Research on monitoring method of flow field distribution based on multichannel ultrasonic flowmeter

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Abstract

In order to solve the problem that it is difficult to monitor the flow field state in the pipeline during the calibration process of the flowmeter, this paper proposes a method to monitor the symmetrical state of the flow field in the pipeline by using the cross four-channel flowmeter with different sound channel velocity. The signal decomposition method based on singular value decomposition (SVD) is separate the noise signal from the single of channel measurement result, the velocity distribution curve of the medium in the pipeline is obtained by using 8 acoustic channel velocities lo quantitatively monitor the flow field distribution. in view of the above flow field monitoring methods, a real flow experimental platform based on water flow standard device and cross four channel flowmeter is built to verify the flow field symmetry state monitoring method in the water flow standard device pipeline, the experimental results show that the method can be used to monitor the symmetrical state of flow field in the pipe of water flow standard device.

1. Introduction

The flow measurement technology plays an important role in the industrial field, and also plays an important role in promoting in the development of national economy [1]. Flowmeter is the main device to realize flow measurement, the calibration and performance evaluation of flowmeter are completed by water flow standard device. At present, in order to realize the calibration of flowmeter, there are corresponding water flow standard devices in the flowmeter manufacturers, flow measurement and measurement research units. As the water flow standard device is in operation, the flow field state in the pipeline will be affected by the power supply voltage, pump blades, regulating valves, valves and pipelines, so the flow field state of the medium in the pipeline is very important in the measurement section of the water flow standard device [2-4]. Although, the flow field in the pipeline has been in an ideal state after the multistage flow stabilizing device. However, when the flowmeter is calibrated, the above sudden changes of working conditions will cause the sudden changes of the flow filed in the pipeline if the water flow device, which will no longer be an ideal symmetrical state, which will affect the measurement results of the calibrated flowmeter, and then cause the deviation of the flow calibration results of the water flow calibration device, it has a great influence on the flow calibration results and the evaluation of flowmeter performance. In addition, due to the influence of service life and environment, the flow stability of water flow device will decrease, which will lead to the change of flow field in the pipeline of water flow standard device. At present, in view of the flow field changes in the pipeline during the calibration of the flowmeter, the flow field in the pipeline changes, there is no simple and effective method to monitor the flow field accurately.

This paper attempts to use the multi-channel flow velocity of the cross four channel flowmeter to monitor the symmetrical state of the flow field in the pipeline. Aiming at the problem that the noise introduced by different ultrasonic transducers and signal acquisition components can not accurately reflect the flow velocity of the sound channel, the signal decomposition method based on singular value decomposition is used to separate the noise signal from the single channel measurement results, 0n this basis, the velocity distribution curves of the medium in the pipeline are drawn by using the eight channel velocities to quantitatively judge the symmetrical state of the low field. According to the above flow field monitoring methods, a real flow experimental platform based on water flow standard device, cross four channel flowmeter and multi-channel ultrasonic flow sensor acquisition device is built, the singular value decomposition noise separation is carried out for the different sound channel measurement results of ultrasonic flowmeter collected by the acquisition device, and the symmetrical state monitoring method of flow field in the pipeline of water flow standard device is verified.

2. Flow field symmetry state monitoring method

2.1 Field symmetry method based on multi-channel velocity

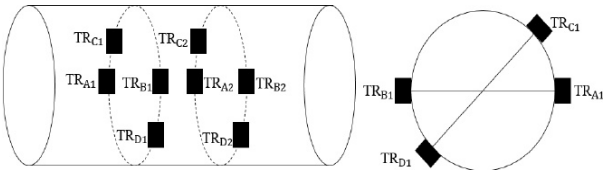


Figure 1: Schematic diagram of ultrasonic flowmeter

The channel distribution of multi-channel ultrasonic flowmeter can be divided into parallel type and cross type. The cross type is to install the transducer of the ultrasonic flowmeter on the axis line passing through the axis of the pipeline, and each independent sound channel is cross distributed in the pipeline. When the transducer is working, each pair of transducers can work independently. When working, the average flow rate is obtained through multiple channels, and the flow in the pipeline is obtained from the introduction. As shown in Figure 1, TRA1, TRB1, TRC1, TRD1 are four pairs of transducers, each of which passes through the axis. In parallel mode, the transducers are distributed in parallel on both sides of the pipe, each pair of transducers corresponds to different channels.

