

## Software for Calculating the Location Coordinates and Weighting Coefficients of Acoustic Paths of Ultrasonic Flow Meters

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### Abstract

The article focuses on the development of software that allows you to calculate the location coordinates ( $x$ ) and weighting coefficients ( $w$ ) of acoustic paths of multipath chordal ultrasonic flow meters. The input data for the calculation are three (and in one case – four) parameters – the number of acoustic paths ( $N$ ) ultrasonic flow meter, the type of numerical integration method, the internal diameter of the pipeline and degree ( $k$ ) of weight function of Jacobi polynomial (if the Gauss-Jacobi numerical integration method was chosen). At the same time, the calculation is based on both table data (from mathematical directories) and on the analytical dependencies developed by the authors  $x = f(k)$  and  $w = f(k)$ . The presence of such calculator software will simplify the work of developers, designers, scientists, and students who theoretically investigate the future influence of the geometric characteristics of ultrasonic flow meters on their metrological accuracy in various conditions of their operation.

**Keywords:** software; ultrasonic flow meter; acoustic paths; weighting coefficients; location coordinates; numerical integration method.

### 1. Definition of the problem to be solved

The velocity principle of multipath ultrasonic flow meters (USM) is to calculate the flow rate due to measured flow velocities along its acoustic paths (APs). In this case, the values of these velocities are summed up with the use of constant or variable weights. For this purpose, variables weight ratios are determined by the measured stream parameters (for example, flow velocity), and constant weighting coefficients are determined based on known numerical integration methods (NIMs) [1]. Also, NIMs is used in calculating the location coordinates of the APs of USM – the distance at which the AP are located relative to the axis of the measuring pipe (MP) [2]-[3]

In the current state of the art of science and computer technologies, scientists, designers, graduate students, students, and those who work in the field of ultrasonic flow measurement may face the question of using NIMs in the most convenient way. However, given previous authors' research, it's not easy to implement because of the following reasons:

- 1) those individual algorithms based on mathematics of NIMs and used for USM tasks are complex and iterative, which is time-consuming [2], [3];
- 2) some NIMs, such as Chebyshev and Gauss methods, already have documented variants of parameter values used for the design of new USMs and research into existing models (location coordinates and weighting coefficients of APs of USM [2]), and this data is collected in the bulky tables of mathematical directories [4], which is also time-consuming;

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- 3) the Gauss-Jacobi method, which is most often used to solve scientific problems of USM [3], [5], as opposed to the previous NIMs, is multivariate, depending on the degree of weighting function of a Jacobi polynomial, which practical application is time-consuming; to automate and simplify the process of using this NIM for USM, we have developed convenient polynomial dependencies in [6], which connect the location coordinates and weighting coefficients of the APs of USM with the degree of weighting function of a Jacobi polynomial.

In view of the above, this work aims to combine the results and to develop simple software (calculator) that would allow the user (for example, to the student, while performing laboratory work) instantly receive the data he needed.

## 2. Analysis of research and existing software

After a detailed analysis of the world and Ukrainian USM market expenditures, their software can be divided into the following four groups:

- 1) human-machine interaction or monitor programs, that are part of the USM itself for installation on the computer, and serve as an interface between it and the user, providing convenient access to data on measurement, configuration and diagnostics; for example, such software includes FLOWgate [7] from SIC AG, software for configuration and parameterization of USM FLOWSIC600-ST and FLOWSIC500; SonicExplorer [8] from Elster Instromet's, software tool for setting up and monitoring of USM Honeywell Q.Sonic Series 6;
- 2) CAD software, which allows solving a wide range of tasks – from the design of new USMs to a comprehensive study of existing ones, such as determining the impact on the error, depending on the degree of distortion of the structure of the flow; such software includes a variety of CAD (with a package that implements computational fluid dynamics methods [9]) – ANSYS Fluent, SolidWorks Flow Simulations and many others;
- 3) data logger software, which are intended for registration of data that generates USM during measurement; the user of such a program can adjust what ports and at what speed the data will be transmitted from the data flow, you need to record and register in the accounting log, which data will be converted into a source file, for example of Excel format; mostly this software is easier than monitor programs and already installed in USM; an example of such software is the DataLogger used in portable ultrasonic fluid flow meters produced by a private enterprise of Ukraine "Donbas-Spetspribor" (Kharkiv);
- 4) software that allows calculating both separate design characteristics of USM and a whole range of errors; such programs include GARUSO [10], and those that are developed by users for their own needs but are not dilapidated; it is the development of such software (calculator) that is devoted to this work.

