# The Design of Optical Fiber Vortex Flowmeter's Probe

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## Abstract

*The vortex flowmeter works in a poor environment, therefore the stability and accuracy of the online testing system have become the core question for getting high accuracy. The optical probe is the main part of the system which produces and obtains the vortex signal. This paper designs the vortex shedder according to the hydromechanics principle, and it is proposed to be ringlike structures, also gives the test results which prove the effectiveness of the shedder on vortex decomposition. A liquid flow online testing system is designed according to the vortex signal characteristics, and the optical fiber is chosen as the sense organ. Then it designed the probe's parameters and the necessary important circuits of the system to further increase its accuracy.*

*It also assembles the sensor system which is designed to insure the rationality, reliability, stability of the structure. Finally it proposed the methods on the coefficient revision and the liquid condition parameter compensation to get higher accuracy.*

## 1.Introduction

Optical-fiber vortex flowmeters are particularly applied in the measurement of fluid flows where instruments without moving parts and wide range ability are required, especially under the flammable explosive environment.

But vortex street flowmeter's working condition is bad; the complex condition makes it difficult to get the high precision. The reasonable design on structure can increase the accuracy greatly besides the right signal processing method. The probe is an important part of the vortex flowmeter. Whether its structure is reasonable decides the vortex detection sensitivity of the flowmeter directly, which is relatedto the precision.

## 2.Design of the vortex shedder

The vortex shedder is the core pat of the vortex flowmeter. The traditional vortex shedder uses the single shedder or the twin shedders, but it has been found that in the circular pipe flowing, the vortex which is generated by the columnar shedder is unstable essentially. In circular pipe's flowing, the fluid has three dimensional axial symmetry speed of flow distribution under the perfect condition, so the axial speeds of slow along columnar are different. Under the influence of upstream resistance, the speed distribution may have distortion, turns and so on. The vortex which is generated by he columnar is not sealed, the both sides extend to the fluid contact surface, so the vortex nearby the pipe wall will be disturbed. To further increase the vortex street flowmeter's precision, the concept of ringlike vortex shedder is proposed in this article.

Formula $f = SrU_1 / d$ is set up in the two dimensional flow fields. However most of the industry pipes are circular section pipe. In the circular pipe, the axial symmetry distribution of the flow speed indicates that axial flow speeds along columnar are different (suppose it is the Y direction), the speed u is the $y$ function. So the above formula should be written as:

$$f(y) = Sr\frac{u(y)}{d(y)} \qquad (1)$$

Where: $u(y)$ - the axial flow speed along columnar.

$d(y)$ - the width of the columnar shedder where axial flow speed along columnar is $u(y)$

If the formula should be suitable for the columnar shedder, the width should satisfy the $u(y) = Kd(y)$, where K is a constant, therefore the columnar shedder's width contour line is a curve which is changed along with the flow speed. But it's difficult to realize it in the processing craft. In the ideal conditions, the flow speed in the tube is the axial symmetry distribution that makes it convenient to use the ringlike vortex shedder. Because in the circular pipe the flow speeds on the points which have the same distance to the axial are the same, if the ringlike shedder's center can dead be dead. In line with the pipe, the points around the ringlike

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vortex shedder will have the same flow speed, therefore formula (1) can be satisfied. This paper refers to columnar shedder's geometry size, according to the observation on the vortex signal which is gotten from massive lab experiments, then designs the ringlike shedder's size relation as**:**

$$\begin{cases} d_0 + d_1 = 22.4mm \\ b_1 + b_0 = 29.56mm \\ m_1 + m_0 = 4.04mm \\ c_0 + c_1 = 2.9mm \\ B = \frac{1}{4}(d_0 - d_1) \end{cases}$$