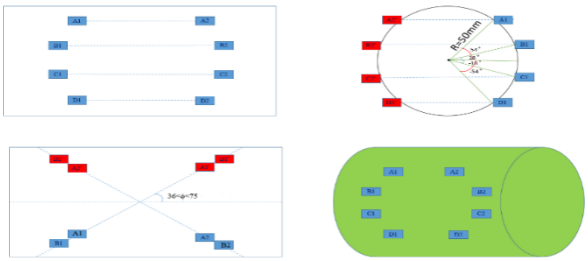


Figure 2: Schematic diagram of cross four-channel ultrasonic flowmeter

The multi-channel ultrasonic flow sensor adopts across four-channel ultrasonic flowmeter, as shown in Figure 2, it is left four channels and right four channels, which are symmetrically distributed on both sides of the pipeline. The transducer installation mode is parallel and direct, each channel is parallel to the pipeline, and the four channels on each channel surface are also symmetrically distributed to realize the cross four channel distribution. The velocity of water flow at different positions in the pipeline can be measured by the arrangement of sound channels at different positions. It is generally believed that the closer to the pipe wall, the greater the friction, so the slower the velocity. for a stable water flow standard device, the flow velocity should be symmetrical in the profile, and the closer to the pipe wall, the smaller the flow velocity. Therefore, the flow field distribution in the water flow standard device can be determined by measuring the flow velocity distribution diagram of the water flow standard device by the cross four channel ultrasonic flowmeter, so as to determine the flow field state in the water flow standard device, and the flow rate in the water flow standard device can be more accurately determined by the average four channel flow rate. singular value decomposition algorithm is used to remove the noise signal in the acquisition, and the velocity data in the pipeline is obtained accurately. According to the velocity distribution curve of the medium in the pipeline, the flow field in the pipeline of the water flow standard device is quantitatively evaluated.

2.2 Noise separation based on singular value decomposition

Due to the noise influence of multi-channel ultrasonic flowmeter and data acquisition system, the average sound velocity of each channel contains certain noise [5]. In order to obtain more accurate channel velocity, this paper uses the signal decomposition method based on SVD to separate the noise signal from the measurement results of a single channel.

Singular value decomposition can remove noise signals to obtain corresponding pure signals [6-8]. Singular value decomposition is a kind of subspace algorithm, which divides the vector space with noisy signals into multiple subspaces dominated by different signals, and different directional quantum spaces correspond to different signals [9-10]. In the denoising technique based on SVD decomposition, the signal is divided into two subspaces: pure dominant signal and noise signal. The pure signal is estimated by removing the noisy signal vector falling in the noise space. The signal subspace and noise subspace can be separated by orthogonal decomposition in linear algebra. Different signals can be recovered from the singular values and vectors corresponding to different vector spaces. By selecting the singular value and vector corresponding to the flow signal, the noise removed flow signal can be effectively separated.

In singular value decomposition, because the vector components corresponding to singular values correspond to the information in the original signal respectively, the singular values corresponding to different subspaces are quite different. Among them, the vector components corresponding to the larger singular values contain the most information in the original signal and are closest to the original pure signal. The smaller part of singular value contains. Less information in the original signal. In this way, the vector corresponding to the larger singular value is the signal vector in the subspace vector, and the vector corresponding to the smaller singular value is the noise vector in the subspace vector. The noise vector corresponding to the smaller singular value is removed, and then the pure signal in the noisy signal is obtained by inverse calculation, so as to achieve the purpose of removing noise.

2.3 Construction of Hankel matrix based on measurement data of ultrasonic flowmeter

The measurement signal of the flowmeter is a one-dimensional signal, and the signal decomposition

principle based on SVD requires a multi-dimensional matrix to decompose. Therefore, it is necessary to upgrade the dimension of the measurement data of the flowmeter and construct a decomposable measurement signal matrix s. By adopting the construction method of Hankel matrix, the measurement data of one-dimensional ultrasonic flowmeter is constructed into a multi-dimensional data matrix [11]. The mathematical expression of Hankel matrix is as (1):

$$H_n = \begin{bmatrix} a_0 & a_1 & \cdots & a_{n-1} \\ a_1 & a_2 & \cdots & a_n \\ \vdots & \vdots & \ddots & \vdots \\ a_{n-1} & a_n & \cdots & a_{2n-2} \end{bmatrix} \quad (1)$$

By continuously sampling the output signal of the flow, the Hankel matrix is constructed by continuing the data of the previous row with one bit. By increasing the dimension of the data, decomposing and removing the noise signal, we can get the pure signal matrix with the noise removed, and then we can get the pure one-dimensional signal I need through the inverse transformation.

