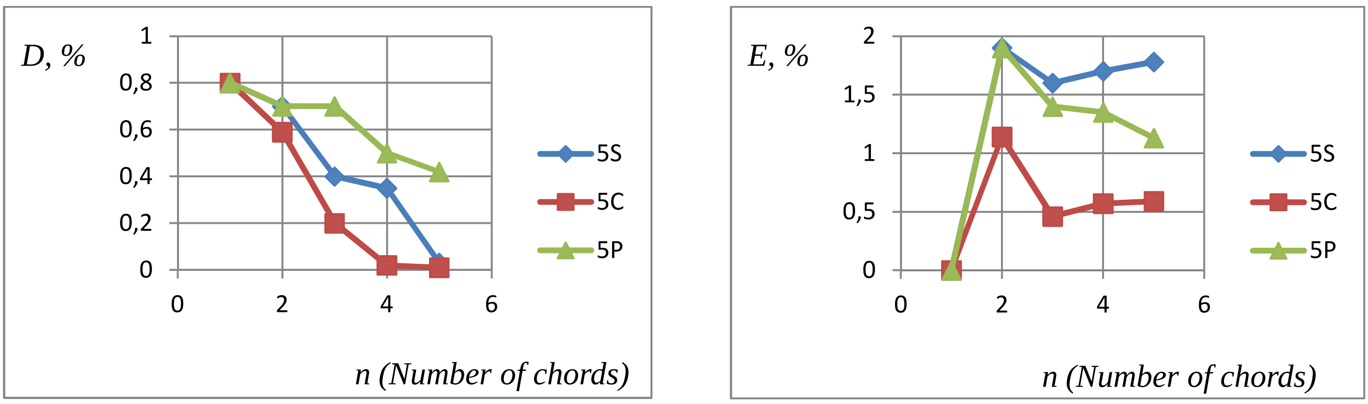

Fig. 15. $D = f(n)$ and $E = f(n)$ for 20DN

Discussion of obtained results

Error caused by flow asymmetry is configured from two parts – an error which depends on orientation of meter regarding flow disturbance (D, %) and error, which doesn't depend on it (E, %). D- error is charged for flow asymmetry. E-error is charged for deviation of velocity profile from developed turbulent. Different chord locations in different ways take an impact of these two errors.
C scheme better than others minimizes D error. For 5C scheme the error is decreased slowly from $\pm 0.4\%$ to $\pm 0.1\%$. However for E error such chord arrangement leads to not so good result because E error changes from -1% to +6% on pipeline section 5DN-20DN.

S scheme realized in 4S-2S configurations minimizes D error worse than C scheme, but at further increasing of chords approaches to C scheme. On 5DN-20DN distance the E error changes from -0.5% to $+2\%$, what is considerably less than in case of C scheme application.
P scheme of chords arrangement gives an ambiguous result, it provides worst minimization of D error. But in case of E error minimization on 5DN-20DN distance the error is changed from -0.5% to $+2.5\%$, which is better than at C chords arrangement but worse than applying S scheme.
From obtained results the best alternative is S scheme of chords arrangement, but in particular cases (at different number of chords) can comply with another scheme.
Generally the D error decreases for any scheme along with increasing of chords from $\pm1.5\%$ to $\pm0.1\%$.

Optimal topology of chords arrangement

Optimal chords arrangement for multipath ultrasonic meter suppose the following:

- Chord topology;
- Number of chords for specific topology;
- Flow profile after certain flow disturbance.

Let's determine chord topology considering number of chords as T_{ij}, where i –number of topology $(i=\overrightarrow{1,n_i})$ j – number of chords in topology $(j=\overrightarrow{1,n_j})$. Velocity profile is defined as P_{ks} , where k –number of pipe configuration $(k=\overrightarrow{1,n_k})$, s – number of straight pipe distance after flow disturbance $(s=\overrightarrow{1,n_s})$. $n_i=3$, $n_j=5$, $n_k=5$, $n_s=3$.
Criteria of quality of chord topology is root-mean-square error for real flow velocity from velocity given by multipath ultrasonic meter.
Root-mean-square error will be calculated for every case of chord topology averaging results by k and obtain a set of deviations, capacity $2ij$.
Deviation caused by flow asymmetry, we determine as D.

$$s_{D\,ij\,i\,s}=\sqrt{\frac{1}{n_k-1}\sum_{k=1}^{n_k}D}\,,i=\overrightarrow{1,n_i}\;,j=\overrightarrow{1,n_j},\quad s=\overrightarrow{1,s}. \qquad (1)$$

Make an average root-mean-square error by s (for all distances from flow disturbance).

$$s_{D\,ij}=\sqrt{\frac{1}{(n_kn_s-1)}\sum_{k=1}^{n_k}\sum_{s=1}^{n_s}D_{k\,s\,ij}{}^2}\,,=\overrightarrow{1,n_i}\;,\quad j=\overrightarrow{1,n_j}. \qquad (2)$$

Make an average root-mean-square error by s (for all distances from flow disturbance), results are brought in table 1.

$$s_{E\,ij}=\sqrt{\frac{1}{(n_kn_s-1)}\sum_{k=1}^{n_k}\sum_{s=1}^{n_s}D_{E\,k\,s\,ij}{}^2}\,,i=\overrightarrow{1,n_i}\;,\quad j=\overrightarrow{1,n_j}. \qquad (3)$$

Table 1. Root-mean-square error $s_{E\,ij}$, %

j / i	5	4	3	2	1
1	0.29	1.12	1.53	2.04	2.63
2	0.14	0.38	0.64	1.23	2.63
3	1.39	1.47	1.33	2.04	2.63

To obtain optimal topology for certain number of chords let's plot set of curves $s_{E\,i}=f(j)$ (Fig.16). Define cases $i=1$ as S, $i=2$ as C, $i=3$ as P.

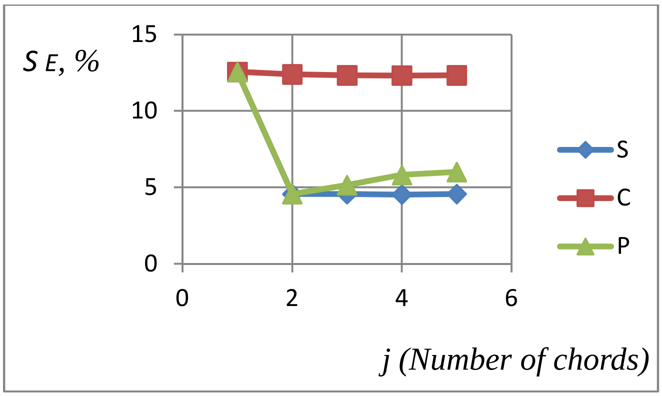

Fig.16 Selection of optimal chord topology

Conclusions

The set of discovered topologies was created and simulated under mostly applied pipe configurations. For each flow disturbance the most appropriate turbulence model has been adopted.
The D error caused by flow asymmetry may be better compensated by C chord topology (chord are crossed in pipe center). At increasing of chords number up to 5 the S scheme (symmetrical chords location on $0.5R$ from pipe center) becomes to compete with C scheme. P Scheme with parallel chords location gives a good compensation at chords number $j\leq3$, further increasing of chords number doesn't improve the result.
The E error caused by flow deviation from classic turbulent form may be best compensated by S topology and number of chords more than 2 doesn't impact on error value. Pretty the same results gives us P scheme. C scheme presents not so good compensation among two others schemes.

References

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[4] L A Salami, " Application of a computer to asymmetric flow measurement in circular pipes", Trans. Inst. Meas.Control, Vol. 6 pp. 197–206, 1984.