The structure is shown in Fig.1

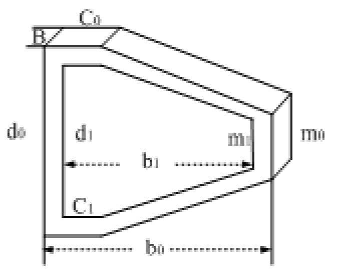



FIG.1 The structure of the ringlike vortex shedder

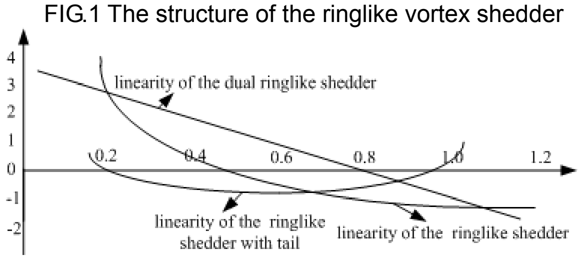



Fig.2 The linearity of different ringlike shedder

## 3.Design the optical fiber probe's parameters and choose the equipment

Considering the optical fiber probe needs large energy light and the high coupling performance between light source and optical fiber, the optical fiber sensor's light source uses laser tube which has strong directivity ,good coherence, high luminance, and the wave length of it is 0.85 $\mu m$ .At the end of the optical fiber ,we choose PIN to receive the signal which has been modulated ,then transform the light signal into the electrical signal, so that further processing can be gotten from the following transformation display circuit.

### 3.1 Choose ~~of~~ the light source

The output power should be as much as possible at the remote fiber when the light source and optical fiber are coupled. This power is associated with the input optical fiber's light intensity and the light source's wave length. Generally GaAs or GaAlAs is chosen which peak value is 0.8-0.95μm. To enhancing the illumination power, the geminate heterogeneous structure is taken.

Generally, the semiconductor light source is the choice. In the light intensity modulation system, the semiconductor laser's coherent output has serious modal noise, therefore a light emitter diode LED is used as the source. According to comparison, the light source in this system is an IRED which is FGE, coaxial sealed, geminate heterogeneous structure, side illumination short wave length near-infrared, and produced by Shanghai Communication Plant.

### 3.2 Choose the optical fiber

According to optical fiber's related knowledge, the multi-mold silica fiber is suitable in the frequency modulation optical sensor. Therefore, the large numerical aperture (NA) multi-mold thick optical fiber is selected in the transmission light intensity modulation system which can enhance the luminous intensity's coupling efficiency. In this paper the multi-mold silica fiber is chosen which core radius is 100μm, envelope thickness is50μm, and the numerical aperture is 0.56.

### 3.3 Choose of the optic-electro detector

According to the request optical fiber vortex flowmeter survey system, in order to cooperate the light source's luminescent spectrum, the2DU-F $N^{+}P$ structure silicon photorectifier made by Chinese Academy of Sciences Semiconductor Factory production 2DU-F the $N^{+}P$ structure silicon photorectifier is used.

## 4.Optical fiber's coupling

Optical fiber's coupling means the luminous power of the light source can transmit into the optical fiber as much as possible. The main request of it is to make the coupling loss as less as possible, and make the coupling structure as easier as possible in the real test system. The main coupling modes are the direct coupling and the lens coupling. The lens coupling may be divided into: end surface ball lens coupling, convex lens coupling, self-focusing lens coupling. This article uses the self-focusing lens coupling. A cylindrical self-focusing lens, in fact is a section of self-focusing optical fiber, and its image principle is shown in Fig. 3.

The self-focusing lens' focal distance $f$ is decided by its length $L$ and the focusing constant $g$. That is:

$$f = \frac{1}{n_0 g \sin(gL)} \qquad (2)$$

Where: $g$ -focusing constant， $g = \frac{1}{a}\sqrt{2\Delta n}$

$a$- lens semi diameter

$\Delta n$ -difference of relative refractive index

$n_0$ -refractive index of the lens axes

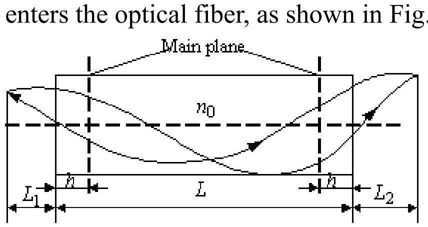
When $L = \frac{T}{4}$ (where T is the sine wave cycle of the self-focusing optical fiber, $T = \frac{2\pi}{g}$ ),the self-focusing lens' focal distance is the shortest, as $f = \frac{1}{n_0 g}$. Taken $g = \sqrt{2}$ , $a$ = 0.1mm， $\Delta n$ = 0.01as an example, then $f$ is 0.5 mm approximately. Generally the lens is very difficult to achieve such a short focal distance, and it is also the characteristic of self-focusing lens'. The distance between the cylindrical self-focusing lens main plane and the end surface is:

