

Contents

1.	Introduction.....	1
2.	Features.....	2
2.1	Principle Features of Vortex Flowmeter	2
2.2	Yokogawa's Unique Features	2
2.2.1	Features of Sensor	2
2.2.2	Features of Transmitter.....	3
3.	Measurement Principle of Vortex Flowmeter	4
4.	Vortex Generation Frequency Detection Method	6
4.1	Principle of Vortex Generation Frequency Detection	7
4.2	Basic Structure and Signal Processing of Vortex Flowmeter VY Series.....	8
4.2.1	Structure of Sensor	8
4.2.2	Signal Processing	9
5.	Operational Configuration	13
6.	Correction Functions	16
6.1	Reynolds Number Correction.....	16
6.2	Instrumental Error Correction	16
6.3	Expansion Correction for Compressible Fluid (Gas/Vapor)	17
7.	Self-diagnostic Function	18
7.1	Errors and Countermeasures.....	18
7.2	Operation when an error occurs	18
7.3	Verification Tool	18
7.3.1	Inspection Items in Standard Verification	18
7.3.2	Inspection Items in Enhanced Verification.....	19
7.3.3	Check/Inspection Result (Report) Output, File Management	19
7.3.4	Data Lock	19
7.4	Remote Maintenance Tool	19
7.4.1	Vortex Waveform Monitor Health Check Items	20
7.4.2	Vortex Frequency Analyzer Health Check Items	23
7.4.3	Vortex Sensor Prediction Health Check Items	25
7.5	Hardware Health Check.....	26
8.	Examples of Changing Flow Rate Measurement Parameters.....	27
9.	Sizing	30
10.	Various Fluid Data	38

1. Introduction

When a columnar object (shedder bar) is inserted into the flow, the boundary layer is separated from the surface, and vortices that rotate in opposite directions, referred to as “Karman vortex street”, are alternately generated downstream. It has been confirmed that the generation frequency of this vortex street is directly proportional to the flow velocity within a certain Reynolds number range. Therefore, by measuring this vortex generation frequency, it is possible to measure the flow velocity or flow rate. The vortex flowmeter is a flowmeter that uses this principle.

We developed the world's first vortex flowmeter in 1969, and commercialized the YEWFLO Series as a general-purpose flowmeter in 1979. As of 2022, we have developed the Vortex Flowmeter VY Series based on our cumulative experience of manufacturing and selling a record 560,000 devices worldwide.

By inheriting and evolving SSP (*) (Spectral Signal Processing), which is a digital circuit technology of digitalYEWFLO, we have achieved a higher level of stability and accuracy in addition to the reliability and durability we have built up in the past.

* SSP is an abbreviation for our original digital signal processing.

2. Features

Vortex Flowmeter VY Series models have features associated with the principle of the vortex flowmeter coupled with Yokogawa's unique technical features.

2.1 Principle Features of Vortex Flowmeter

- **High accuracy**

High accuracy for both liquid and gas is obtained, which is $\pm 1\%$ (pulse output) of the reading, compared to that of the orifice flowmeter. Depending on the fluid and its characteristics, it is possible to provide a high level of accuracy of maximum $\pm 0.75\%$ for liquid.

- **Wide rangeability**

Rangeability is defined here as the ratio of the maximum and minimum values within the measurable range. The wide rangeability makes it possible to handle processes in which the measurement point of the flow rate changes significantly.

- **Output and flow rate in proportional relationship**

The output is proportional to the flow rate (flow velocity), so the square root extraction is not required unlike orifice flowmeters.

- **No zero point fluctuation**

A frequency is output from the sensor, which does not cause any zero point fluctuation.

- **Small pressure loss**

Only a shedder bar is contained in the pipe of the vortex flowmeter and the throttle of the flow path is small; therefore, the pressure loss is relatively small compared to that of instrumentation that has an orifice or similar object.

2.2 Yokogawa's Unique Features

2.2.1 Features of Sensor

- **The sensor does not come into contact with fluid**

The flow sensor (piezo electric device) of the Vortex Flowmeter VY Series is inside the shedder bar. Therefore, the sensor does not directly come into contact with the measured fluid.

The shedder bar contains a temperature sensor (Pt1000) with the built-in temperature sensor type.

- **Robust and simple structure with no moving parts**

The flow path only has a shedder bar with a trapezoidal cross section and no moving parts, which results in a robust and simple structure. It is basically maintenance-free. You can easily check the soundness of the sensor at any time by using the self-diagnostic function and remote maintenance function described later. These functions can show signs that maintenance is required. Even if maintenance is required, Yokogawa's unique detachable structure can minimize downtime and maintenance costs.

- **Can be used for high temperature and high-pressure fluids**

It is also possible to measure high-temperature fluids up to 450°C (25 to 400 mm, type of shedder bar: high temperature type) using a integral flowmeter. In addition, it can be sufficiently used for standard pressure up to the pressure rating of the ASME class 1500 flange (25 MPa at room temperature).

■ Low total cost

The total cost including the instrumentation/maintenance cost is lower than that of other flowmeters.

2.2.2 Features of Transmitter

■ Spectral signal processing (SSP)

Yokogawa's unique SSP (Spectral Signal Processing) amplifier, which utilizes digital circuit technology, always carries out automatic adjustment to the optimum conditions. By inheriting and evolving this function that has been proven in digital YEW FLO, long-term stability and safe operation has been realized.

■ Adaptive Noise Suppression (ANS)

This is a function that always carries out full-automatic adjustment to the optimum conditions immediately after the power is turned on. With this function, it is now possible to accurately capture the vortex signal without being affected by vibration, and secure a stable output signal.

■ Advanced Self-diagnostic function

This function predicts and displays changes in the application status (piping vibration, fluid turbulence, etc.). By understanding the status, early on-site diagnoses and responses became possible.

The Vortex Flowmeter VY Series enables you to confirm the normal operating status of the device by using the FSA130 software tool.

■ Improved parameter operability

Operability has been improved by extracting the frequently used parameters and combining them into one block.

■ Multi-functional display

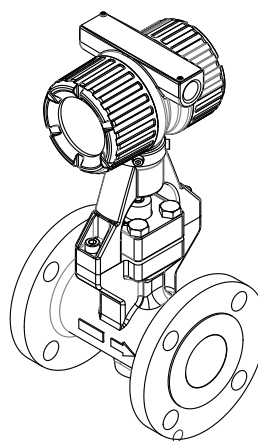
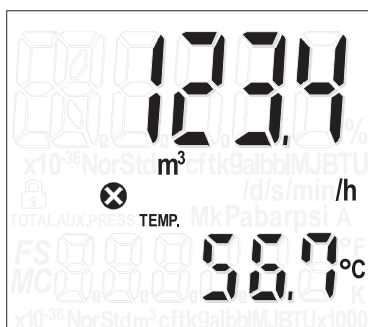
The instantaneous flow rate value and the integrated flow rate value can be displayed simultaneously in the two-column configuration. The self-diagnostic result is also displayed by category based on NE107.

■ Simultaneous current/pulse output

Both instantaneous and integrated values can be measured simultaneously.

■ Various calculation functions

It is possible to perform temperature compensation, pressure compensation, and calculation of energy by analog input of the pressure signal from the external pressure gauge. With the built-in steam table, it is possible to more accurately measure the steam flow rate.



F0201.ai

3. Measurement Principle of Vortex Flowmeter

When the shedder bar is placed in the flow as shown in Figure 3.1, a Karman vortex street arranged in sequence is generated downstream.

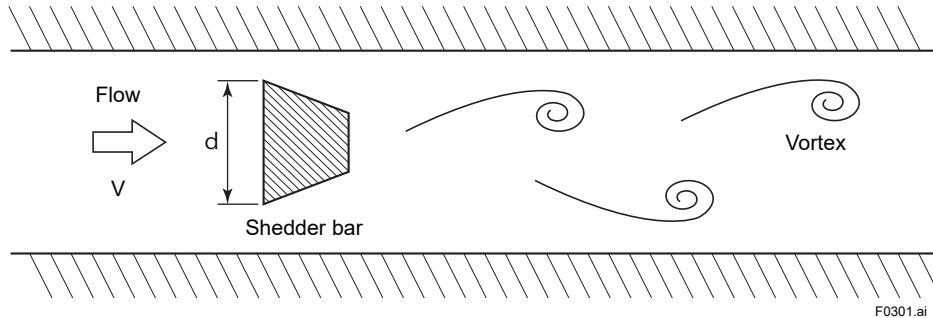


Figure 3.1 Karman vortex streets

Assuming that the frequency of the vortex generated at this time is f , the flow velocity is v , and the width of the shedder bar is d , the following relationship is obtained:

$$f = St \cdot \frac{v}{d} \quad (1)$$

This can also be applicable to a vortex flowmeter that flows through a circular pipe. Here,

$$v = \frac{Q}{\frac{\pi \cdot D^2}{4} - d \cdot D} \quad (2)$$

Q : Volume flow rate

D : Inner diameter of vortex flowmeter

St : Strouhal number

Equations (1) and (2) can be collectively expressed with the volume flow rate as shown below.

$$Q = \frac{f \cdot \left(\frac{\pi \cdot D^2}{4} - d \cdot D \right) \cdot d}{St} \quad (3)$$

The Strouhal number (St), which refers to a dimensionless number determined by the shape and dimensions of the shedder bar, provides a constant value over the wide Reynolds number range by selecting the shape appropriately.

Figure 3.2 shows the relationship between the Strouhal number and the Reynolds number.

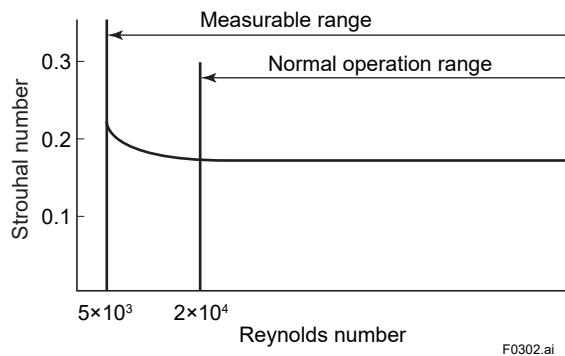


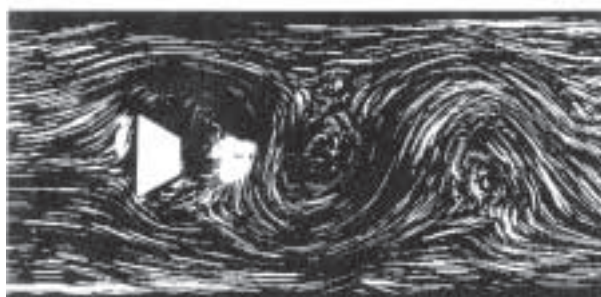
Figure 3.2 Relationship between Strouhal number and Reynolds number

Therefore, if you know the Strouhal number in advance, you can measure the flow rate by measuring the vortex frequency.