## 3. Presenting main material

The volume flowrate ( $q_{USM}$ ) measured by chordal multipath USM is calculated by the equation [3], [11]:

$$q_{USM} = \pi R^2 \sum_{i=1}^N \left( \frac{2\sqrt{R^2-x(i)^2}}{\pi R} w(i) u_h(i) \right), \quad (1)$$

where  $R$  is the internal radius of MP (or the USM body);  $x(i)$ ,  $w(i)$  is the location coordinate and the weighting coefficient of the  $i$ -th AP;  $u_h(i)$  is averaged along the  $i$ -th chord AP flow velocity;  $N$  is the number of AP.

To implement the formula (1), you must have the value of  $x(i)$  and  $w(i)$ , as well as the value of the average flow velocity  $u_h(i)$  along each chord AP. As mentioned above, the values of  $x(i)$  and  $w(i)$  are calculated using NIMs. The use of NIMs for multipath USM has been investigated and presented in many scientific works [3], [11]-[13] in particular, in the reports of the American Gas Association (AGA Report No.7) and the European Gas Group (GERG Technical Monograph No.11).

The NIMs that are most commonly found in scientific works on USM include: Chebyshev's method [14], which allows for the given values  $w(i)$  and  $N$ , to find the optimal value of  $x(i)$ ; Gauss method (or Gauss-Legendre method), which allows you to find the optimal values  $x(i)$  and the corresponding values  $w(i)$ ; the Gauss-Jacobi method and methods developed on its basis, such as OWICS (Optimal Weighted Integration for Circular Section) [3]. Opinions on the use of NIMs for USM are not only adhered to by scientists, so, for example, company DANIEL uses the Gauss-

Jacobi method for its USMs, company RMG uses the Gauss-Chebyshev method, company CALDON – Gauss-Legendre method. In this work, attention is focused on these three NIMs.

It so happens that the values of  $x(i)$  and  $w(i)$  for the Gauss-Chebyshev method and the Gauss-Legendre method can be calculated independently by using the methodology [2], [3], or using mathematical directories, where they are already calculated and erected in the table. Table 1 shows the values of  $x(i)$  and  $w(i)$  for  $N = 2, 3$  and 4 taken from a mathematical directory [4].

Table 1. Location coordinates and weighting coefficients APs USM

$N$	Gauss-Chebyshev NIM [4, table 25.5]		Gauss-Legendre NIM [4, table 25.4]	
	$x(i)$	$w(i)$	$x(i)$	$w(i)$
2	$\pm 0.5773$	1	$\pm 0.5773$	1
3	$\pm 0.7071$	$2/3$	$\pm 0.7745$	0.5555
	0	$2/3$	0	0.8888
4	$\pm 0.7946$	0.5	$\pm 0.8611$	0.3478
	$\pm 0.1875$	0.5	$\pm 0.3399$	0.6521

As for the Gauss-Jacobi method,  $x(i)$  and  $w(i)$  can be found by applying the method adapted to the USM [2], [3]. Let's look at this method in detail. Method of calculating location coordinates and weighting coefficients APs USM:

- 1) Choosing a value  $N$ .
- 2) Choosing the degree ( $k$ ) of weighting function of orthogonal Jacobi polynomial from the range  $-1 \dots 1$ .
- 3) Construction of recurrent equations of a Jacobi polynomial by a modified classical formula (2), in which "native" coefficients  $\alpha$  and  $\beta$  are replaced by  $k$ :

$$\left\{ \begin{array}{l} p_{j+1} = \frac{(d_j + e_j x) p_j - f_j p_{j-1}}{c_j}; (j = 0, 1, \dots, N-1); k > -1; \\ c_j = 2(j+1)(j+2k+1)2(j+k); \\ d_j = 2(j+k+0.5); \\ e_j = 2(j+k)2(j+k+0.5)2(j+k+1); \\ f_j = 2(j+k)4k(j+k+1); \\ p_{-1} = 0; p_0 = 1. \end{array} \right. \quad (2)$$

- 4) Finding the roots of the Jacobi polynomial  $p_{j+1}$ , which will be the values of the weighting coefficients APs USM. To calculate  $x(i)$  the authors of this work use m-function *roots* of MATLAB software.
- 5) The calculation of the weighting coefficients APs USM is performed by the following formula [8], [9]:

$$w(i) = \frac{1}{w(x(i))} \int_a^b W(x) PL_i(x) dx; (i = 1, 2, \dots, N), \quad (3)$$

where  $PL_i(x)$  is Lagrange polynomial  $PL_i(x) = \prod_{\substack{l=0 \\ l \neq i}}^N \frac{x-x(l)}{x(i)-x(l)}$ .

