Measurements of flow velocity of water under ice

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At present there are no apparatus for simple measurements of flow velocity of water under ice. We propose a practical measuring method based on the mechanical analysis. Furthermore we develop an apparatus to automatically measure water velocity for frazil slush. Such a developed apparatus is simple and low cost. This present work therefore suggests a novel and feasible technique for industrial applications.

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1. Introduction

The measurements of velocity in the hydrological tests are very important. The velocity is measured to get the information of water flow which is one of the important parameters in the reservoir dispatch by hydrological stations. And only the water flow of river section is acquired then the total amount of water flowing downstream is obtained by hydrological station, which meets downstream demand for water and forecast the disasters of downstream. In addition, the measurement of velocity is of great significance to the law of water movement rules and the interaction mechanism of flow and sediment. Therefore measurement techniques of velocity are paid more attention in recent years.

The measuring principle and methods of flow transducer are related to water body environmental factors, which are related to many factors. There is a wide range of instruments for measuring flow velocity, which can be divided into rotor and non-rotor flow-velocity meters. However, most of these flow-velocity meters are used to measure flow on the surface. If the temperature is about minus twenty degrees, water under the ice contains ice flowers. Yet there are few special instruments for measuring flow under ice, and flow-velocity meters in the market have their limitations if being directly used to measure the flow velocity under ice.

A new flow transducer which measures water velocity under ice sheet of rivers by fluid thrust and its application are proposed in this paper, which provides new technology to measurement of water velocity under ice sheet of rivers in monitoring ice conditions.

2. Basic principles of flow detection

The velocity of water measured by the characteristics of particles is a new detection method which bases on theory of fluid resistance acting on the rigid floating ball of characteristics of particles in the two-phase flow dynamics. If fluid flows around the floating ball there is a empirical formula between the fluid thrust and velocity of fluid.

Flow is supposed to be completely uniform, the still fluid resistance acting on a moving sphere and the moving fluid thrust acting on still sphere is equal. In the following discourse, there is no strict distinguish between two cases [1].

If the sphere is moving in the viscous fluid resistance F_d acting on the sphere is composed of the friction and the pressure drag. Expression of resistance F_d is as followed:

$$F_d = C_D \frac{1}{2} \rho_f \, |V_f - V_p| \, (V_f - V_p) S \tag{1}$$

where C_D is the resistance coefficient, ρ_f the fluid density, V_f the fluid velocity, V_p the sphere velocity and S is the sphere frontal area ($S = \pi r_p^2$, where r_p is the sphere radius).

At present, the resistance coefficient C_D mainly depends on the experiments to determine. Resistance coefficient C_D is related to the Reynolds number R_e:

$$C_D = \begin{cases} \frac{24}{R_e} & (R_e < 1.0) \\ \frac{13}{R_e} & (1.0 < R_e < 10^3) \\ 0.44 & (10^3 < R_e < 2\times10^5) \end{cases} \quad (2)$$

Reynolds number R_e which is calculated according to the experimental condition of experimental device of velocity sensor meets: $5\times10^3<Re<1.5\times10^5$. Therefore, resistance coefficient C_D is taken as 0.44 in expression of resistance F_d. Expression of fluid force F_d acting on the sphere is as follows:

$$F_t = 0.22\,|V_f - V_p|(V_f - V_p)S \quad (3)$$

Suppose the sphere radius is r, the water density ρ, flow speed V, the sphere speed 0, fluid force acting on sphere is thrust F_t. Thrust F_t can be calculated according to the formula (3) .

$$F_t = F_d = 0.22\pi r^2 \rho V^2 \quad (4)$$

Given $K = 0.22\pi r^2 \rho$, then $F_t = KV^2$ (5)

Empirical formula (5) between fluid thrust F_T acting on still sphere and fluid velocity V can be gotten according to the above derivation.

3. Structure of new thrust flow transducer

Flow transducer can be designed based on empirical formula between fluid thrust F_t acting on still sphere and fluid velocity V in two-phase flow dynamics. The measurement block diagram [2-12] is shown in Fig. 1.

If the thrust F_t is known value of fluid velocity V can be gotten by empirical formula (5). However, it is difficult to measure thrust F_t directly. As we can be seen from Fig. 1 thrust F_t acting on sphere is converted to drawn wire pull T which is measured easily by transfer structure. The precise spring and displace are used to measure the drawn wire pull T. The scope of drawn wire pull T is within 1N in measuring process. TH4802 weighing sensor can directly measure the drawn wire pull T, however, the measuring structure is not discussed in this paper. The measured data is transferred to MCU processing circuit to calculate fluid velocity V. It makes the problem easy that drawn wire pull T is measured to get indirectly fluid thrust F_t acting on sphere and then fluid velocity V can be gotten by (5).

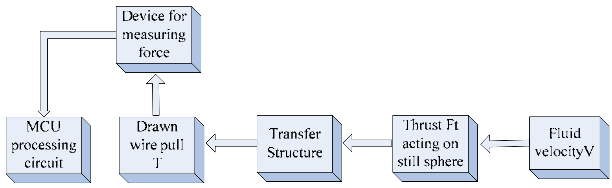

Fig.1. Block diagram of the flow transducer.