In addition, it can be seen from equation (3) that the flow rate can be measured regardless of the pressure, temperature, density, viscosity, etc. of the fluid. However, the temperature compensation or pressure compensation is required to measure the volume flow rate or mass flow rate in the standard (reference) state.

4. Vortex Generation Frequency Detection Method

The shedder bar of the vortex flowmeter has a trapezoidal cross-sectional shape. The trapezoidal cross section has excellent linearity of the vortex generation frequency, enabling you to generate stable Karman vortices. Figure 4.1 shows the visualized photograph of the vortices generated from the shedder bar with the trapezoidal cross section.



F0401.ai

Figure 4.1 Karman vortex streets of trapezoidal columnar object

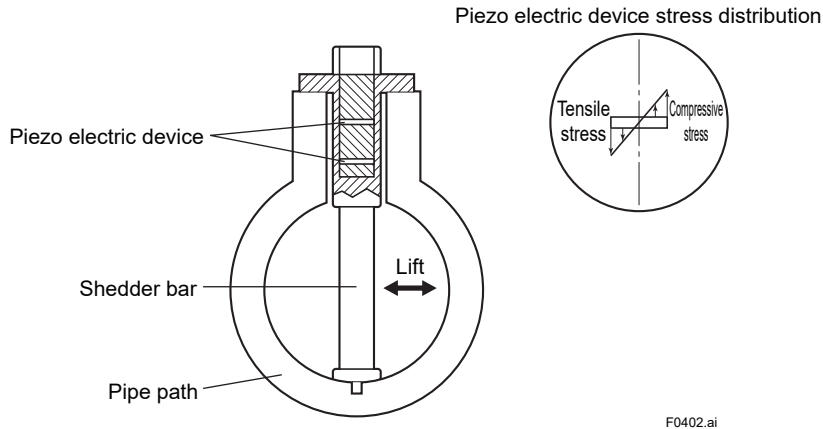
The vortex flowmeter uses the piezo electric device to detect the stress generated by the alternating lift applied to the shedder bar when the vortex is generated, as the vortex generation frequency detection method.

The piezo electric device method has the following features.

- (1) The piezo electric device, which is a sensor, can be constructed so that it does not come into contact with fluid.
- (2) This method is based on the system that detects stress, so it is not necessary to significantly displace the shedder bar, which helps create a sturdy structure.
- (3) The piezo electric device has high-level sensitivity, so it is possible to measure a wide range of flow rates.
- (4) It is possible to make the operating temperature and pressure range very wide.

4.1 Principle of Vortex Generation Frequency Detection

Figure 4.2 shows the principle of vortex generation frequency detection.



F0402.ai

Figure 4.2 Principle of vortex generation frequency detection

As the fluid flows perpendicular to the surface of the paper, vortices are emitted from the shedder bar. At this time, an alternating lift of the same frequency as the vortex generation frequency is applied to the shedder bar. This alternating lift causes a stress change in the shedder bar, and the piezo electric device fixed to the shedder detects the frequency of this stress change, that is, the vortex generation frequency.

The magnitude of the alternating lift is proportional to the square of the flow velocity, and the peak value F_L of the alternating lift is expressed by the following equation:

$$F_L = \pm 1/2 \cdot C_L \cdot \rho \cdot V^2 \cdot d \cdot D \quad (4)$$

Here,

C_L : Dimensionless coefficient

V : Flow velocity

D : Pipe inner diameter

ρ : Fluid density

d : Shedder bar width

The average stress σ_M generated in the piezo electric device and the charge amount q induced in the piezo electric device are expressed by the following equations:

$$\sigma_M = K \cdot F_L$$

$$Q = d_0 \cdot \sigma_M \cdot S$$

Here,

K : Constant determined by the shape and support method of the shedder bar

d_0 : Piezoelectric coefficient

S : Area of piezo electric device

This AC charge amount is signal-processed by an electronic circuit, and the vortex frequency is detected.

4.2 Basic Structure and Signal Processing of Vortex Flowmeter VY Series

4.2.1 Structure of Sensor

Figure 4.3 shows the sensor structure.

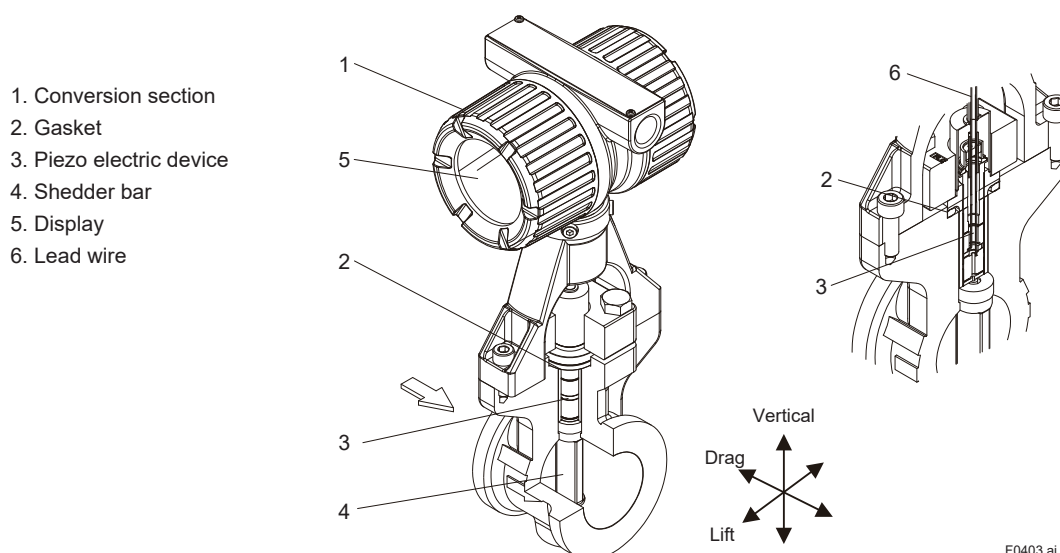


Figure 4.3 Structure of sensor

As shown in Figure 4.4, two piezo electric devices are placed above the shedder bar to efficiently detect the signal generated by the vortex and eliminate the effects of noise such as pipe vibration.

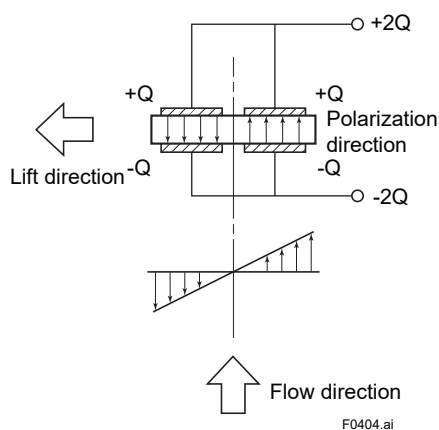


Figure 4.4 Piezo electric device

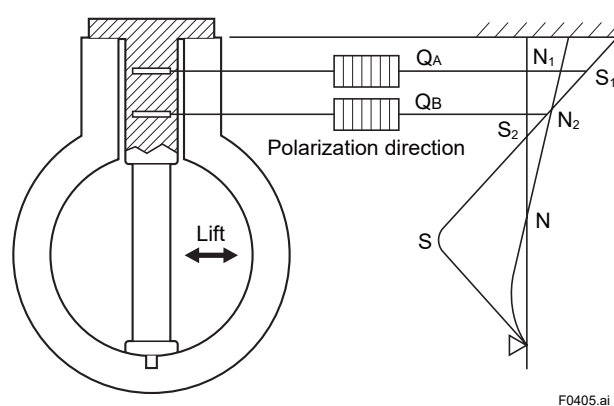


Figure 4.5 Distribution of signal and noise in the lift direction

As shown by the arrow in Figure 4.3, pipe vibration is assumed to be caused due to the lift, drag, or vertical vibration.

Normally, drag and vertical vibration are not detected based on the structure of the piezo electric device shown in Figure 4.4. The vibration in the lift direction is in the same direction as the vortex generated by the fluid; therefore, this vibration noise may be falsely detected as a vortex signal.

In the Vortex Flowmeter VY Series, noise such as pipe vibration is eliminated by effectively combining the structure of two piezo electric devices and SSP technology for this vibration in the lift direction.

4.2.2 Signal Processing

(1) Spectral signal processing (SSP)

Figure 4.6 shows the block circuit diagram of the transmitter equipped with SSP.

This circuit incorporates the latest technologies to efficiently eliminate piping vibration.

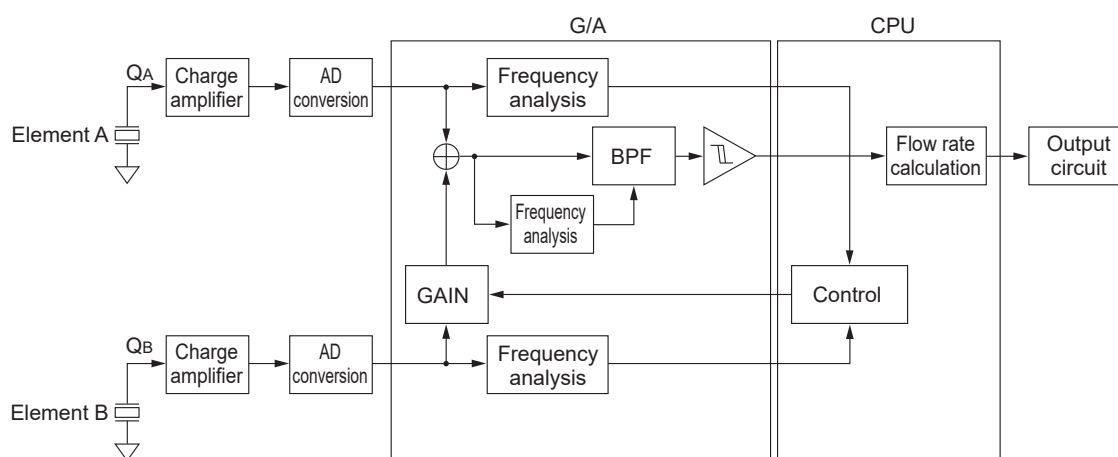


Figure 4.6 Transmitter block circuit diagram

These digital technologies have the following effects:

(1) Improved vibration performance!

The vibration performance is greatly improved compared to that of conventional models.

(2) Achieved stable measurement at low flow rate!

Output fluctuations due to vibration noise are removed, and only vortex signals are output.

(3) Advanced self-diagnostic function!

The signal analysis (frequency analysis) is always performed, so an alarm can be issued in the event of an abnormal flow such as an unstable flow, adhesion, or vibration.

(2) Adaptive Noise Suppression (ANS)

The signal from the piezo electric device is accurately captured by the frequency analysis, and vibration noise is always automatically removed.

Vortex Flowmeter VY Series models are configured to eliminate noise from piping vibration by using the signal and noise distribution in the lift direction shown in Figure 4.5. Here, this function is referred to as “adaptive noise suppression (ANS)” because it removes signals and noise in a well-balanced manner.

