Study on the influence of reflecting channel position on flow velocity characteristics of ultrasonic heat meter

Yonghui Liu¹, Fengyan Yi¹*, Changfeng Zhou¹ and Lili Tao¹

1 Shandong Jiaotong University, Jinan, China
* Corresponding author
E-mail: lyh1981@139.com

Abstract. In this paper, LES (Large eddy simulation) method is used to study the influence of different channel positions on the flow velocity of the ultrasonic heat meter, and the variation of the average linear velocity of different channel with time is researched. Through the calculation results, the velocity characteristics of 11 channels of the U-shaped reflecting device ultrasonic heat meter are analysed. The results show that the vortex behind the reflecting cylinder affects the velocity distribution in the channel. Statistical analysis shows that the linear average velocity in different positions of the channel fluctuates with time, but the fluctuation amplitude is basically the same. The average linear velocity asymmetry of reflecting channel far from the vortex zone is smaller, and the deviation of the average velocity is less than that of the average velocity, therefore, the distribution of the velocity is more reasonable.

Key words. Ultrasonic heat meter; Reflecting channel; LES

1. Introduction
It is important of the ultrasonic heat meter for the metering and charging in heating reform. Transit time ultrasonic heat meter is widely used in the market, and its measurement accuracy depends on the structure of the internal reflecting channel. The accuracy and stability of domestic meter are poor compared with the imported, especially in the case of small flow rate. Therefore, the influence of the reflecting channel position of the ultrasonic heat meter on the flow characteristics at low Reynolds number is studies, which based on the method of LES.
Many scholars have used LES method to carry out applied research, Zhang Zhao-shun⁴ et al. expound the theory and application of LES; Wu Ting, Zhao Yue-zhen²,³ et al. have studied the near wall model of LES and the method of synthesis of imported turbulence; Ai Guo-yuan, Yu Xi, Jang Hyunchul⁴,⁶ et al. have applied LES method to study the wing, circle, the flow around cylinders, horizontal pipes and propellers; the previous research work of the author⁷,⁸ also used the method of
LES and PIV to study pipes and obtain some results. In conclusion, the method of LES is less used to study the ultrasonic reflection channel, but it is feasible to study the internal flow field of the ultrasonic heat meter.

In this paper, LES method is used to study the influence of the position of the ultrasonic reflection channel on the flow velocity characteristics, and the relevant laws are obtained. It provides a theoretical basis for the selection of the ultrasonic heat meter, and has a certain theoretical significance and application value.

2. Physical model

2.1 Internal structure of ultrasonic heat meter

In this paper, the structure of a U-shaped ultrasonic heat meter is studied, which is shown in Figure 1. The reflecting device is composed of two stainless steel cylinders, and a 45 degree reflecting surface located on the center of the flow. After two reflections, the acoustic wave is received by the receiving transducer, and the transmitting process is completed.

\[ \text{Figure 1. Structure of U-shaped Reflecting device} \]

2.2 Computational domain model

In order to eliminate the influence of the inlet section, according to the literature \([7,8]\), the 10D-length straight pipe is taken before the inlet, and the 5D-length straight pipe after the outlet of the channel. The physical model of the computational domain is shown in Figure 2.

\[ \text{Figure 2. Computational domain model} \]

2.3 Grid resolution

The method of combining structured grid and unstructured grid is used for mesh generation. For the zone with complex flow in the middle, the structured grid method is adopted, and other zone adopted unstructured grid, and the grid close to the wall is refined. The mesh size of the middle reflection area is 0.8mm, and the total number of meshes is 2122545. The meshing is shown in Figure 3.

\[ \text{Figure 3. The meshing of reflecting zone} \]

\[ \text{Figure 4. Size distribution of } y^+ \]

The LES method requires high resolution grids, and generally requires $y^+ < 5$, where $y^+$ \([1]\) is the dimensionless distance from the central mass of the first layer grids to the wall. In this paper, the size
of $y^+$ is obtained via trial calculation, and the distribution of $y^+$ is shown in Figure 4. The horizontal ordinate is the size of $y^+$ and longitudinal coordinates is the proportion of size. It can be seen that maximum size are about 1%, which meets the requirements of LES method for grid resolution.

3. Method of numerical simulation

3.1 LES model

The mathematical equations of LES used in this paper are as follows:

$$\frac{\partial \vec{u}_i}{\partial t} + \frac{\partial \vec{u}_i \vec{u}_j}{\partial x_j} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left( \nu \frac{\partial \vec{u}_i}{\partial x_j} \right) - \frac{\partial \tau_{ij}}{\partial x_i}$$

(1)

$$\tau_{ij} = \rho \left( \vec{u}_i \vec{u}_j - \vec{u} \vec{u} \right)$$

(2)

Where $\tau_{ij}$ is defined as Subgrid stress, and Smargorinsky model is used.

3.2 Boundary condition

Inlet conditions: when the flux is 0.05m3/h, the inlet speed is 0.01966m/s; Inlet disturbance: Inlet turbulence intensity $I$ and hydraulic radius $D$ are used, where $I = 0.16 \text{Re}^{-1/8} = 0.72$ and $D = 0.003$ m. Outlet conditions: Free outflow is adopted.