3. Real flow detection experiment of flow signal of standard water flow device

3.1 Experimental platform construction

This experimental platform is built based on the water flow standard device of the national Institute of metrology of china. The water flow standard device is a set of standard water flow devices of China Metrology Science Research Institute. It is composed of storage tank, measured flowmeter, regulating valve, pump, regulating valve, diverter, bypass, weighing system and upper computer system. The inner diameter of the measuring pipe section of the calibrated flowmeter is 65mm~200mm. The medium temperature ranges from normal temperature to 90 ℃. The static weighing method is used for flow measurement. The device can maintain the stable operation of pipeline flow in the flow of 50m^3/h~100 m^3/h. The actual figure is as shown in Figure 3.

Figure 3: physical diagram of water flow standard device.

The flowmeter is a cross four channel ultrasonic flowmeter. Each channel surface has four pairs of transducers, a total of 8 pairs of transducers. The diameter of the flowmeter is 10cm. Its physical diagram is shown in Figure 4, which can simultaneously collect the flow velocity at four different positions in the pipeline on the water flow standard device. The valve is a gate valve. The state of the flow field in the flow field is changed by the opening of the gate valve. Its physical diagram is shown in Figure 5.

Figure 4: cross four channel flowmeter

Figure 5: gate valve

The experimental device includes water flow standard device, gate valve, plug-in cross four channel ultrasonic flowmeter, data acquisition device and upper computer program. in the experiment, the gate valve and flowmeter are installed on the pipeline of the water flow standard device. The actual position distribution of gate valve and cross four channel flowmeter in the pipeline is shown in Figure 6.

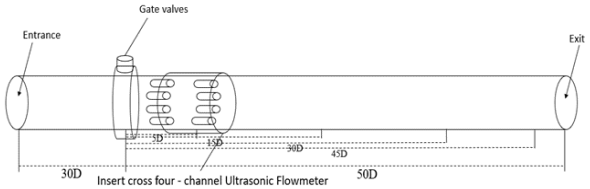


Figure 6: installation drawing of experimental pipeline

In the experiment, the cross four channel ultrasonic flowmeter installed on the water flow standard device was used to collect the flow data in the pipeline of the water flow standard device under the stable operation state. The multi-channel ultrasonic flow data is transmitted to the upper computer program through the acquisition device, and then the data is saved and analyzed through the upper computer program. During the experiment, changing the valve opening has an impact on the pipeline in the water flow standard device, and the flow status in the pipeline is obtained through the cross four channel ultrasonic flowmeter and the

acquisition device to verify the analysis of the flow field in the pipeline by the whole acquisition system.

3.2 Data acquisition device

In the real flow experiment of flowmeter, the whole acquisition device is composed of hardware and software. The hardware part of the flow acquisition device consists of American NI data acquisition device and industrial computer of Advantech, including acquisition shielded cable, acquisition data box, acquisition card and industrial computer. Connect the output signal of the flowmeter to the acquisition device. The acquisition device completes the conversion of analog signals, and communicates with the upper computer to complete the data transmission. The industrial control computer is Advantech P-3066 series industrial control computer, which has a high-performance CPU and multiple data conversion interfaces, and can connect to the multi-channel acquisition device. The acquisition card is the high-speed acquisition board Pcle-6363 of NI. The signals that can be collected include current signal, single terminal voltage signal, differential voltage signal, frequency signal, etc. it can collect the signals collected by the flowmeter. It has high-precision and high-frequency acquisition performance, and can complete the accurate acquisition of multiple analog signals at the same time. In the software part of the device, the upper computer receiving software adopts the LabVIEW program development environment, designs the upper computer receiving program through Data acquisition in LabVIEW, receives the data collected by the data acquisition board, and stores and processes the data. When there is fluid flowing through the pipeline, the eight-channel ultrasonic flowmeter will output analog signals according to some corresponding relationships, collect signals through the data acquisition board, and then convert the collected signals through the upper computer software to obtain the corresponding flow rate signals, so as to realize the storage of the whole data, and then analyze the data. The program interface of the data acquisition unit is shown in the figure 7