The signals Q_A and Q_B generated from the two piezo electric devices are converted into AC signals by the two charge converters. Each AC signal is converted to a digital signal by A/D conversion.

SSP constantly analyzes the frequency of this digital signal and measures the signal component and noise component generated from the piezo electric device. Using this measurement result, noise removal is always performed based on the following principle.

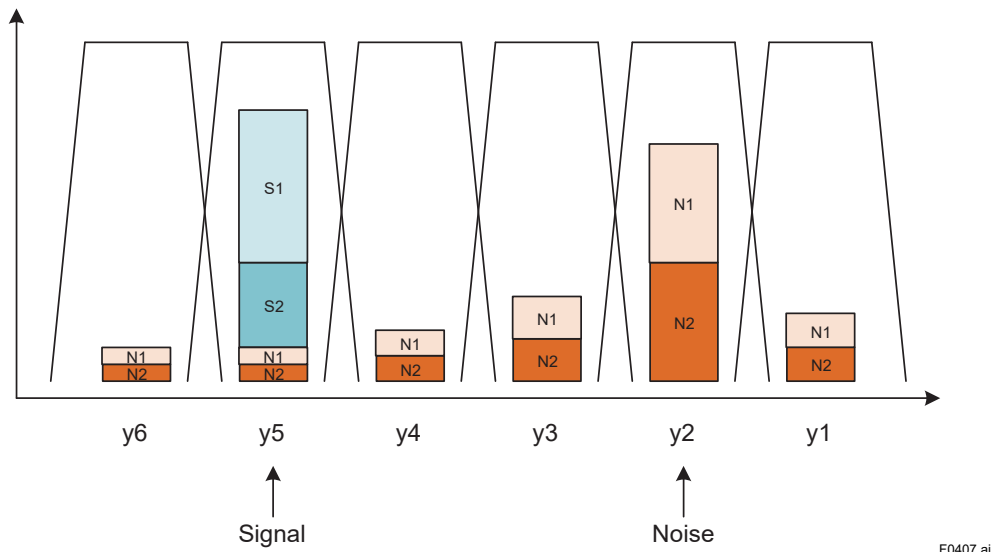


Figure 4.7 ANS operation block diagram

Figure 4.7 shows the ANS operation block diagram.

If it is assumed that the outputs of the two piezo electric devices are Q_A and Q_B , the signal analysis is S_1 and S_2 , and the noise components are N_1 and N_2 as shown in Figure 4.5, the following equations are obtained because the polarizations of the two piezo electric devices are reversed.

$$Q_A = S_1 + N_1 \quad (1)$$

$$-Q_B = -S_2 - N_2 \quad (2)$$

Here, if the output Q_B of the piezo electric device is multiplied by λ ($0.5 < \lambda < 1.2$),

$$-\lambda Q_B = -\lambda S_2 - \lambda N_2 \quad (3)$$

If this signal and the output Q_A of the piezo electric device are added,

$$Q_A - \lambda Q_B = S_1 - \lambda S_2 + N_1 - \lambda N_2 \quad (4)$$

Here, if $N_1 = \lambda N_2$ is set,

$$Q_A - \lambda Q_B = S_1 - \lambda S_2 \quad (5)$$

Therefore, only the signal component can be detected.

In this way, when the noise magnitudes (amplitudes) N_1 and N_2 are measured by the frequency analysis and λ is determined, it is possible to remove noise generated by piping vibration.

In the Vortex Flowmeter VY Series, the optimum λ is always calculated automatically and the value is applied, so even if noise changes, the influence is removed and only the signal components can be extracted.

(3) Spectral Adaptive Filter (SAF)

The signal frequency from the piezo electric device is constantly analyzed, the optimum filter is always selected from the results, the vortex signal and vibration noise are separated, and noise is removed.

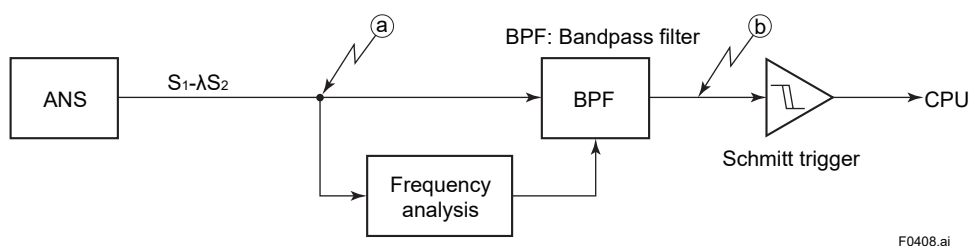


Figure 4.8 Spectral Adaptive Filter (SAF) block diagram

Figure 4.8 shows the Spectral Adaptive Filter (SAF) block diagram.

The two signals converted to digital signals by the A/D conversion circuit are input to the bandpass filter (BPF) after ANS processing. Normally, noise components are removed by ANS, however, if a signal that cannot be completely removed, such as a high-frequency noise, remains, the signal waveform is made as shown in Fig. 4.9 (A).

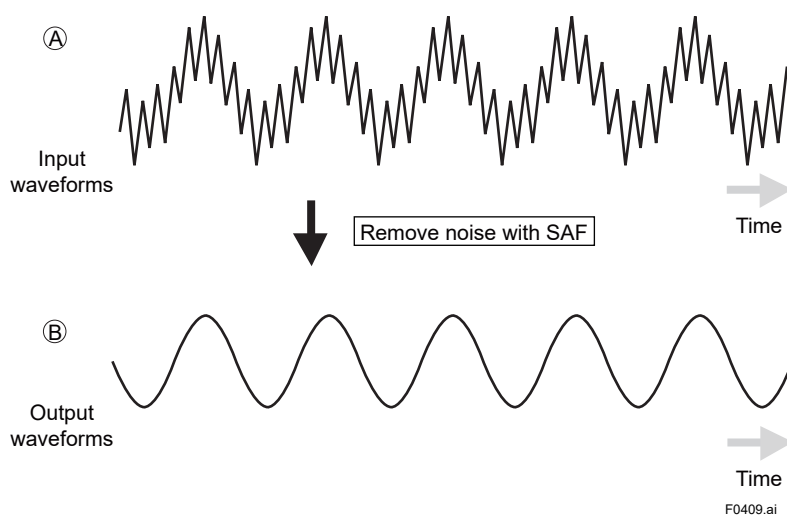


Figure 4.9 Input/output waveform diagram

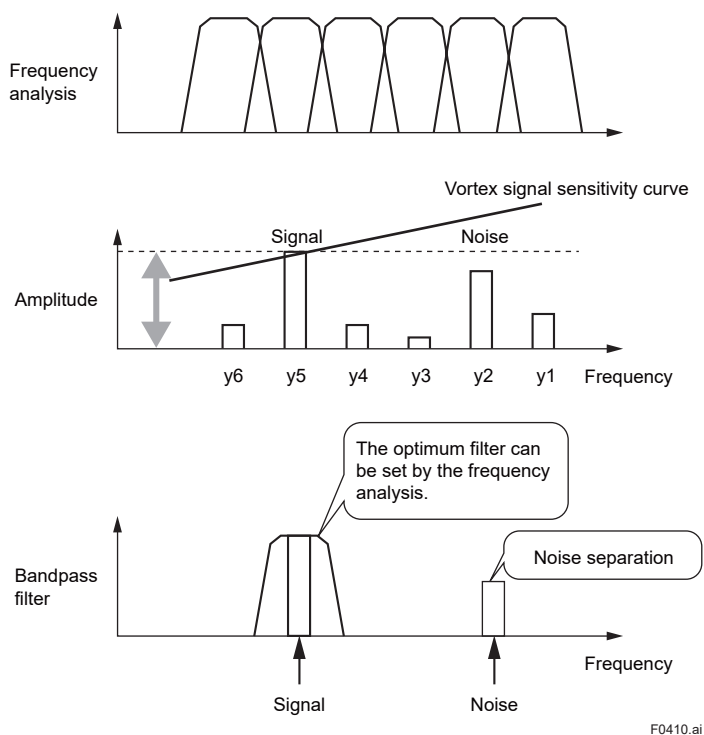


Figure 4.10 SAF operation

SAF has a bandpass filter (BPF) divided into multiple bands.

When a signal containing noise as shown in Figure 4.9 ① is input, the frequency analysis is performed in each band. This analysis result is compared with the vortex signal sensitivity curve defined for each caliber. Based on this comparison result, the signal component and noise component can be automatically distinguished, so a filter that allows only the signal component to pass can be set automatically. Therefore, SAF can change the waveform shown in Figure 4.9 ① to the clean waveform shown in Figure 4.9 ②.

5. Operational Configuration

(1) Flow rate calculation

The flow rate calculation is performed using the following formula, assuming that the count number N of the generated vortexes is N.

a) Instantaneous flow rate (actual flow rate unit) (RATE)

$$\text{RATE} = N \times 1 / \Delta t \times \varepsilon_f \times \varepsilon_e \times \varepsilon_r \times 1 / KT \times U_k \times U_{TM}$$

$$KT = KM \times U_{KT} / \{1 + Et (T_f - 15) \times 10^{-5}\}$$

b) Instantaneous flow rate (%) (RATE (%))

$$\text{RATE (\%)} = \text{RATE} \times 1 / F_s \times 100$$

c) Integrated value (TOTAL)

$$\text{TOTAL} = \text{TOTAL} + \Delta \text{TOTAL}$$

$$\Delta \text{TOTAL} = \text{RATE} \times \Delta t \times 1 / T_R \times 1 / U_{TM}$$

d) Pulse output frequency (PULSE FREQ)

- For scaled pulse

$$\text{PULSE FREQ} = \text{RATE} \times 1 / P_R \times 1 / U_{TM}$$

- For unscaled pulse (Unitless conversion)

$$\text{PULSE FREQ} = N \times 1 / \Delta t \times 1 / P_R$$

e) Flow velocity (V)

$$V = N \times 1 / \Delta t \times 1 / KT \times U_{KT} \times 4 / \{ \pi \times D^2 \}$$

f) Reynolds number (Re)

$$\text{Re} = V \times D \times \rho_f \times 1 / \mu \times 1000$$

N : Number of input pulses (pulse)

Δt : Time corresponding to N (sec)

ε_f : Instrument error correction coefficient

ε_e : Expansion correction coefficient of compressible fluid

ε_r : Reynolds correction factor

KT : K-factor (p/l) at temperature in use

KM : K-factor at + 15°C (p/l)

Et : Expansion coefficient

U_{KT} : K-factor unit conversion factor

U_k : Flow rate unit conversion factor (Refer to “(2) Flow rate unit conversion factor (Uk)”.)