To simplify this method, the authors in [6] obtained arrays of values  $x(i)$  and  $w(i)$  at  $N = 2, 3$  and 4 for the entire range of values  $k = 0.1 \dots 0.9$ . By approximation of these arrays by polynomials of different degrees, the following analytical dependencies were obtained:

$$x = f(k)$$

$$N = 2: x_{1,2} = 0.0368k^2 - 0.1604k + 0.571.$$

$$N = 3: x_{1,3} = 0.0251k^2 - 0.1423k + 0.772; x_2 = 0.$$

$$N = 4: x_{1,4} = 0.0146k^2 - 0.1098k + 0.8602; x_{2,3} = 0.0115k^2 - 0.0647k + 0.3385.$$

$$w = f(k)$$

$$N = 2: w_{1,2} = 0.0349k^2 - 0.1992k + 0.9978.$$

$$N = 3: w_{1,3} = -0.013032k^2 - 0.002628k + 0.55996; w_2 = 0.047k^2 - 0.2185k + 0.8828.$$

$$N = 4: w_{1,4} = -0.0185k^2 + 0.0457k + 0.351; w_{2,3} = 0.02k^2 - 0.116k + 0.65.$$

In order to combine tabular data and analytical dependencies into a single convenient shell, we have developed the software-calculator *NumericalMethods 1.0*, which in console communication mode asks the user for information about the internal radius of the MP ( $r$ ), the number of APs ( $N$ ) and type of NIM ( $M$ ). Additionally, if the user selects the Gauss-Jacobi method, the program prompts for the value of  $k$ . At the output, the program produces three arrays of data:

- 1) array of values of the relative location coordinates the APs of the USM  $x(i)$ ;
- 2) array of values of the real location coordinates the APs of the USM  $X(i)$ ;
- 3) array of values of the weighting coefficients of APs of the USM  $w(i)$ .

The block diagram of the developed software *NumericalMethods 1.0* is shown in Fig. 1. The software, according to the block diagram in Fig. 1, was developed in the free development environment *Visual Studio Community 2019* using the C# programming language.

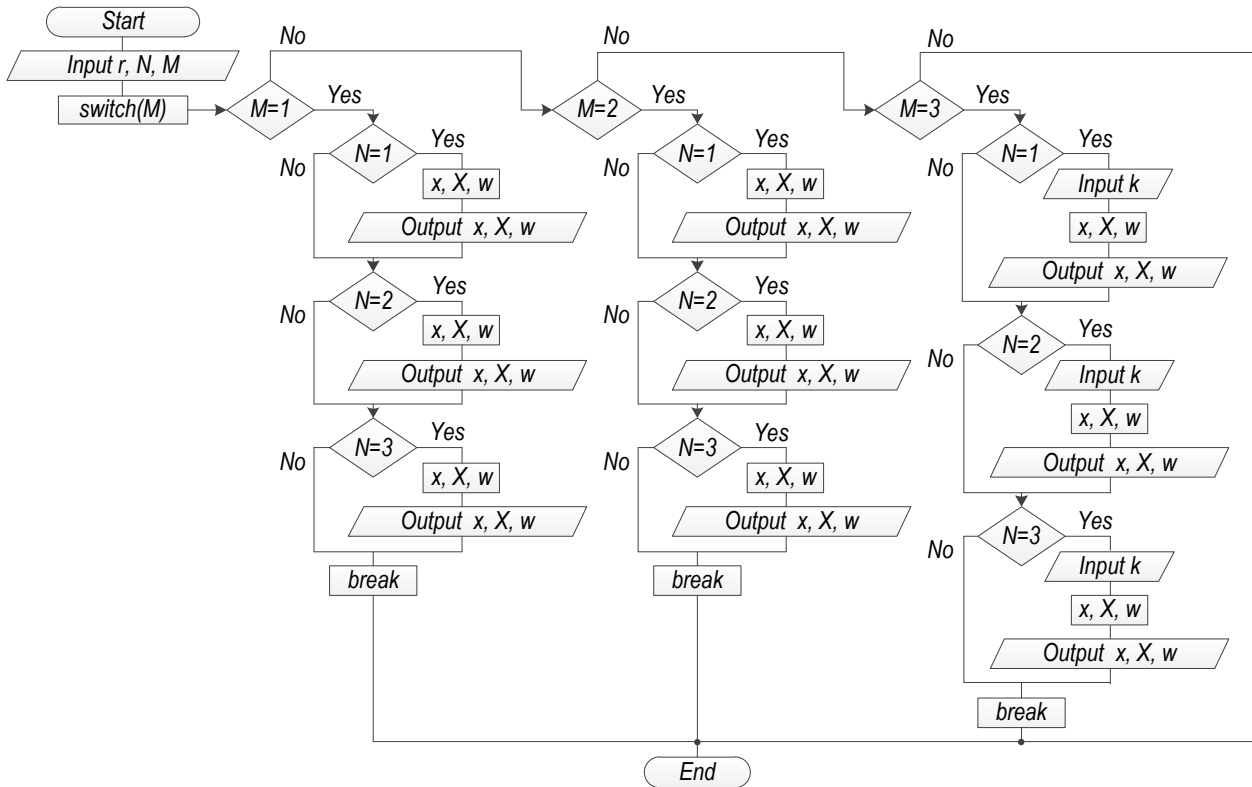


Fig.1. A simplified flow-chart of the "logic" of *NumericalMethods 1.0* software.