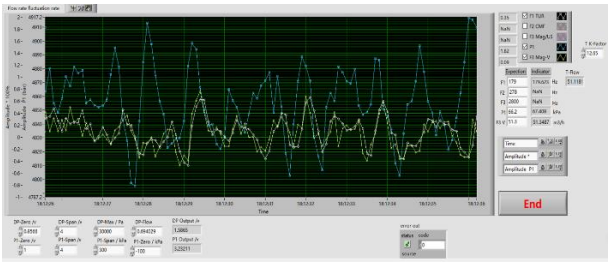
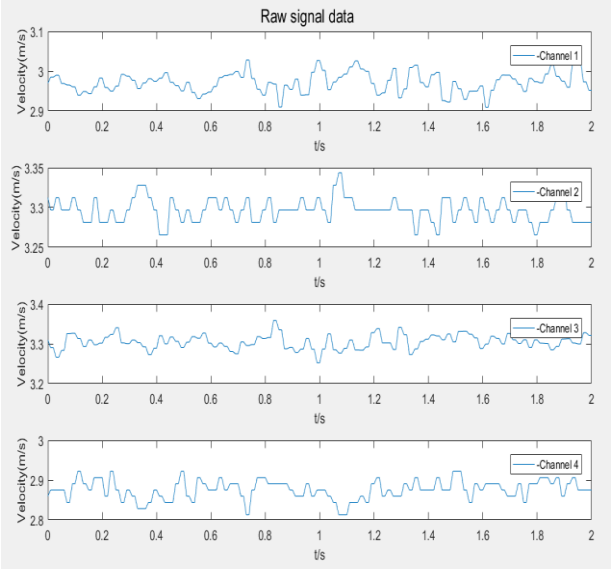


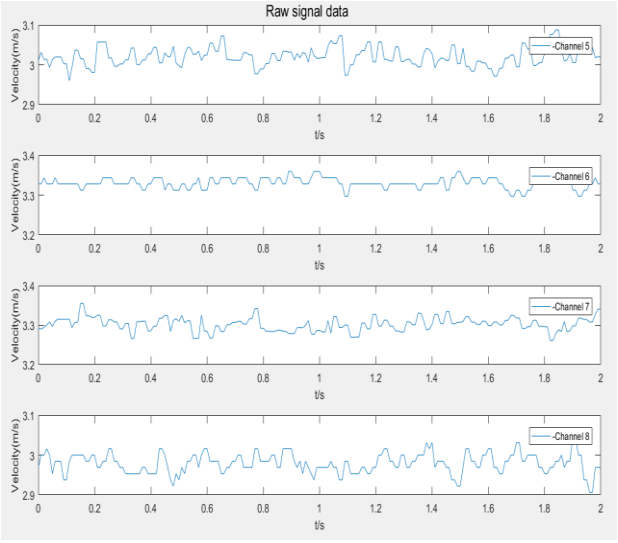
Figure 7: upper computer acquisition program

3.3 Data analysis

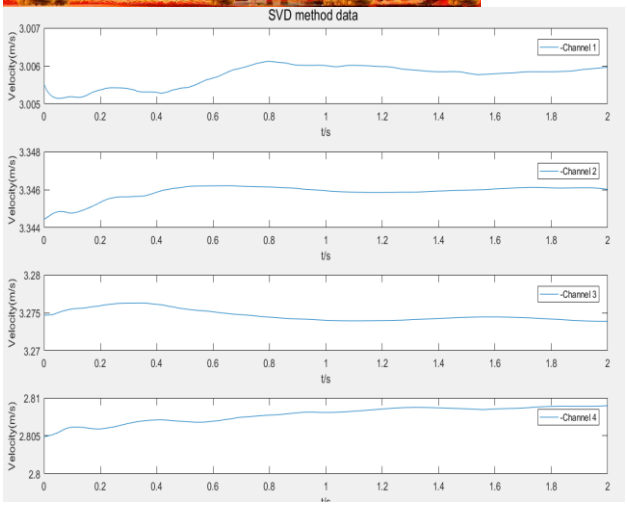
According to the entire experimental platform and acquisition device, the designed sampling frequency is 100Hz, and the data acquisition through the cross four-channel ultrasonic flowmeter during the stable operation of the water flow standard device is completed. Perform SVD decomposition on the flow velocity data of the 8 channels separately to obtain the flow velocity data in the pipeline after noise removal, as shown in Figure 8, which are the original data of the left and right channel surfaces and the data of each channel obtained after passing SVD. The data is smoother and more stable. The accurate flow velocity in the pipe measured by each individual channel at the corresponding time is obtained from the individual channel flow velocity data. The symmetry analysis of the left 4 channels and the right 4 channels is carried out respectively, and the flow velocity distribution map of the pipeline flow field is obtained through the experimental data.