U_{TM} : Time unit conversion factor (eg. /m (minutes) = 60)

P_R : Pulse rate

T_f : Temperature in use (°C)

F_s : Flow span

T_R : Integrated rate

D : Inner diameter (m) of the detection section of the vortex flowmeter

μ : Viscosity coefficient (mPa·s)

ρ_f : Density in use (kg/m³)

(2) Flow rate unit conversion factor (U_k)

The flow rate conversion factor U_k is calculated as follows depending on how the measurement fluid and the flow rate unit are selected.

a) Steam

For M (mass)

$$U_k = \rho_f \times U_{pf} \times U_k \text{ (kg)}$$

For Q_f (flow rate)

$$U_k = U_k \text{ (m}^3\text{)}$$

b) Gas

For Q_n (flow rate)

$$U_k = \{P_f / P_n\} \times \{(T_n + 273.15) / (T_f + 273.15)\} \times 1 / K \times U_k \text{ (Nm}^3\text{)}$$

For M (mass)

$$U_k = \rho_f \times U_{pf} \times U_k \text{ (kg)}$$

For Q_f (flow rate)

$$U_k = U_k \text{ (m}^3\text{)}$$

[Flow unit] N: Represents the standard state (normal).

c) Liquid

For Q_f (flow rate)

$$U_k = U_k \text{ (m}^3\text{)}$$

For M (mass)

$$U_k = \rho_f \times U_{pf} \times U_k \text{ (kg)}$$

d) For user-specified unit

$$U_k = U_k \text{ (User)}$$

(3) Mass flow rate calculation (with temperature sensor, with analog input)

a) Steam

For the saturated steam (temperature), the mass flow rate is calculated by obtaining the density from the measured value of temperature, or the analog input value from the temperature gauge based on the built-in saturated steam table.

For the saturated steam (pressure), the mass flow rate is calculated by obtaining the density from the analog input value from the external pressure gauge based on the built-in saturated steam table.

For superheated steam, the mass flow rate is calculated by obtaining the density from the measured value of temperature and the analog input value from the external pressure gauge based on the built-in heated steam table.

In each calculation, the fixed value entered in the parameter can be used as the temperature or pressure value.

$$M = \rho_{ft} \times Q_f$$

b) Gas

For gas, the volume flow rate in the standard state is calculated by correcting the temperature pressure from the measured value of temperature. The pressure uses the fixed value input to the parameter or the analog input value from the external pressure gauge.

$$Q_n = Q_f \times \{P_f / P_n\} \times \{(T_n + 273.15) / (T_f + 273.15)\} \times 1 / K$$

c) Liquid

For liquid, the change in density is secondarily corrected from the temperature.

The mass flow rate is calculated by obtaining the change in density from the measured value of temperature.

$$M = Q_f \times \rho_n \times \{1 + a_1 \times (T_f - T_n) \times 10^{-2} + a_2 \times (T_f - T_n)^2 \times 10^{-6}\}$$

[Tips]

$$a_1 = \{(k_1 - 1) \times \Delta T_2^2 - (k_2 - 1) \times \Delta T_1^2\} / \{(\Delta T_1 \times \Delta T_2^2 - \Delta T_2 \times \Delta T_1^2) \times 10^{-2}\}$$

$$a_2 = \{(k_1 - 1) \times \Delta T_2 - (k_2 - 1) \times \Delta T_1\} / \{(\Delta T_1^2 \times \Delta T_2 - \Delta T_2^2 \times \Delta T_1) \times 10^{-6}\}$$

$$k_x = 1 + a_1 \times \Delta T_x \times 10^{-2} + a_2 \times \Delta T_x^2 \times 10^{-6}$$

$$\Delta T_x = T_x - T_n$$

$$(x = 1, 2)$$

M : Mass flow rate

Q_n : Volume flow rate in the standard state

Q_f : Volume flow rate in use

T_f : Temperature in use (°C)

T_n : Temperature in the standard state (°C)

P_f : Pressure in use (kPa)

P_n : Pressure in the standard state (kPa)

K : Deviation coefficient

ρ_n : Density in the standard state (kg/m³)

ρ_f : Density in use (kg/m³)

ρ_{ft} : Density obtained from the measured temperature (kg/m³)

U : Density unit conversion factor

U_k (kg), U_k (Nm³), U_k (m³): Unit conversion factor of flow rate

a_1 : Primary correction factor of liquid

a_2 : Secondary correction factor of liquid

Example, U_k (kg): Unit conversion factor from kg

For kg, U_k (kg) = 1

For ton, U_k (kg) = 0.001

(Tips)

To obtain the compensation coefficients a_1 and a_2 , the maximum temperature T_{max} and its density ρ_{Tmax} and the minimum temperature T_{min} and its density ρ_{Tmin} in the compensation temperature range and the reference temperature T_n and its density ρ_{Tn} in between are required. From the correction formula, the following equation can be obtained.

$$\rho_f = M / Q_f$$

$$\rho_f = \rho_n \times \{1 + a_1 \times (T_f - T_n) \times 10^{-2} + a_2 \times (T_f - T_n)^2 \times 10^{-6}\}$$

The density of the maximum temperature and the density of the reference temperature and the density of the minimum temperature and the density of the reference temperature are applied to the above equations to solve the simultaneous equations to obtain a_1 and a_2 .

$$\rho_{Tmax} = \rho_{Tn} \times \{1 + a_1 \times (T_{max} - T_n) \times 10^{-2} + a_2 \times (T_{max} - T_n)^2 \times 10^{-6}\}$$

$$\rho_{Tmin} = \rho_{Tn} \times \{1 + a_1 \times (T_{min} - T_n) \times 10^{-2} + a_2 \times (T_{min} - T_n)^2 \times 10^{-6}\}$$

6. Correction Functions

Vortex Flowmeter VY Series models are equipped with various correction functions to support various applications. The following provides an overview of each correction function.

6.1 Reynolds Number Correction

In the three-dimensional flow in the circular pipe, the Strouhal number (K-factor) gradually increases as the Reynolds number (≤ 20000) decreases, as shown in Figure 6.1. This K-factor bend is corrected by a 5-point broken line approximation.

Example: For water, the Strouhal number deviates by about 1% between the Reynolds number 40000 and the Reynolds number 20000. Therefore, by applying a correction of -1%, it is possible to recover the change in the Strouhal number (K-factor) and measure the correct flow rate.

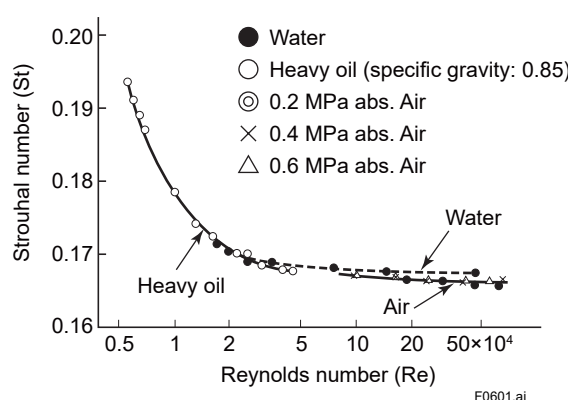
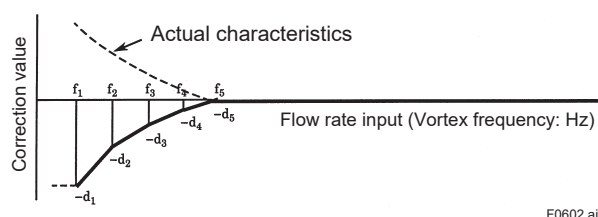


Figure 6.1 Strouhal number at low Reynolds number

6.2 Instrumental Error Correction

As shown in the figure, the flow error due to the reference flow value is corrected with a broken line approximation by setting the correction data corresponding to the vortex frequency of any five points.



F0602.ai

6.3 Expansion Correction for Compressible Fluid (Gas/Vapor)

As the flow speed of compressible fluid increases, the pressure changes and an error occurs. If the status change of the fluid is assumed to be an adiabatic change, it can be expressed as the vortex generation frequency (15) equation of the compressed fluid.

$$f = A \times \left(\frac{P_1}{P_2} \right)^{1/K} \times St \times \frac{V_2}{d} \dots\dots\dots (15)$$

Here,

V_2 : Local average flow velocity at shedder bar downstream 2.5D

P_1 : Pressure of shedder bar downstream 1D

K : Specific heat ratio of gas

A : Coefficient that shows the influence of flow velocity distribution and drawing ratio

P_2 : Pressure of shedder bar downstream 2.5D

St : Strouhal number

d : Inner diameter

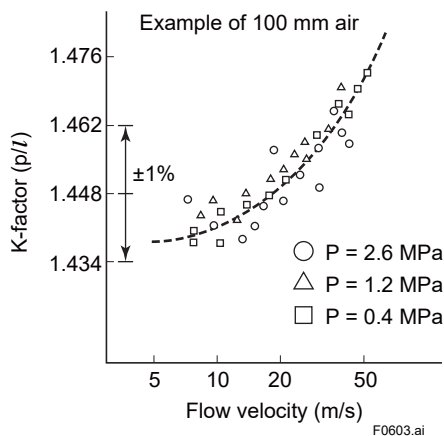


Figure 6.2 K-factor of compressible fluid

Normally, a pressure tap is provided at the positions of shedder bar downstream 2 to 6D, where the pressure is stable, to correct the temperature and pressure. However, in reality, the pressure drops the most even near 0.5D, so as shown in Figure 6.2, an error occurs in the K-factor due to the difference in the measurement points of P_2 in equation (11) as the flow becomes faster. By approximating this error with a quadratic function of the flow velocity, the error due to the difference at measurement points is corrected.

7. Self-diagnostic Function

Vortex Flowmeter VY Series models have the self-diagnostic function shown below.

7.1 Errors and Countermeasures

Please refer to the following document for details on alarm contents

Vortex Flowmeter VY Series HART Communication Type:IM 01F07A02-01EN

Vortex Flowmeter VY Series FOUNDATION™ Fieldbus Communication Type:IM 01F07A02-02EN

Vortex Flowmeter VY Series Modbus Communication Type:IM 01F07A02-03EN

7.2 Operation when an error occurs

Please refer to the following document for details on operation when an error occurs

Vortex Flowmeter VY Series HART Communication Type:IM 01F07A02-01EN

Vortex Flowmeter VY Series FOUNDATION™ Fieldbus Communication Type:IM 01F07A02-02EN

Vortex Flowmeter VY Series Modbus Communication Type:IM 01F07A02-03EN

7.3 Verification Tool

The verification tool diagnoses the VY health by inspecting multiple items and confirms that the device (VY) is operating normally. There are two modes of verification: standard verification and Enhanced verification. These enable you to check the normal operating status by connecting another instrument to a single device or devices. In addition, you can save the verification result data in a database, print it, or output it as a PDF file. For details about the operation method and other related information, please read the instruction manual IM 01F07A04-01EN of the Vortex Flowmeter VY Series verification tool.

7.3.1 Inspection Items in Standard Verification

- (1) Circuit & alarm: Check the normal operating status of various circuits and the output status of the alarm.
- (2) Appearance: Visually check the sensor, transmitter, and connected cables for any failures.
- (3) Display: Check the normal operating status of the display function for the transmitter with the display.