$$h = \left[\tan\left(\frac{1}{2} gL\right)\right] \Big/ n_0 g \qquad (3)$$

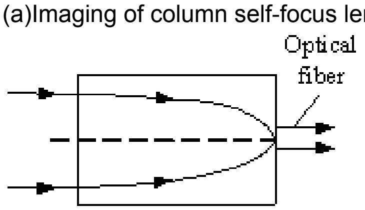
The distance between object and the end surface is $L_1$ , and it between image and the end surface is $L_2$ .The relation of $L_1$ and $L_2$ is

$$L_1 = \frac{[n_0 L_2 g \cos(gL) + \sin(gL)]}{n_0 g [n_0 L_2 g \sin(gL) - \cos(gL)]} \qquad (4)$$

The image can be reduced or magnified by adjusting the lens. In the system, the self-focusing lens is chosen as $L = T/4$ , and the fiber and the lens are agglutinated together. The parallel light enters the self-focusing lens, then all enters the optical fiber, as shown in Fig. 2.




(a)Imaging of column self-focus lens




(b)Coupling of $L = T/4$ self-focus lens and optical fiber

Fig.3 Coupling of self-focus lens

The efficiency of this coupling is 50%~60%. It's a good coupling mode because of agglutination, the structure is compact, reliable and stable.

## 5.Design of the Optical probe circuits

The circuits are also important to get the higher precision. In this paper, the coupling circuit, the PSD and the zero and temperature compensation circuit are designed.

### 5.1 Coupling and amplification circuit

In this circuit, LED sends out the constant intensity light, which projects to the vibration diaphragm, and then the receiving optical fiber sends the intensity periodic changed light which is reflected by the diaphragm to the photosensitive triode. The light-emitting system which is composed by the LED, the transistor, the Zener diode and the voltage-stabilizer circuit guarantee the light source emits light which has the constant intensity. The pre-amplification circuit is composed by the photosensitive triode, the electrical source, which sends out the constant current and the integrated circuit. The transformation from the vortex frequency to the voltage signal is carried out through optical coupling and current amplification.

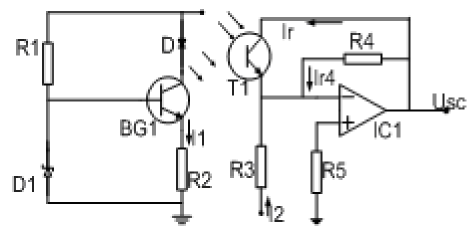



Fig.4 Coupling and amplification circuit

### 5.2Design of the PSD

In order to filter the disturbance of the background light's, a phasic sensitive detecting circuit (PSD) is used. Incident light enters the receiving optical fiber after modulated by the incident optical fiber; however a part of background light has mixed into the projection optical fiber, and both of them are transformed to the voltage signal by the optic-electro transformation circuit, as well as enlarged by the pre-amplification circuit. Therefore, the disturbance of the background light has to be filtered to obtain the precise measurement result. The background light is filtered, whose frequency is different from the incident light, through the PSD to get the useful signal. The PSD circuit is composed by a four bidirectional analog switch CD4066 and a low pass filter. Its structure is shown in Fig.5.

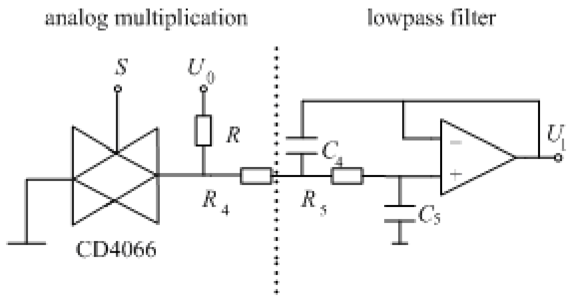



Fig.5 PSD schematic circuit

### 5.3 Design of the compensation circuit

In the optical fiber sensing system, many disturbance factors may cause the system unstable and the precision drop, so the corresponding compensating circuit must be used to enhance the reliability of system. In order to eliminate the influence of zero and temperature excursion, this system uses the differential compensation. Its circuit is shown in Fig. 6.