Experimental device of new thrust velocity sensor is designed based on basic principles of flow detection and block diagram of the flow transducer. The experimental device is composed of sensing element, transfer structure and displace detected structure. Structure is shown in Fig. 2. In the experimental device, the hollow tube and floating ball are stainless steel, the coefficient of stiffness of the precision spring is 0.9N/m, the pulley is plastic, the pulley support is stainless steel, the pull wire is nylon, the laser and photoelectric receiving module adopt infrared light (wavelength: 850nm), and the dimmer is black plastic.

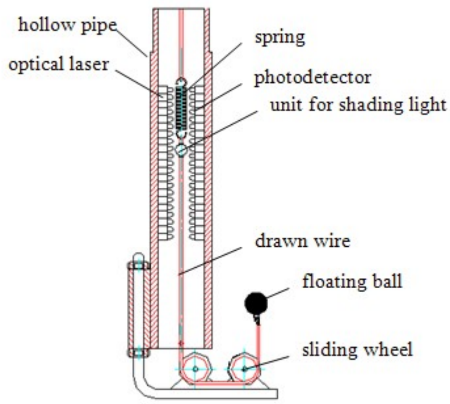

Fig.2. Schematic of experimental facilities of flow transducer.

Floating ball in Fig. 2 is sensing element of velocity sensor. Floating ball establishes a connection between thrust F_t acting on sphere and fluid velocity V. Thrust F_t is associated with pull T by force analysis. If flow of water is steady the forces of floating ball in balanced state is analyzed. Gravity of floating ball G, buoyancy F_{fl} , drawn wire pull T and thrust F_t can always be gotten. The force condition of floating ball is shown in Fig. 3. Orthogonal decomposition is shown in Fig. 4:

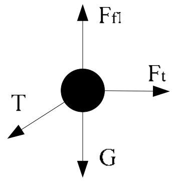

Fig.3. Force conditions of floating ball.

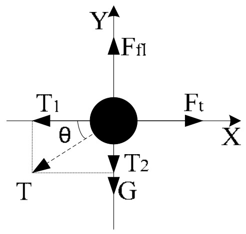

Fig. 4. Orthogonal decomposition.

To get orthogonal decomposition X, Y axis is established in Fig.4. Balance equation can be gotten as:

$$Tcos\theta = F_t \tag{6}$$

$$Tsin\theta + G = F_{fl} \tag{7}$$

Combining (6) and (7) thrust, F_t can be calculated as:

$$F_t^2 = T^2 - (F_{fl} - G)^2 \tag{8}$$

Empirical formula between the fluid thrust and velocity of fluid is shown as:

$$F_t = KV^2 \tag{9}$$

Combining (8) and (9), velocity V can be calculated as:

$$V^2 = \frac{\sqrt{T^2 - (F_{fl} - G)^2}}{K} \tag{10}$$

According to Archimedes principle buoyancy, F_{fl} can be shown as:

$$F_{fl} = \rho g v_p \tag{11}$$

Gravity of floating ball G is shown in (12)

$$G = mg \tag{12}$$

Combining (10), (11) and (12), velocity V can be calculated as:

$$V^2 = \frac{\sqrt{T^2 - (\rho g v_p - mg)^2}}{K} \tag{13}$$

K in (13) can be gotten by empirical formula (5) in two-phase flow dynamics. Where ρ, v_p, m are known, so water velocity V can be gotten by measuring the drawn wire pull T. Because the above force analysis is carried on in arbitrary balance state in measuring progress (13) is able to adapt to velocity changing circumstances.

Fluid thrust F_t is converted to drawn wire pull T which can be measured easily by transfer structure. Transfer structure is composed of spring and drawn wire. Drawn wire pull T can be measured based on Hooke's Law by displace detected structure. The value of drawn wire pull T is small. Therefore the non-contact displace detected structure is required in experimental device of velocity sensor. In addition, considering the installation, displacement detection device is composed of optical laser, unit for shading light, photodetector and MCU processing circuit. A row of spaced optical lasers are fixed on inner wall of hollow pipe. At the same time a row of spaced photodetectors are fixed on opposite inner wall of hollow pipe. A row of photodetectors receive laser which is emitted by corresponding optical laser and then transfer TTL level to MCU processing circuit. The space of photodetectors is 0.5 cm. The deformation band of spring is 25-100 cm. Although the resolution of the displacement detecting device is not high, it can meet measurement requirements relative to the spring deformation range. When laser is shaded by unit for shading light TTL level of corresponding optical laser will invert. At this time the position of shaded photodetector is judged by MCU processing circuit. Spring deformation can be calculated by MCU processing circuit as the photodetector is spaced. Then the drawn wire 'pull T will be calculated further based on Hooke's Law by MCU processing circuit. Finally, water velocity V can be calculated by (13).

