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The experiment and analysis of transitional flow in pipe*

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Abstract: The transitional flow in a pipe is important for delivery, but its characteristics remain to be explored. In this paper, the two-dimensional laser Doppler velocimetry (LDV) is used for the study, focusing on the attenuation characteristics of the axial velocity, the variation of the velocity gradient, the effect of the angle between the axis and the resultant velocity vector, and the relationship between the energy coefficient and the flow state. The attenuation characteristics of the axial velocity along the radial direction are obtained. It is shown that with the increase of the Reynolds number, the change rate of the velocity gradient slows down with a similar distribution, and a rapid decrease is seen in the near wall region. The amplitude and the frequency of the angular variation are obviously improved with the increase of the Reynolds number. The instability of the velocity field is enhanced with the increase of the energy coefficient.

Key words: transitional flow, attenuation, velocity gradient, flow instability, energy coefficient

Introduction

The pipe flow is one of the most common phenomena in industrial processes, the flow in the pipe is complicated, unstable, and related with a complex fluid dynamics. Aravinth[1] studied the heat and mass transfer processes of the turbulent fluid flow in the pipe, and proposed formulas obtained from a wide range of experimental data. References [2,3] analyzed the fully developed turbulent pipe flow by experiments, and obtained the velocity distribution and the von Karman's coefficient in the pipe.

Most of the researches mentioned above deal with the turbulence. The transition from the laminar to the turbulent flows has not been paid due attention, while there are significant differences between the flow field of a fully developed turbulence and that in the transitional area. A simplified flow model is often adopted to analyze it, and the experimental results focus on the change of the turbulent velocity field in the pipe.

The transitional flow may be found in civil and industrial processes, and it is often treated as a turbulence. Using this method to design the pipe system and to make the flow measurement will cause a remarkable error, therefore, it is important to make a study of the flow of the transition area. The difference between a simplified theoretical model and the actual flow will bring about some errors, as the simplified model cannot fully reflect the essence of the pipe flow. In this paper, we study the transition area in the pipe by the experimental method to avoid the disadvantage of the simplified model. In the meantime, the factors affecting the pipe flow are discussed based on the velocity field.

The Navier-Stokes (N-S) equation[4] of the incompressible fluid is usually used in the study of the pipe flow. In order to analyze the flow situation, the traditional method of analysis is to simplify the N-S equation by a dimensionless method. The dimensionless N-S equation takes the form

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$$\mathrm{div}W = 0 \tag{1}$$

$$\frac{\partial W}{\partial t} + (W \cdot \nabla)W = -\nabla p + \frac{1}{Re}\nabla^2 W + f \tag{2}$$

In Eq.(1) and Eq.(2), W is the speed, t is the time, p is the pressure, Re is the Reynolds number and f is the volume force.

It can be found from the dimensionless equations that the flow states with the same Reynolds number are similar. It is seen that the speed item plays an important part in the flow process, so that the attenuation and the change of the velocity in the pipe can affect the flow significantly.In this paper, we use the two-dimensional laser Doppler velocimetry (LDV)[5,6] for the measurements in the transition area of the pipe flow. Because of the measuring advantage of the LDV[7,8] in the near wall region, the results can reflect the true state of the flow due to the uniformity of distribution and the good flow property of the natural impurities in water. The test area is arranged depending on the structural characteristics of the three-dimensional coordinate frame.

From the pipe wall to the axis in the radial direction, the LDV is utilized sequentially for different positions and sections of the flow at different Reynolds numbers to obtain the flow parameters. From the experiment results, we can further analyze the variation and the attenuation of the flow and check the effects of the relevant parameters on the flow state. A reference can be provided for the numerical simulation of the pipe, the design of the piping system and the flow measuring device.

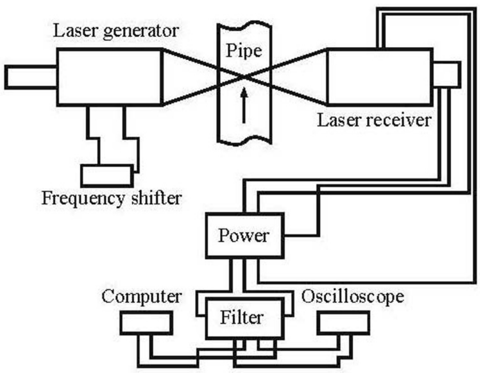

Fig.1 Doppler testing system

1. Experiment devices

The experimental system includes a water circulation system[9-11] and a Doppler testing system, the water circulation system includes an upper water tank, a pipe system, an electromagnetic flow meter, a regulating valve, a circulating water pump and a lower water tank. The Doppler testing system is shown in Fig.1[12], the position of the measuring points can be adjusted by the use of a three-dimensional coordinate frame.

2. Experiment method

The water cycling system is started to form different flow states by the regulation of the valve opening, the flux is measured by the flow meter. To ensure the accuracy of the measurement, the LDV should be adjusted in accordance with the requirements of the experiment[12-14]. The test section of the pipe is made of transparent plexiglass, its inner diameter is 0.04 m. The LDV is adjusted according to the technical parameters of the three-dimensional coordinates frame, the test area is shown in Fig.2.

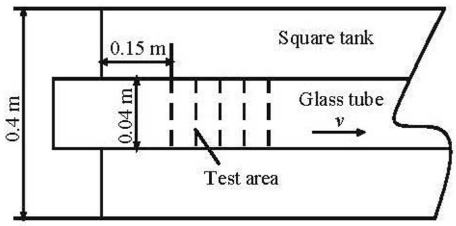

Fig.2 Test area

According to the characteristics of the pipe flow, the flow velocity near the pipe wall changes greatly and the velocity decreases from the pipe center to the pipe wall. The measuring points near the wall are arranged densely to reflect the flow characteristics, the inner wall of the pipe is the starting point, on each section the beam intersection point is used as a measuring point and a set of data is obtained. There are 40 nodes in the radial direction and 70 nodes in the axial direction, the entire test area contains 2 800 nodes.A set of samples is chosen in the speed measurement, according to the initial setting of the test system, the average values are taken as the required data. The Reynolds number of the test area is from 2 000 to 8 000. On each test section, 400 sets of data are obtained for every Reynolds number.

3. Analysis of test results

3.1 *Attenuation characteristics of average axial velocity*

The axial velocity distribution varies greatly in different flow areas in the pipe[15,16], the attenuation characteristics have much to do with the flow state. Six flow states in the experiment (Re = 2 400, 3 800, 4 800, 5 800, 6 800, 7 800) are selected.

Comparing the velocity of each measuring point with the average velocity in each flow state, it can be