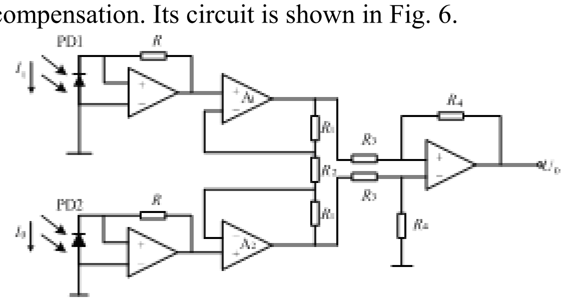
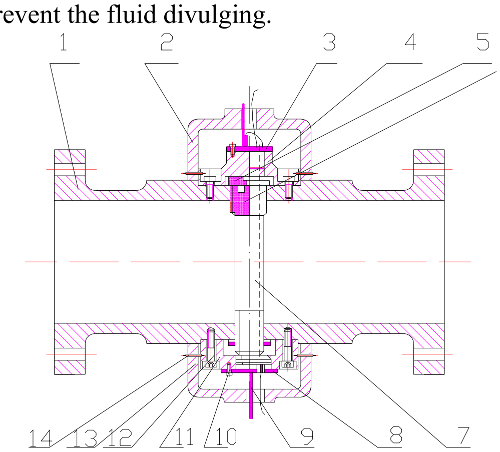



Fig.6 Differential compensation circuit for zero and temperature excursion

The point worth to notice is it's difficult to get two photorectifiers which have the same characteristic, but this is the foundation of the compensating circuit. Therefore, it's very important to do the characteristic measurement for the two chosen photorectifier. When characteristics are the same, differential compensation circuit can remove the influences from the photorectifier's dark current and the zero and temperature excursion through increasing the common mode rejection ratio to get the higher precision.

## 6 Assembly result of the system

The entire flowmeter's material is the 45 steel which is used in the industry. The assembly diagram of the design is shown in Fig.7, 3D assembly drawing is shown in Fig.8, and effect diagram which assembled with the pipe is shown in Fig.9. The vortex shedder is put in the shell vertically, the semicircular slot on the cylinder is used to put and fix the optical fiber. The vortex shedder is fixed by the locating key6, and twists the nut 14. Because the vortex flowmeter directly connects to the fluid transmission pipe in the project locale, seal is a question that must be taken into account. In the design which focuses on the seal, a rubber gasket is needed between the flowmeter's shell flange and the pipe, as well as the shell and the shedder to prevent the fluid divulging.




1shell 2top cover 3top baffle 4top nog 5baffle 6locating key 7vortex shedder 8bottom baffle 9optic-electro receiver 10bolt 11bottom cover 12big bolt 13bottom nog 14nut