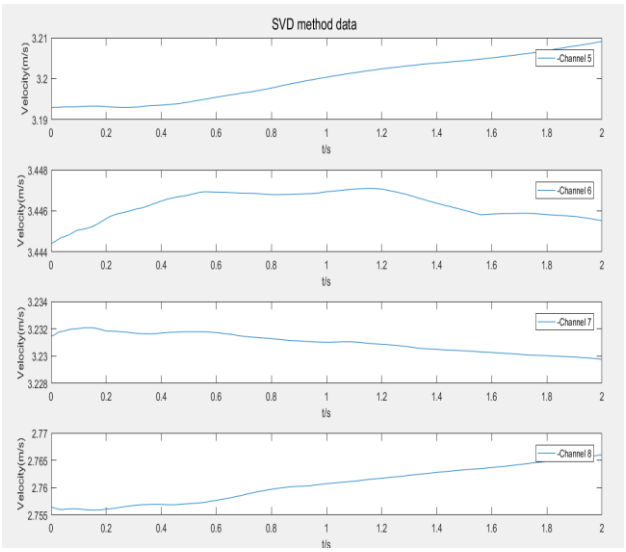
a) left channel surface



b) right channel surface



c) left channel surface

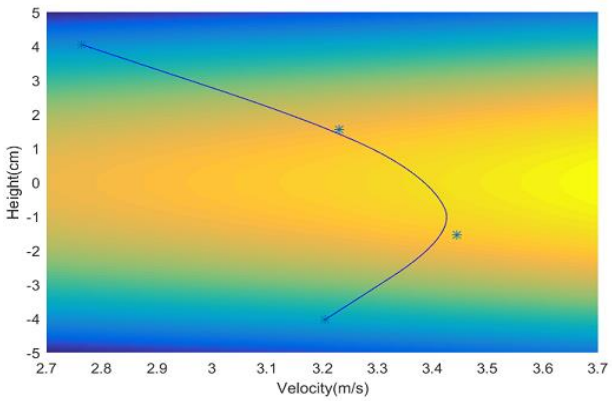


d) right channel surface

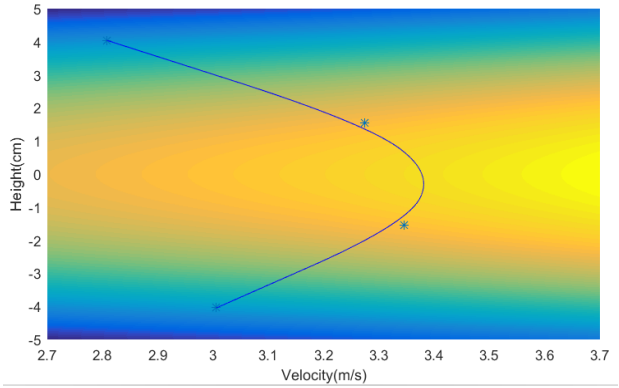
Figure 8: channel data

The average flow velocity data is used to obtain the medium flow velocity distribution diagram of the standard device, as shown in Figure 9, which are the left and right channel flow velocity distribution diagrams with gate valve openings of 50%, 75%, and 100%, respectively. The medium flow velocity distribution diagram takes the flow velocity in the pipeline as The abscissa, the height of the transducer relative to the center of the pipe is the ordinate.