In the case of  $M = 1$  and  $M = 2$ , the values of location coordinates ( $x$ ) and weighting coefficients ( $w$ ) of the APs of the USM are obtained according to the data in Table 1. The value of the real location coordinates ( $X$ ) of the APs of the USM is obtained by multiplying  $x$  by the inner radius ( $r$ ) of the MP. For the more complicated case  $M = 3$ , where the user must additionally enter the value of  $k$ , the location coordinates ( $x$ ) and weighting coefficients ( $w$ ) of the APs of the USM are obtained by the corresponding polynomial analytical dependencies:  $x = f(k)$  and  $w = f(k)$ . After that, the value of the real location coordinates ( $X$ ) of the APs of the USM is also obtained by multiplying  $x$  by the inner radius ( $r$ ) of the MP.

Fig. 2 and Fig. 3 show the window of the developed program in the "request" mode and in the "response" mode.

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1. Enter the internal radius of the measuring pipeline (r) in mm: 100
2. Enter the number of acoustic paths USM (N = 2, 3 or 4): 4
3. Choose a NMI (enter the number):
    1 - Gauss-Legendre
    2 - Gauss-Chebyshev
    3 - Gauss-Jacobi
3
4. Since you have chosen a Gauss-Jacobi NMI, you need to enter the
degree of weight function polynomial Jacobi (k) from the range
of 0,1 ... 0,9: 0,5_

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Fig.2. *NumericalMethods 1.0* software window in "request" mode.

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r: 100 mm
N: 4
NMI: Gauss-Jacobi
k: 0,5
x: 0,8090 0,3090 -0,3090 -0,8090
X: 80,8950 30,9025 -30,9025 -80,8950 (mm)
w: 0,3693 0,5976 0,5976 0,3693

--> To close the program, press any key

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Fig.3. *NumericalMethods 1.0* software window in "response" mode.

Subsequently, as a continuation of the topic of research, the authors plan to expand the functionality of the software and switch to the graphic interface. This will allow visualizing the results of the calculation, which will simplify the process of understanding when applying the software for educational purposes.

#### 4. Conclusion

After the theoretical justification of the need, the authors developed a software-calculator *NumericalMethods 1.0*, which in the console mode calculates the values of location coordinates and weighting coefficients of acoustic paths of multipath ultrasonic flowmeters. For its successful application, the user enters three (or four, in individual cases) input parameters: 1) internal diameter of the pipeline; 2) the number of acoustic paths of the ultrasonic flowmeter; 3) type of numerical integration method; 4) the degree of the weighting function of the Jacobi polynomial, if the Gauss-Jacobi numerical integration method was chosen. The developed algorithm of the program is based both on tabular data (from mathematical reference books) and on analytical dependencies  $x = f(k)$  and  $w = f(k)$  developed by the authors. The result is obtained instantly, which will simplify the work of developers, designers, scientists and students who theoretically investigate the future influence of the geometric characteristics of ultrasonic flowmeters on their metrological accuracy in various conditions of their operation.

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## **Комп'ютерна програма для розрахунку координат розташування та вагових коефіцієнтів акустичних каналів ультразвукових витратомірів**

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### **Анотація**

Стаття присвячена розробці комп'ютерної програми, яка дозволяє розрахувати координати розташування ( $x$ ) та вагові коефіцієнти ( $w$ ) акустичних каналів багатоканальних хордових ультразвукових витратомірів. Вхідними даними для розрахунку є три (та у одному випадку – чотири) параметри – кількість акустичних каналів ( $N$ ) ультразвукового витратоміра, тип числового методу інтегрування, внутрішній діаметр трубопроводу та степінь ( $k$ ) вагової функції поліному Якобі (якщо був обраний числового методу інтегрування Гауса-Якобі). При цьому, розрахунок базується як на табличних даних (з математичних довідників), так і на розроблених авторами аналітичних залежностях  $x = f(k)$  та  $w = f(k)$ . Наявність такої програми-калькулятора, дозволить спростити роботу розробникам, проектантам, науковцям і студентам, які теоретично досліджують майбутній вплив геометричних характеристик ультразвукових витратомірів на їх метрологічну точність в різноманітних умовах їх експлуатації.

**Ключові слова:** комп'ютерна програма; ультразвуковий витратомір; акустичні канали; вагові коефіцієнти; координати розташування; числовий метод інтегрування.