3.3 Numerical simulation method

Central difference scheme is used to discretize the diffusion term, and the second-order Euler difference scheme is used to discretize the time term. In this paper, the calculating time step is 0.0005s at the beginning, and then it increases according to the convergence situation. At last, the step time reaches 0.001s after stable flow. A total of 7500 steps were calculated, and the physical time was 7.3235s.

4. Analysis of velocity characteristics of reflecting channel

4.1 Distribution characteristics of flow field

The whole calculation is unsteady. The flow field at the time $t$ of 7.3235s is analyzed in step 7500 of the calculation process. There are 11 reflecting channels from the two reflection surface, as shown in the Figure 5. It can be seen that there are vortices on the first reflecting cylinder from the velocity distribution in Fig.6, and the action area of the vortices covers the front of channel 7-11. The direction of the velocity vector in the middle is mainly X direction, and the flow tends to be stable. The fluid flow is impeded by the second reflecting cylinder, and velocity vector accumulates on the reflecting surface and flows out from the surface upper forming a trailing vortex area.

Figure 6 is a horizontal cross-sectional velocity vector diagram. Pair of vortices is formed on both sides of the first reflecting cylinder, but they do not develop backwards. The reflecting channels are in the middle of the two vortices. The velocity vector direction of the middle part is basically the flow
direction. Two rows of vortices are formed at the back end of the second reflecting cylinder and fall off backwards.

Figure 5. Velocity vector of the longitudinal section

Figure 6. Velocity vector of the horizontal section

4.2 Velocity characteristics of reflecting channel

The propagation speed of ultrasonic wave is influenced by the velocity of fluid in the channel. The distribution of flow field will affect the velocity characteristics in the channel. The linear velocity vectors of 11 channels in the reflector are taken as shown in Figure 7.

Figure 7. Vector of linear velocity of reflecting channel

From the distribution of vectors, it can be seen that the velocity vector direction of channel 7-11 varies greatly after the first reflector, and then it is impeded by the second reflector, resulting in upward flow direction. The vortices generated at the top of the first reflector influence the velocity characteristics in channel 7-11, and the propagation of ultrasonic is also affected.

4.3 Analysis of the time domain characteristics of velocity in the reflecting channel of ultrasonic heat meter

It is important for the measurement stability of heat meter to the characteristics of linear average velocity in time domain. Therefore, the linear average velocity with time in the reflecting channel is calculated at each time step. Figure 8 shows the linear average velocity in 11 reflecting channels in the time range of 0-7.3235s.

Figure 8. Linear Average Velocity of 0-7.3235s

Figure 9. Average velocity of 11 channels of reflecting channels

From the velocity curve of Figure 8, it can be seen that the average linear velocity of all reflecting channels increases rapidly at first, and then tends to be stable after about 4 seconds, and the fluctuation
amplitude of the average linear velocity in different positions is almost the same. The average velocities of 11 channels are different, and the average velocity of each channel is shown in Figure 9. Six channels are located in the central of the pipeline. The average velocities of 1-6 channels are gradually increasing, which is accord with the distribution of velocities in the pipe. After the seventh channel, it is shown that the velocity becomes irregularly, which increases first, then decreases, and then increases. The main reason is that the influence of the vortex region located the first reflector surface.

5. Conclusion
(1) The vortices generated by the reflecting cylinder of fluid flow will influence the velocity in the channel at different locations, and the velocity distribution law is not consistent with that of in pipe.
(2) The fluctuation amplitude of the average linear velocity in different positions is almost the same with time, which indicates that the reflecting device of U-shaped reflecting device is reasonable.
(3) The average linear velocity in channel 1-6 far from the vortex region is accord with the distribution of velocities in the pipe, and the distribution of the velocity is more reasonable.

Acknowledgments
This work is supported by the Shandong Province Natural Science Foundation, China. The item number is ZR2015EL034.

References
[1] Zhang Zhao-shun, Cui Gui-xiang, Xu Chun-xiao. Theory and application of numerical simulation of turbulent large eddy simulation[M]. Tsinghua University Press, 2008
[2] Wu Ting, Shi Beiji, Wang Shizhao, Zhang Xing, He Guowei. Wall-model for large-eddy simulation and its applications[J]. Chinese Journal of Theoretical and Applied Mechanics, 2018, 50 (03),453-466
[3] ZHAO Yuezhen, GUO Jie. Inlet synthetic turbulent methods for large eddy simulation[J]. Journal of Aerospace Power, 2018,33(07) 1622-1629
[4] Ai Guoyuan, Ye Jian. Large eddy simulation of low Reynolds number airfoil with different separating flow regime [J]. ACTA AERODYNAMICA SINICA, 2017,35(02),299-304
[5] YU Xi, LIU Mei, WEI Hong-yuan. Large Eddy Simulation for Flow Field of Horizontal Pipe[J]. Journal of Tianjin University, 2007,40(3):342-345
[6] Jang Hyunchul, Mahesh Krishnan. Large eddy simulation of flow around a reverse rotating propeller[J]. Journal of Fluid Mechanics. 2013
[7] LIU Yong-hui, DU Guang-sheng, TAO Lili, SHEN Fang. The calculation of the profile-linear average velocity in the transition region for ultrasonic heat meter based on the method of LES[J]. Journal of hydrodynamics, 2011,23(1):89-94
[8] Liu Yonghui. Study of the flow characteristics of the ultrasonic heat meter based on the method of PIV[J]. Chinese Journal of Scientific Instrument, 2015,36(10):119-123