7.3.2 Inspection Items in Enhanced Verification

- (1) Analog output 1: Connect the external measuring instrument (ammeter) and check the normal operating status of the analog output.
- (2) Analog output 2: Connect the external measuring instrument (voltmeter) and check the normal operating status of the analog output.
- (3) Pulse output: Connect the external measuring instrument (pulse counter) and check the normal operating status of the pulse output.
- (4) Status output: Connect the external measuring instrument (voltmeter) and check the normal operating status of the status output.
- (5) Analog input: Connect the external signal (current generator) and check the normal operating status at the time of analog input.

7.3.3 Check/Inspection Result (Report) Output, File Management

You can save the results of standard and Enhanced verifications to a file or database.

7.3.4 Data Lock

If the result data is locked to prevent it from being changed after verification was performed, items other than [Generate test report] are disabled and cannot be changed.

7.4 Remote Maintenance Tool

Remote maintenance utilizes the following three tools:

- Vortex Waveform Monitor
- Vortex Frequency Analyzer
- Vortex Sensor Prediction

For details about the operation method and other related information, please read the instruction manual IM 01F07A04-01EN of the Vortex Flowmeter VY Series verification tool.

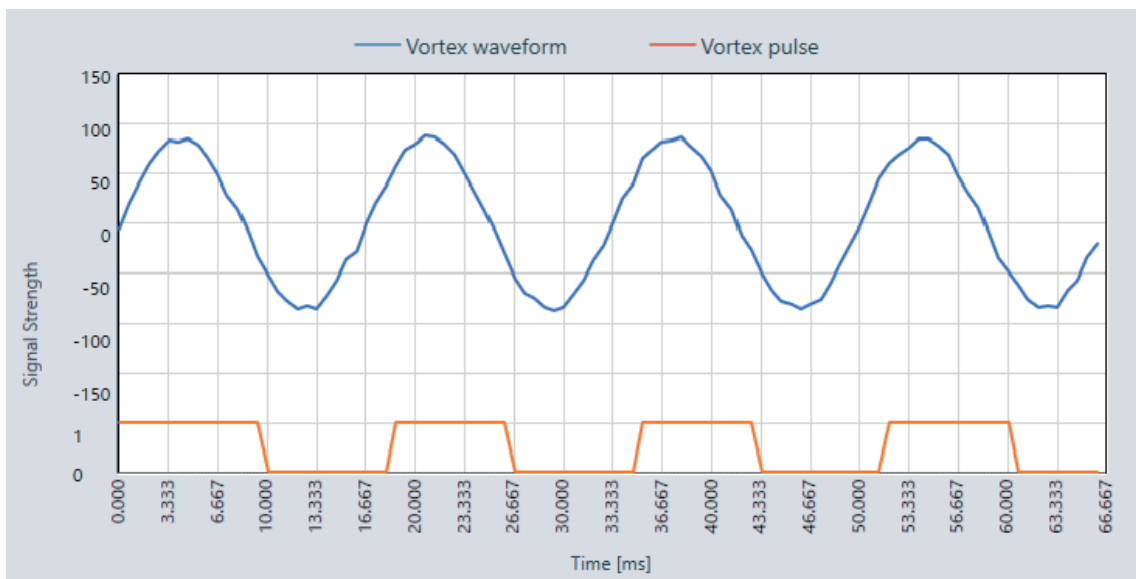
7.4.1 Vortex Waveform Monitor Health Check Items

- (1) Vortex signal: Check whether a vortex is generated by the flow. (Blue: Vortex waveform, Orange: Vortex pulse)

When a vortex is generated by the flow in the pipe, the vortex signal generated by the flow becomes a regular sine wave, so the following waveforms can be observed on the Vortex Waveform Monitor.

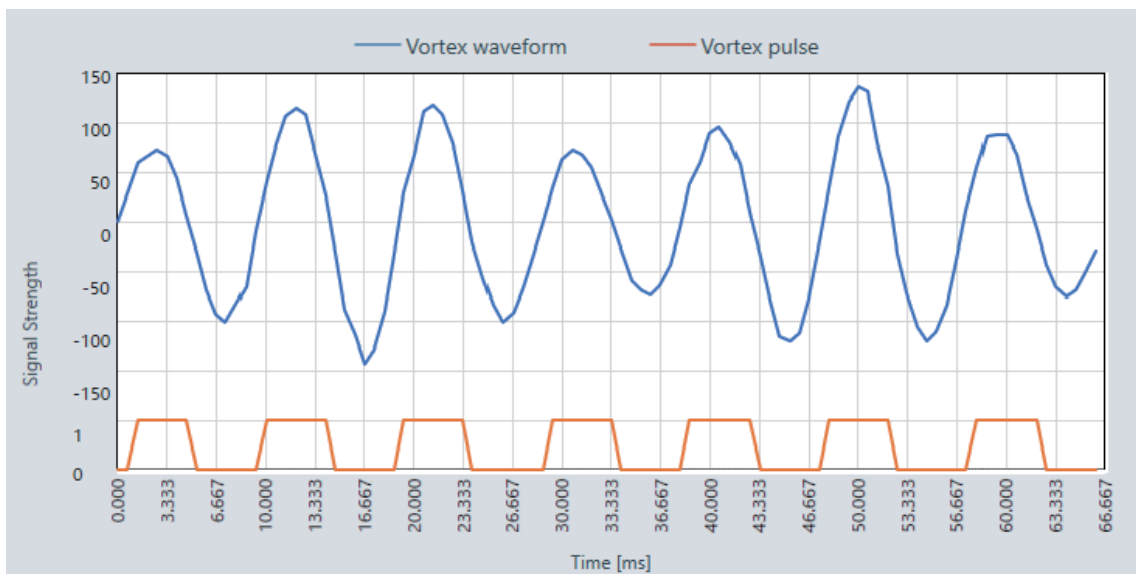
In addition, if a change in the density or flow velocity is detected in the flow, a fluctuation occurs in the amplitude of the vortex waveform.

- Example where regular vortex pulses are observed



F0701.ai

- Examples where a fluctuation occurs in the density and flow velocity

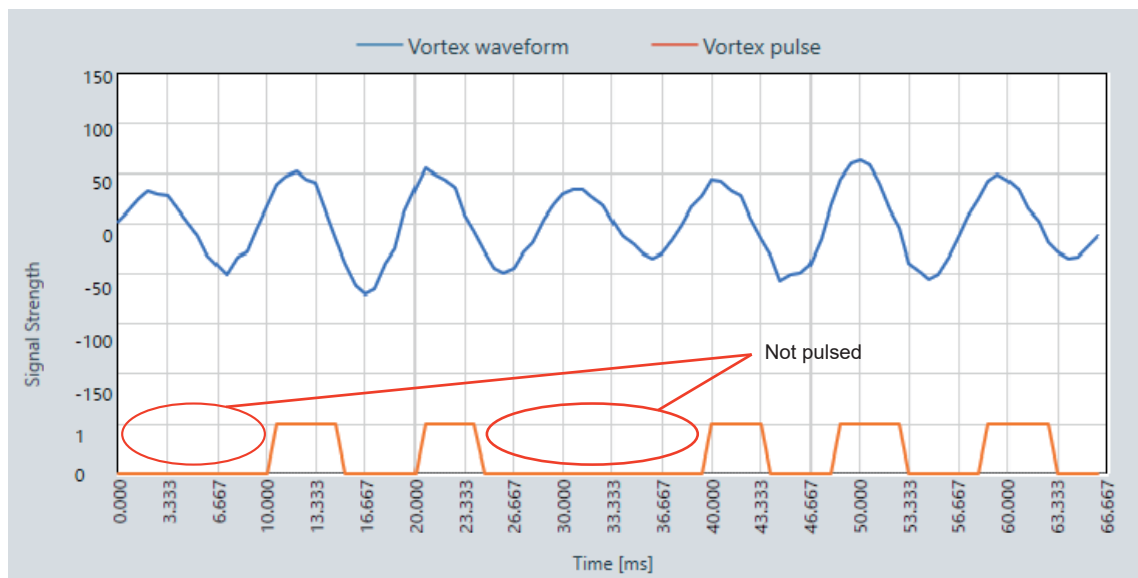


F0702.ai

- (2) Vortex pulse: Check the validity of the threshold value when pulsing the vortex frequency generated by the flow.

When the sensor sensitivity decreases, the amplitude of the vortex waveform becomes smaller and the following waveforms are observed. If the amplitude becomes smaller and falls below the threshold value for pulsing the vortex frequency, the vortex frequency is not pulsed, causing a pulse drop (0 to 6.667 ms, 30 to 36.667 ms in the figure below). In that case, you can prevent the pulse from dropping by lowering the TLA, which is the threshold. If the TLA is lowered, even a signal with a small amplitude such as a noise is pulsed, so consider cleaning the shedder bar. Cleaning increases the amplitude of the signal and allows it to be pulsed without lowering the TLA.

- Example where the signal amplitude becomes smaller and falls below the threshold value and the pulse drops

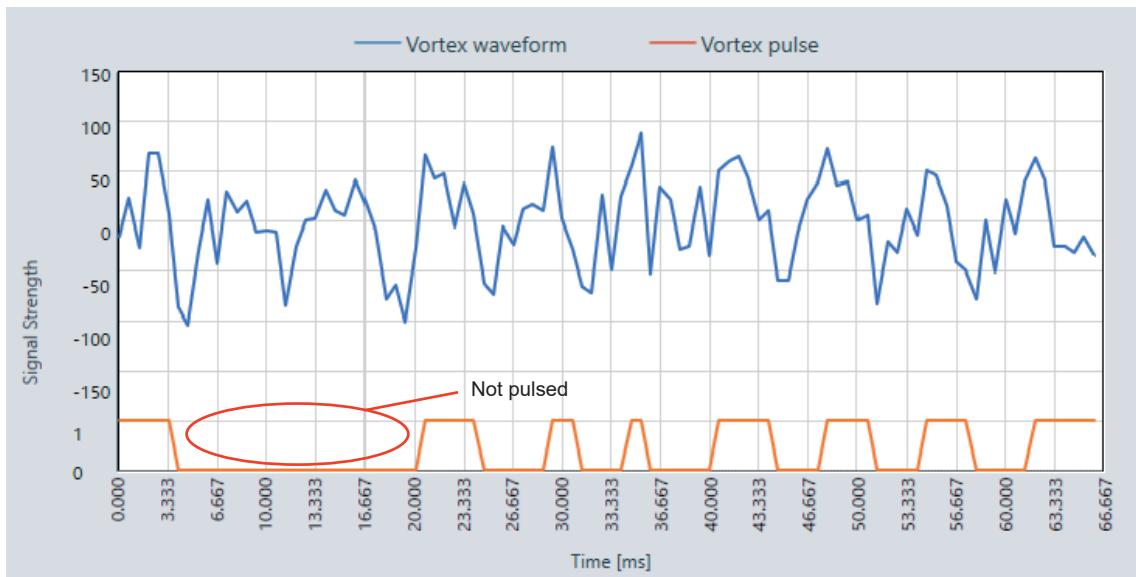


F0703.ai

- (3) Mechanical/electrical noise: Check whether the vortex signal is superimposed with a mechanical noise due to a vibration or an electrical noise.