4. Practical application and data analysis of velocity sensor

A. Field Experiment

In the late December 2009 to March 2010 the practicability of principle of experimental device of velocity sensor is tested in Yellow River in Inner Mongolia. Specific test location is in Toudaoguai hydrological station which is in Tuoketuo county of Hohhot of Inner Mongolia. During the first experiment, dug a hole on the ice and then stretched the measuring end of the sensor under the ice through the hole to measure flow velocity. During retracting the sensor, the ice had formed on the sensitive device of it, the pull wire and pulley had been frozen together, and the floating ball couldn't swing freely. As the temperature rose at noon, the ice of some stretches of the Yellow River melted, allowing measuring flow velocity in the middle of the river by water. Just in the same operating method as the first experiment, vertically inserted the device into the layer of ice flowers, and ensured that the lower end of the sensor being in the layer of ice flowers below the ice layer and at least one third of the upper end of it being exposed outside. Fig. 5 is the photograph of the experiment site.

Fig.5. Experiment site.

B. Experimental Analysis

A lot of original data were obtained from the experiment, of which five groups of original data were sampled as Table 1. The spring deformation in Table1 is used to calculate drawn wire pull T by Hooke's Law and then fluid velocity V can be gotten by (13). The curve of water depth and water velocity is shown in Fig.6.

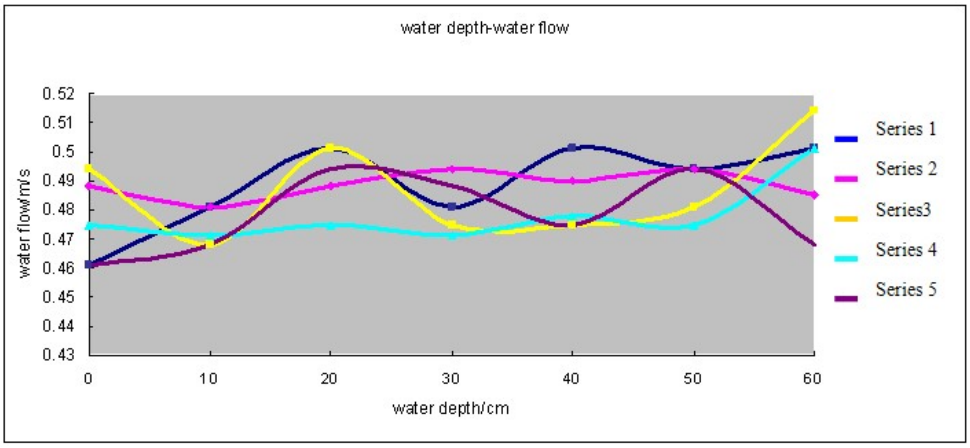

Fig.6. Curve of water depth and water flow.

Table 1. Spring deformation which is acquired in different depths in vertical section of the Yellow River.

Distance from the surface of the water /cm	Spring deformation (1)/cm	Spring deformation (2)/cm	Spring deformation (3)/cm	Spring deformation (4)/cm	Spring deformation (5)/cm
0	33	36	33	38	33
10	36	35.5	36	34	34
20	39	35	39	39	38
30	36	36.5	36	35	37
40	39	38	39	35	35
50	38	39	38	36	38.5
60	39	41	39	41	34

It is obvious that the deformation of the precision spring varied with the distance from the sensitive device of the sensor to the surface. And Fig.6 shows that flow velocity in different depths is different. As flow velocity measurements of all groups were not completed synchronously, the figure also reflects flow velocity change of the same position in the river section at different times.

Because the experiment site is at a bend of the Yellow River, where the topography and flow field distribution are complex, it happened the following problems during the experiment:

(1) The force measuring part of the device, precision spring, is exposed to air and vulnerable to winds, making the spring unstable and influencing our readings.

(2) The pulley support of the device is fixed, so the floating ball can't comply with the change in flow in time.

(3) The pull wire connecting the floating ball tends to stuck in the clearance between the pulley and pulley support, so the force measuring device can't sense the pull wire's pulling force to the floating ball.

(4) It is required that the buoyant acting on the floating ball should be slightly higher than its weight. During the first experiment, we achieved this by adding weights on the floating ball and continuously adjusting the weights added. But this method changes the stressed area of the floating ball and is unreasonable.

5. Conclusions

At present there is no practicable flow measurement equipment which is applied to measure velocity of water under ice sheet of rivers. Therefore, there is no the data which is measured by other devices to compare with the above measured data which can only verify the practicability of velocity sensor. The influence of frazil slush on forces of floating ball, measurement errors caused by spring deformation and repeated expansion in testing process, low measuring precision of displace detected structure are not considered in this paper. The problems will be researched and resolved in the future.

The measuring method of water velocity from the mechanical point is new. It can not only be used for automatic measuring in velocity of water including frazil slush which is under ice sheet of water but also be used for surface velocity of water. Flow transducer is simple and low cost. In conclusion, combined with a large number of basic experiments of fluid sensor, the measuring method of velocity is feasible.

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