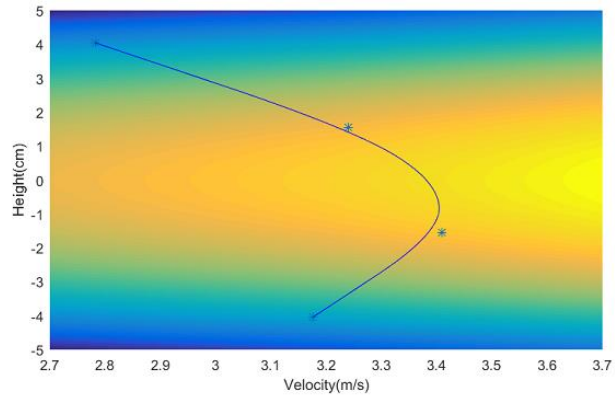
The left side of the figure is the flow velocity distribution diagram of the left four-channel medium, and the right side of the figure is the flow velocity distribution diagram of the right four-channel medium. Due to the influence of the gate valve on the flow field, when the gate valve opening is 50%, due to the influence of the gate valve, the flow velocity corresponding to the left and right channel surfaces in the entire water flow device has a large gap, which does not show a symmetrical distribution. The flow field is in an unstable state. When the gate valve opening is 75%, the flow field is affected, and the distribution of flow velocity is not completely symmetrical. When the gate valve opening is 100%, the influence of the gate valve on the flow field is reduced, and the distribution of the entire flow field is symmetrical. The flow velocity distribution of the water flow rate is centrally symmetric, and the flow field in the whole standard device can be judged to be symmetrical, and the stability of the flow field in the calibration process of the water flow standard device can be determined.



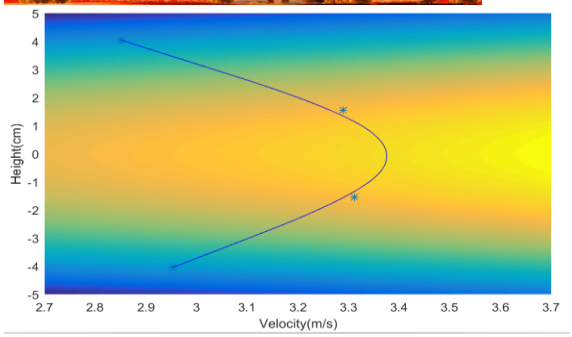
a) 50% opening velocity distribution of left channel surface



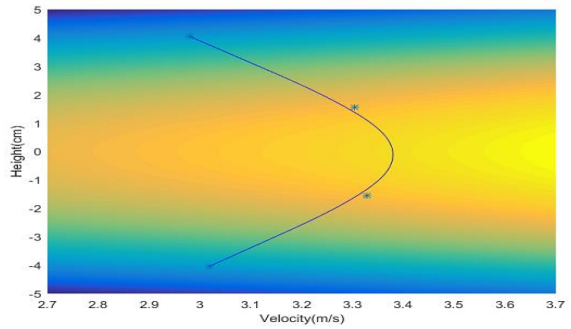
b) 50% opening velocity distribution of right channel surface



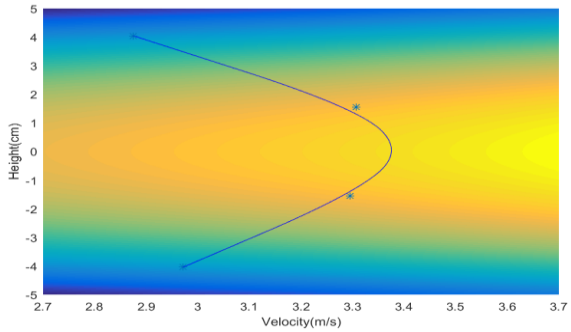
c) 75% opening velocity distribution of left channel surface



d) 75% opening velocity distribution of right channel surface



e) 100% opening velocity distribution of left channel surface



f) 75% opening velocity distribution of right channel surface

Figure 9: velocity distribution

4. Conclusion

In this paper, a flow field state detection method based on multi-channel ultrasonic flowmeter is proposed. A data acquisition system based on water flow standard device is built by using the cross four channel ultrasonic flow sensor. The velocity data of eight channels are collected and stored through the acquisition board, industrial computer and host computer program, and the original signal is denoised by using the method based on singular value decomposition, to solve the problem that the noisy signal introduced by different channel ultrasonic transducers and signal acquisition components can not accurately reflect the velocity of the channel, finally the velocity distribution curve of the medium in the measured pipeline is obtained accurately. The symmetrical state of the flow field is quantitatively judged by the velocity distribution curve of the medium in the pipeline, and the flow field state of the water flow standard device is accurately detected. The results of real flow experiments show that this method simply and effectively realizes the accurate monitoring of the flow field in the pipeline durintg the calibration process of the flowmeter.

Acknowledgement

Financial support for this study was provided by National Key Research and Development Project (Grant No. 2019YFB2006602 and No. 2019YFB2006601).

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