When a mechanical/electrical noise is superimposed on the vortex signal, the waveform shown in the figure below is observed, and the pulse may not be pulsed without exceeding the pulsed threshold, or the pulse may be erroneously counted due to noise. If such a waveform is detected, it may be improved by taking the following measures:

- Mechanical vibration noise: Measure the vibration of the pipe. If a vibration is detected, attach a support to suppress the vibration.
- Electrical noise: Identify the noise path and take measures to remove the influence of noise.



F0704.ai

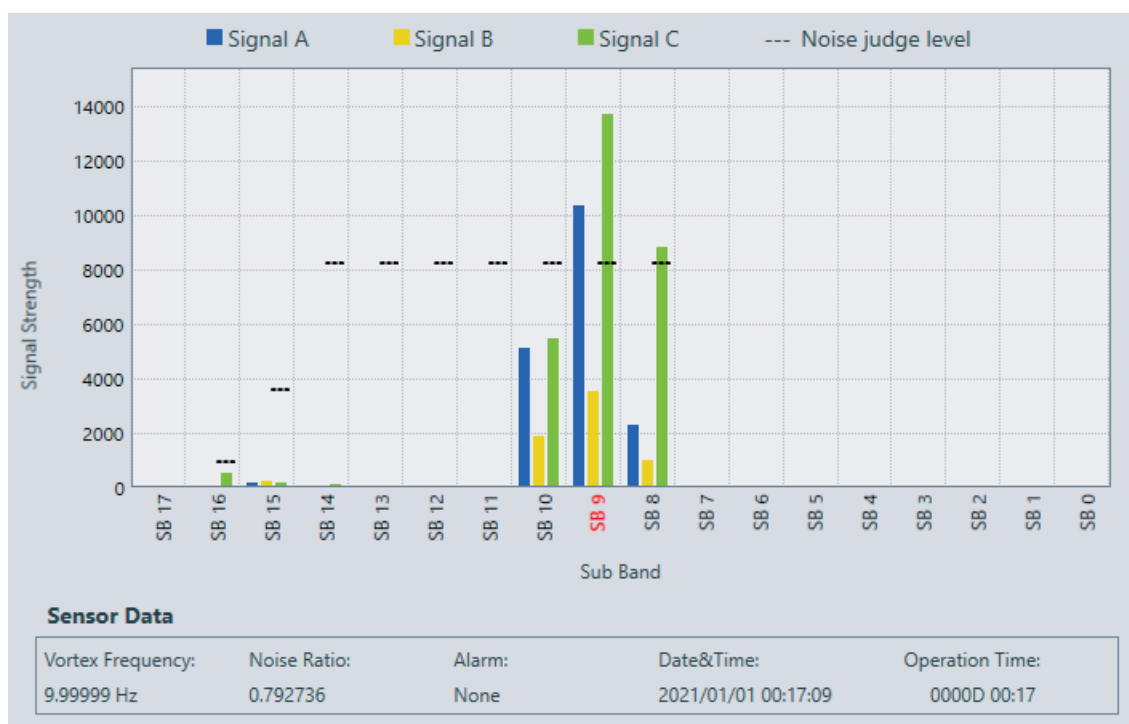
7.4.2 Vortex Frequency Analyzer Health Check Items

- (1) Vortex signal: Check the signal strength according to the vortex frequency.

With the Vortex Frequency Analyzer, you can check the signal strength of each band by SSP.

When the signal strength is sound, you can observe the following characteristics:

- The signal ratio of Signal A and Signal B is $\text{Signal A} / \text{Signal B} > 1$.
- The signal strength of Signal C becomes larger than the threshold value (black dotted line in the figure below) for determining noise.
- Example where a sound signal is obtained



F0705.ai

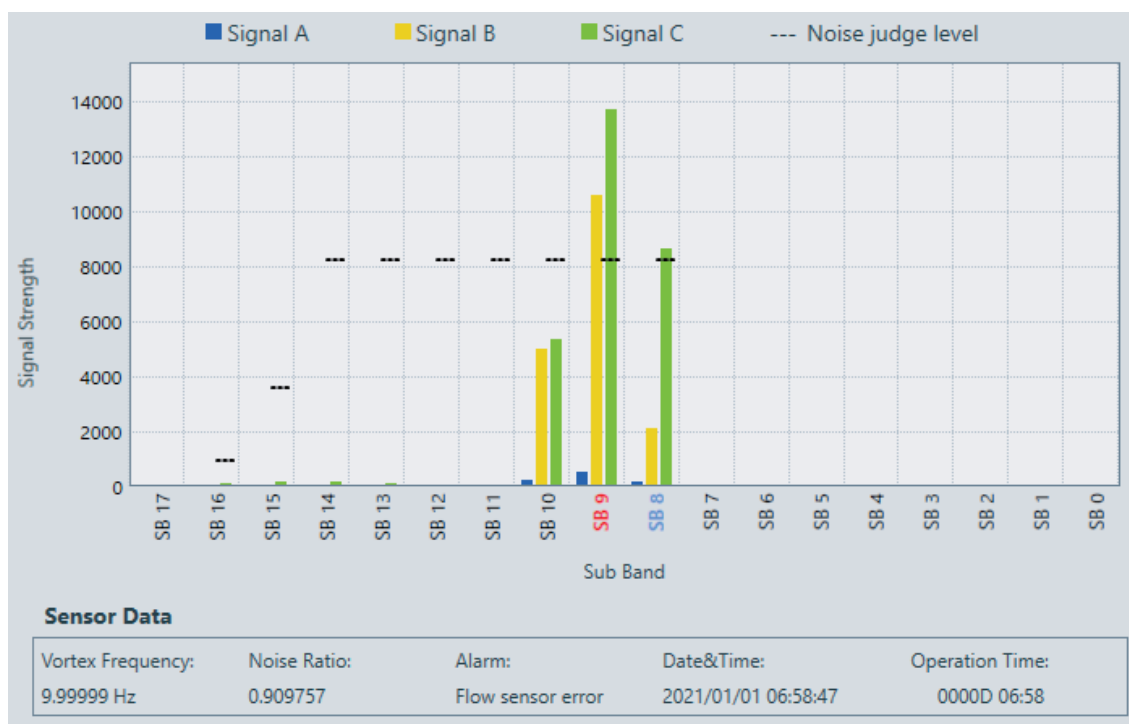
In the figure, SB9 is the band in which Signal C is largest. In the band in which Signal C is largest, Signal A and Signal B are set to 2.93, which is well above 1. Moreover, Signal C in SB9 is set to the value that is sufficiently larger than the black dotted line in the figure, so it can be said that the vortex signal is sound.

- (2) A/B ratio: Grasp the environment and sensor status from the signal ratio of the upper and lower sensors.

With the Vortex Frequency Analyzer, it is possible to judge environmental problems and sensor status from the conditions of Signal A, B, and C. The following provides a description using an example of a sensor failure. If a sensor failure occurs, the sensitivity of either Signal A or B decreases, and the signal strength may decrease as shown below.

In the case of the figure below, it can be seen that the value of Signal A of SB9, which is the largest band of Signal C, is significantly smaller than that of Signal B. In this case, the piezo electric device on the upper side is abnormal, so it will be necessary to consider replacing the sensor. Similarly, if Signal B is significantly smaller than Signal A, it is presumed that there is a failure in the piezo electric device in the lower side.

Example where a sensor failure occurs



F0706.ai

7.4.3 Vortex Sensor Prediction Health Check Items

- (1) Sensor parameter trend: Acquire the sensor trend over a long period of time and check for deterioration (failure, clogging, etc.) of the sensor.
- (2) Deterioration prediction time: Create a sensor parameter prediction curve from the sensor parameter trend, and identify the sensor maintenance time.

■ Parameter description and setting example of Vortex Sensor Prediction



F0707.ai

In the example above, the settings are as follows:

- Prediction select:Sensor sensitivity
- Prediction Level (blue line in the figure): 5.00
- Prediction Alarm time (orange line in the figure): 60 h
- Prediction Period:120 min

This setting means “an alarm should be issued 60 hours before the Sensor sensitivity reaches 5.00”. On the other hand, the time to actually reach the Prediction Level is 86 hours later, so an alarm is not emitted.

In addition, the prediction line can only be drawn up to 160 points. Therefore, when the prediction period of this time is 120 min, it results in “120 min x 160 point = 19200 min = 320 h ≈ 13 days”, which causes the prediction line of up to 13 subsequent days to be drawn.

From the above, the following shows a setting example for the use case below

Setting example when you want to get the prediction line for three years and issue an alarm one year before the A/B ratio reaches 0.9.

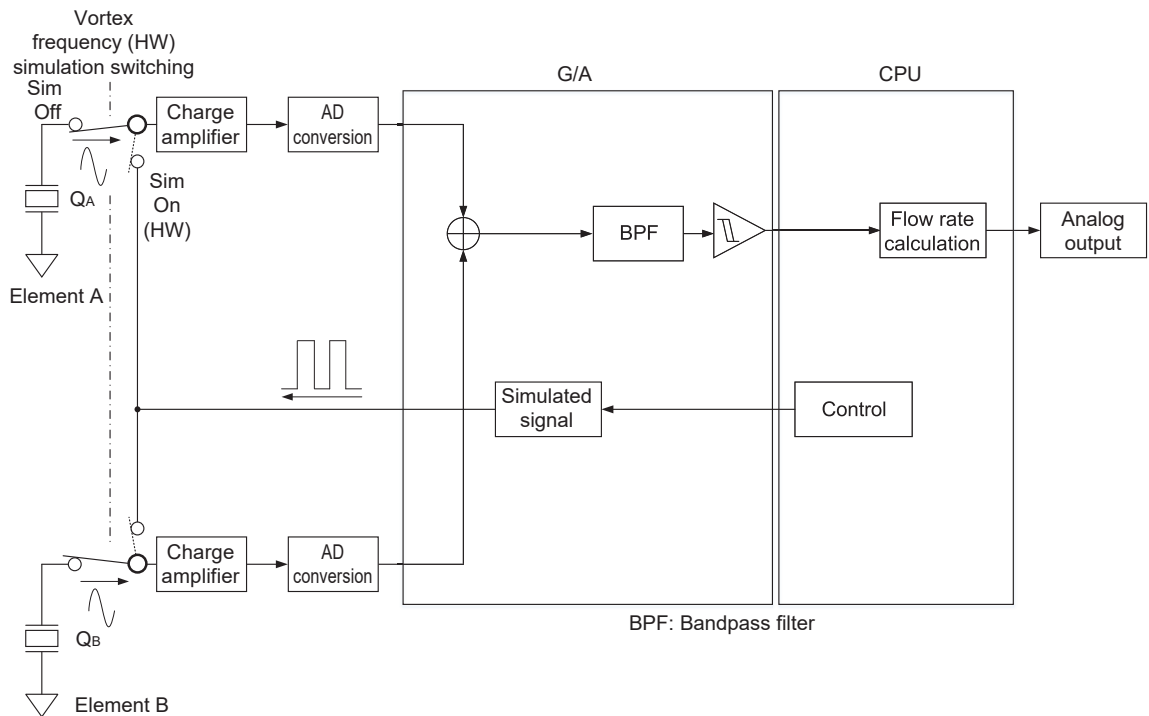
- Prediction select:A/B ratio
- Prediction Level:0.9
- Prediction Alarm time: 8760 h (*)
- Prediction Period:9855 min (**)

(*) To issue an alarm one year before the Prediction Level is reached, set as follows:
1 year = 365 days = 8760 h

(**) To get the prediction line up to 193 years ahead, set as follows:
3 year = 1095 days = 26280 h = 1576800 min
1576800 min / 160 point = 9855

7.5 Hardware Health Check

In the Vortex Flowmeter VY Series, you can now check the health of the entire hardware by checking the health of the sensor element and adding the simulated signal from the charge amplifier in the stage before the CPU in addition to setting the simulated frequency to the CPU in the digital YEW FLO series and checking the health of the flow rate calculation and analog output.