Fig.7 The assembly diagram of the flowmeter

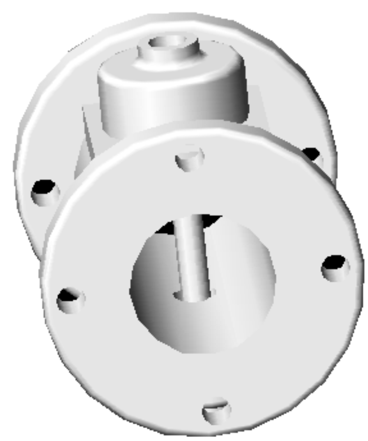


Fig.8 The 3D assembly drawing

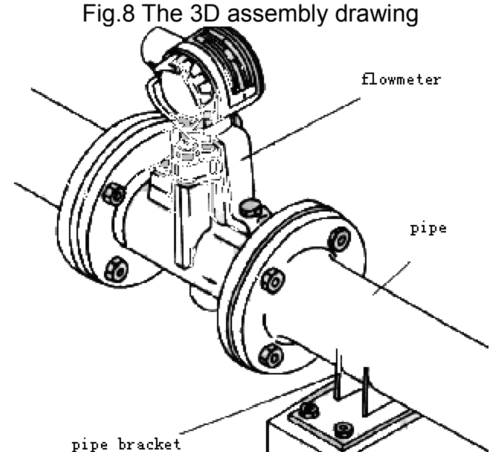



Fig.9The assembly diagram with the pipe

## 7 The coefficient revision and the liquid parameter compensation

### 7.1 The coefficient revision

Generally, the scaling factor of the vortex flowmeter is decided by the liquid or the gas flow amount calibrating device in the normal temperature and the atmospheric pressure condition, therefore when the measuring appliance's working condition is far away from the demarcation condition, it needs to revise the scaling factor K. The main factors which influence the K are Reynolds number, the medium temperature and the pipeline difference.

**7.1.1Reynolds number revision.** When the vortex flowmeter is working on scene, the flow, density and so on can be gotten from the parameters those are gotten in real-time and have been written in the instrument, the Reynolds number is gotten further. So the correction coefficient $E_{Ri}$ can be calculated through the interpolation to realize the revision of the K. $K_i = E_{Ri}\overline{K}$.

**7.1.2Medium temperature revision.** The temperature revision coefficient of the high temperature medium is: $E_t = \left[1 + (2\alpha_0 + \alpha_x)(t - t_0)\right]^{-1}$.

Where: $\alpha_0$ -shell material expansion coefficient of the flowmeter

$\alpha_x$ -expansion coefficient of the vortex shedder

$t$ -liquid temperature

$t_0$ -liquid temperature of the lab demarcation condition

So, we can get $K = E_t\overline{K}$.

**7.1.3Pipeline difference revision.** When the vortex flowmeter connects to the pipe, there are some differencese between the flowmeter and the pipe's inside diameter. The experiment indicates if the match pipe's inside diameter $D_p$ is equal to or a little bigger than the measurement pipe's inside diameter $D_b$ ,there's no influence on the K, if $D_p < D_b$ ,and the difference is within or less than3%, the K has to be revised. $E_D = (D_b/D_p)^2$ , $K = K_D K_0$

Where: $E_D$ -pipe revision coefficient

$K_0$ -floemeter's demarcation coefficient

### 7.2 The liquid parameter compensation

Density of the gas and the stream may change because of the change of work condition; therefore the result may have big error. So the temperature and the pressure compensation should be taken into account to reduce the error.

**7.2.1Temperature compensation for the liquid density.** The majority of the liquid is regarded as the incompressible fluid; therefore the influence of the pressure on the density is smaller than that of the temperature. So the temperature compensation is used for liquid to get higher precision. The formula is:

$$\rho = \rho_0\left[1 - \lambda(t_0 - t)\right]$$

Where: $\rho$ -density of the liquid when its temperature is $t$

$\rho_0$ - density of the liquid when its temperature is $t_0$

$\lambda$ -volume expansion coefficient of the liquid

**7.2.2Gas density compensation.** Both of the pressure and the temperature exert a great influence on the intensity of gas, so both of the temperature and pressure compensation should be considered. This paper just discusses the dry gas's compensation because the conditions of the wet gas, the mixed gas and the saturated gas are complicated. The compensation formula is: $\rho = \rho_n \frac{p}{p_n} \cdot \frac{T_n}{T} \cdot \frac{Z_n}{Z}$.

Where: $\rho_n$ -the gas density under the standard condition

$P$ and $P_n$ -gas absolute pressure under the work condition and the standard condition

$T$ and $T_n$ -gas thermodynamic temperature under the work condition and the standard condition

$Z$ and $Z_n$ - gas compressibility coefficient under the work condition and the standard condition

## 8.Conclusion

This paper has designed the vortex flowmeter's probe. On the concept of the traditional vortex shedder, it proposes the concept of the ringlike vortex shedder. At the same time, it designs the optic-electro coupling circuit, composition circuit and the physical structure of the optical probe, and carries out the assembly. The assembly diagram shows that the structure of the flowmeter's optical probe is rational. At the end of this paper, the revision to the scaling factor and the composition for the liquid parameters are used to get the higher precision.

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