F0708.ai

Figure 7.1 Block circuit diagram of vortex frequency (hardware) simulation mode

Figure 7.1 shows the block circuit diagram of the vortex frequency (hardware: HW) simulation mode to check the hardware health. You can check the health of the entire hardware by outputting a simulated signal corresponding to the vortex signal from the G/A to the charge amplifier and checking the analog output according to the specified vortex frequency. Simulated signal: A signal that simulates the vortex frequency (frequency range that can be specified): 0.0 to 10000.0 Hz)

* For information about the frequency at the span flow rate of the vortex flowmeter used, refer to the parameter display "K36" and HART/Modbus "Maintenance ► Signal controls ► Vortex frequency span".
FOUNDATION Fieldbus"Device Configuration ► STB ► Device Configuration ► Calibration ► Signal Controls ► Monitor/Calculated Values ► Vortex frequency span"

8. Examples of Changing Flow Rate Measurement Parameters

It is necessary to change the flow rate measurement parameters when changing the flow rate to be measured or when using spare parts attached to the line. Follow the procedure below to perform the setting procedure and parameter settings in each flow rate measurement.

- Changing to the volume flow rate

- (1) Set the following parameters related to the sensor.
 - Sensor type
 - Nominal size
 - Body type
- (2) Set Fluid type to the desired fluid.
- (3) Change Flow select to 0:Volume.
- (4) Set the fluid density selected in step (2) to Fixed density.
- (5) set Flow span and Flow lowcut.*1

- Changing to the mass flow rate

- (1) Set the following parameters related to the sensor.
 - Sensor type
 - Nominal size
 - Body type
- (2) Set Fluid type to the desired fluid.
- (3) Change Flow select to 1:Mass.
- (4) Set the desired correction method to Compensation type.*2
- (5) Set the operating condition parameters of the fluid selected in step (2).
 - Fixed density
 - Fixed temperature
 - Fixed pressure
- (6) Set the standard parameters of the fluid selected in step (2).
 - Base density
 - Base temperature
 - Base pressure"
- (7) To use the analog input in step (4), set the analog input.
 - Analog input LRV
 - Analog input URV
- (8) Set Flow span and Flow lowcut.*1

-
- Changing to the criterion or standard flow rate
 - (1) Set the following parameters related to the sensor.
 - Sensor type
 - Nominal size
 - Body type
 - (2) Set Fluid type to the desired fluid.
 - (3) Change Flow select to 2:Standard/Normal.
 - (4) Set the desired correction method to Compensation type.*2
 - (5) Set the operating condition parameters of the fluid selected in step (2).
 - Fixed density
 - Fixed temperature
 - Fixed pressure
 - (6) Set the standard parameters of the fluid selected in step (2).
 - Base density
 - Base temperature
 - Base pressure
 - (7) To use the analog input in step (4), set the analog input.
 - Analog input LRV
 - Analog input URV
 - (8) Set Flow span and Flow lowcut.*1
-
- Changing to the calorie flow rate
 - (1) Set the following parameters related to the sensor.
 - Sensor type
 - Nominal size
 - Body type
 - (2) Set Fluid type to the desired fluid.
 - (3) Change Flow select to 4:Energy.
 - (4) Set the desired correction method to Compensation type.*2
 - (5) Set the operating condition parameters of the fluid selected in step (2).
 - Fixed density
 - Fixed temperature
 - Fixed pressure
 - (6) Set the standard parameters of the fluid selected in step (2).
 - Base density
 - Base temperature
 - Base pressure
 - (7) To use the analog input in step (4), set the analog input.
 - Analog input LRV
 - Analog input URV
 - (8) Set Fixed enthalpy.
 - (9) Set Flow span and Lowcut.*1
-

- Changing to the heat difference flow rate
- (1) Set the following parameters related to the sensor.
 - Sensor type
 - Nominal size
 - Body type
 - (2) Set Fluid type to the desired fluid.
 - (3) Change Flow select to 4:Energy(Heat difference).
 - (4) Set Heat difference conv unit to the desired value.
 - (5) Set Heat difference select to the desired value.
 - (6) Set Heat difference conv factor to the desired value.
 - (7) Set the desired correction method to Compensation type.*2
 - (8) Set the operating condition parameters of the fluid selected in step (2).
 - Fixed density
 - Fixed temperature
 - (9) Set the base parameters of the fluid selected in step (2).
 - Base density
 - Base temperature
 - (10) Set the analog input.
 - Analog input LRV
 - Analog input URV
 - (11) Set Flow span and Lowcut.*1

*1 In FOUNDATION Fieldbus, change EU100 in XD_SCALE and OUT_SCALE in AI FB with Flow rate selected for the channel instead of Flow span.

*2 Compensation type options

Option	Display condition	Description
0:Not used	Always displayed	Do not perform temperature pressure compensation
1:Built-in temp.	Only displayed in models that have a temperature sensor.	Make compensation using the temperature sensor.
2:Built-in temp. & A-in press.	HART:Only displayed in models that have a temperature sensor and an analog input. FOUNDATION Fieldbus:Always displayed	HART:Make compensation using the temperature sensor and the analog input (pressure). FOUNDATION Fieldbus:Make compensation using the temperature sensor and the external input in MAO FB (pressure).
4:A-in temp.	HART:Only displayed in models with an analog input. FOUNDATION Fieldbus:Always displayed	HART:Make compensation with the analog input (temperature). FOUNDATION Fieldbus:Make compensation with the external input in MAO FB (temperature).
5:A-in press.	HART:Only displayed in models with an analog input. FOUNDATION Fieldbus:Always displayed	HART:Make compensation with the analog input (pressure). FOUNDATION Fieldbus:Make compensation with the external input in MAO FB (pressure).
6:A-in density	HART:Only displayed in models with an analog input. FOUNDATION Fieldbus:Always displayed	HART:Use the analog input (density). FOUNDATION Fieldbus:Use the external input in MAO FB (density).
9:A-in temp & A-in press	FOUNDATION Fieldbus:Always displayed	Make compensation with the external input in MAO(temperature/pressure)

Compensation type that can be selected with Modbus are 0 or 1.

9. Sizing

The details of sizing are described in GS 01F7A00-01. This chapter shows the sizing to check various fluids.

Please use the “Specification Selection System” for specific sizing.

(1) For liquid

■ Checking the maximum measurable flow rate

Table 9.1 Maximum measurable range of various liquids

Maximum measurable range [m ³ /h]											
Nominal diameter	15 mm	25 mm	40 mm	50 mm	80 mm	100 mm	150 mm	200 mm	250 mm	300 mm	400 mm
Various liquids	6	18	44	73	142	248	544	973	1506	2156	3547

- (1) The reference value is 15°C, but -40°C for ammonia.
- (2) The maximum flow rate was calculated from the flow velocity of 10 m/s.

■ Checking the minimum measurable flow rate

Table 9.2 Minimum measurable range of various liquids

Minimum measurable range [m ³ /h]											
Nominal diameter	15 mm	25 mm	40 mm	50 mm	80 mm	100 mm	150 mm	200 mm	250 mm	300 mm	400 mm
Various liquids											
Water (H ₂ O)	0.3	0.65	1.3	2.2	4.3	7.5	17	34	60	85	177.36
Methanol (CH ₃ OH)	0.4	0.7	1.5	2.5	4.8	8.4	18	38	67	97	199.30
Ethanol (C ₂ H ₅ O)	0.5	0.9	1.5	2.5	4.8	8.4	18	38	67	97	199.67
Aniline (C ₆ H ₅ N)	0.8	1.5	2.4	3.1	4.3	7.3	16	33	59	85	175.48
Acetone (CH ₃)	0.34	0.73	1.5	2.5	4.7	8.3	18	38	67	96	199.48
Carbon disulfide (CS ₂)	0.26	0.58	1.2	2.0	3.8	6.6	15	30	54	77	157.79
Carbon tetrachloride (CCl ₄)	0.24	0.51	1.1	1.8	3.4	5.9	13	27	48	68	140.47
Ammonia (NH ₃)	0.34	0.74	1.5	2.5	4.8	8.4	18	37	65	93	202.02

If the minimum normal flow rate falls below the measurable range in a Vortex Flowmeter VY Series device with the same nominal diameter as the normal pipe, reduce the pipe size so that it is one or two sizes smaller than a normal pipe. If there are no problems, select the Reduced Bore Type for that size.

■ Cavitation check

When measuring liquid, when the line pressure is low and the flow velocity is high, cavitation occurs, which may prevent you from carrying out accurate measuring.

(2) Pressure loss and cavitation

■ Pressure loss

108 kPa with water at a flow velocity of 10 m/s

For air under atmospheric pressure, 9 kPa at flow velocity 80 m/s

The pressure loss is calculated by the following equation:

$$\Delta P = 108 \times 10^{-5} \times \rho \times V^2 \dots\dots\dots (1)$$

or

$$\Delta P = 135 \times \rho \times \frac{Q^2}{D^4} \dots\dots\dots (2)$$

- ΔP : Pressure loss (kPa)
- ρ : Fluid density in use (kg/m³)
- V : Flow velocity (m/s)
- Q : Volume flow rate in use (m³/h)
- D : Vortex flowmeter inner diameter (mm)

Figure 8.1 is a graph based on this equation.
 When the adjacent pipe is a Sch40 pipe with a nominal diameter of 15 mm to 50 mm, and when the adjacent pipe is a Sch80 pipe with a nominal diameter of 80 mm to 300 mm, the pressure loss is about 10% smaller than the figure produced by the equation.

■ Cavitation (minimum line pressure)

When measuring liquid, cavitation may occur when the line pressure is low and the flow velocity is high, which may prevent you from correctly measuring the flow rate.

The minimum line pressure to prevent cavitation is calculated by the following equation:

$$P = 2.7 \times \Delta P + 1.3 \times P_o \dots\dots\dots (3)$$

- P : Line pressure from the edge face of the downstream side of the flowmeter to 2 to 7D in the downstream side [kPa abs]
- ΔP : Pressure loss [kPa]
- P_o : Saturated steam pressure of the liquid in use [kPa abs]

■ (Example) Pressure loss calculation example

What is the pressure loss when the flow rate is 30 m³/h, the nominal diameter is 50 A, and the temperature of hot water is 80°C?

- (1) The density of hot water at 80°C is 972 kg/m³; therefore, the pressure loss is obtained from equation (2).

$$\begin{aligned}\Delta P &= 135 \times 972 \times \frac{30^2}{51.1^4} \\ &= 17.3 \text{ kPa}\end{aligned}$$

- (2) Obtain the pressure loss from equation (1). When the flow rate is 30 m³/h, the flow velocity is obtained as follows:

$$\begin{aligned}V &= \frac{354 \times Q}{D^4} = \frac{354 \times 30}{51.1^2} = 4.07 \text{ m/s.} \\ \Delta P &= 108 \times 10^{-5} \times 971.8 \times 4.065^2 \\ &= 17.3 \text{ kPa}\end{aligned}$$

- (3) Method to obtain the pressure loss from Figure 8.1

This can be read as "C = 18.5"; therefore, $\Delta P = 98.1 \times 18.5 \times 972 \times 10^{-5} = 17.6 \text{ kPa}$

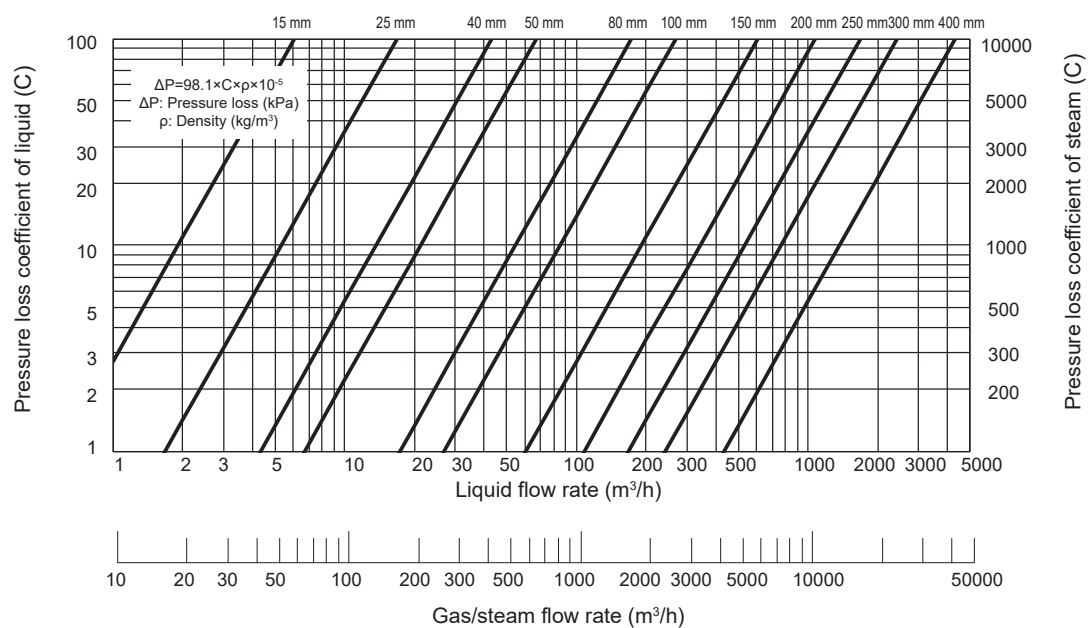
■ (Example) Checking whether or not cavitation occurs

If it is assumed that the line pressure is 120 kPa abs. and the flow rate scale is 0 to 30 m³/h in the above example, it is only necessary to check at the maximum flow rate. So, the saturated steam pressure of water at 80°C is $P_o = 47.4 \text{ kPa}$ based on the saturated steam table.

Therefore, the value is obtained from equation (3) as follows:

$$\begin{aligned}P &= 2.7 \times 17.3 + 1.3 \times 47.4 \\ &= 108.3 \text{ kPa abs.}\end{aligned}$$

The line pressure (120 kPa) is higher than the minimum line pressure (108.3 kPa), so it was confirmed that cavitation does not occur.



F0901.ai

Figure 9.1 Relationship between pressure loss and flow rate (usage condition)

(3) In the case of air

■ Checking minimum and maximum measurable flow rates

Table 9.3 Air measurable range

Model code - Type of body			Flow rate	Measurable range (Nm ³ /h)									
-0: General Type	-1: Reduced Bore Type: 1 Size Reduction -4: High Pressure Reduced Bore Type: 1 Size Reduction	-2: Reduced Bore Type: 2 Size Reduction		0 MPa	0.1 MPa	0.2 MPa	0.4 MPa	0.6 MPa	0.8 MPa	1.0 MPa	1.5 MPa	2.0 MPa	2.5 MPa
VY015-0	VY025-1 VY025-4	VY040-2	Min.	4.8(11.1)	6.7(11.1)	8.2(11.1)	10.5(11.1)	12.5	16.1	19.7	28.6	37.5	46.4
			Max.	48.2	95.8	143	239	334	429	524	762	1000	1238
VY025-0	VY040-1 VY040-4	VY050-2	Min.	11.0(19.5)	15.5(19.5)	19.0(19.5)	24.5	29	33.3	40.6	59	77.5	95.9
			Max.	149	297	444	739	1034	1329	1624	2361	3098	3836
VY040-0	VY050-1 VY050-4	VY080-2	Min.	21.8(30.0)	30.8	37.8	48.7	61.6	79.2	97	149	184	229
			Max.	356	708	1060	1764	2468	3171	3875	5634	7394	9153
VY050-0	VY080-1 VY080-4	VY100-2	Min.	36.2(38.7)	51	62.4	80.5	102	131	161	233	306	379
			Max.	591	1174	1757	2922	4088	5254	6420	9335	12249	15164
VY080-0	VY100-1 VY100-4	VY150-2	Min.	70.1	98.4	120	155	197	254	310	451	591	732
			Max.	1140	2266	3391	5642	7892	10143	12394	18021	23648	29274
VY100-0	VY150-1 VY150-4	VY200-2	Min.	122	172	211	272	334	442	540	786	1031	1277
			Max.	1990	3954	5919	9847	13775	17703	21632	31453	41274	51095
VY150-0	VY200-1	-	Min.	268	377	485	808	1131	1453	1776	2583	3389	4196
			Max.	4358	8659	12960	21559	30163	38765	47365	68867	90373	111875
VY200-0	-	-	Min.	575	809	990	1445	2202	2599	3175	4617	6059	7501
			Max.	7792	15482	23172	38549	53933	69313	84693	123138	161591	200046
VY250-0	-	-	Min.	1037	1461	1788	2306	3127	4019	4911	7140	9370	11600
			Max.	12049	23939	35833	59611	83400	107181	130968	190418	249881	309334
VY300-0	-	-	Min.	1485	2093	2561	3303	4479	5756	7033	10226	13419	16612
			Max.	17256	34286	51317	85370	119441	153499	187556	272699	357856	443017
VY400-0	-	-	Min.	2790	3933	4812	7020	9821	12622	15422	22424	29426	36427
			Max.	28378	56385	84391	140405	196418	252432	308445	448479	588513	728547

Notes:

- Each pressure reading is the gauge pressure reading at 0°C.
- The flow rate value is converted to the standard state [0°C, 0.101325 MPa (1 atm)] before being displayed.
- The maximum value is calculated from the flow velocity of 80 m/s (all within the accuracy specification range).
- The minimum value in parentheses () indicates the lower limit of the accuracy specification range. All others are the same as the lower limit of the accuracy specification range.

If the maximum normal flow rate falls below the measurable range in a Vortex Flowmeter VY Series device with the same diameter as the normal pipe, reduce the pipe size so that it is one or two sizes smaller than a normal pipe to make a check. If it is possible, use the reduced bore type of that size to install in the pipe.

(4) For steam

■ Checking the maximum measurable flow rate

Table 9.4 Measurable range of saturated steam

Model code - Type of body			Flow rate	Measurable range (kg/h)									
-0: General Type	-1: Reduced Bore Type: 1 Size Reduction -4: High Pressure Reduced Bore Type: 1 Size Reduction	-2: Reduced Bore Type: 2 Size Reduction		0.1 MPa	0.2 MPa	0.4 MPa	0.6 MPa	0.8 MPa	1.0 MPa	1.5 MPa	2.0 MPa	2.5 MPa	3.0 MPa
VY015-0	VY025-1 VY025-4	VY040-2	Min.	5.8(10.7)	7.0(11.1)	8.8(11.6)	10.4(12.1)	11.6(12.3)	12.8	15.3	19.1	23.6	28.1
			Max.	55.8	80	129	177	225	272	390	508	628	748
VY025-0	VY040-1 VY040-4	VY050-2	Min.	13.4(18.9)	16.2(20.0)	20.5	24.1	27.1	30	36	41	49	58
			Max.	169.7	247.7	400	548	696	843	1209	1575	1945	2318
VY040-0	VY050-1 VY050-4	VY080-2	Min.	26.5(29.2)	32	40.6	47.7	53.8	59	72	93	116	138
			Max.	405	591	954	1310	1662	2012	2884	3759	4640	5532
VY050-0	VY080-1 VY080-4	VY100-2	Min.	44	53	67.3	79	89	98	119	156	192	229
			Max.	671	979	1580	2170	2753	3333	4778	6228	7688	9166
VY080-0	VY100-1 VY100-4	VY150-2	Min.	84.9	103	130	152	171	189	231	300	371	442
			Max.	1295	1891	3050	4188	5314	6435	9224	12024	14842	17694
VY100-0	VY150-1 VY150-4	VY200-2	Min.	148	179	227	267	300	330	402	524	647	772
			Max.	2261	3300	5326	7310	9276	11232	16102	20986	25907	30883
VY150-0	VY200-1	-	Min.	324	392	498	600	761	922	1322	1723	2127	2536
			Max.	4950	7226	11661	16010	20315	24595	35258	45953	56729	67624
VY200-0	-	-	Min.	697	841	1068	1252	1410	1649	2364	3081	3803	4534
			Max.	8851	12918	20850	28627	36325	43976	63043	82165	101433	120913
VY250-0	-	-	Min.	1256	1518	1929	2260	2546	2801	3655	4764	5882	7011
			Max.	13687	19977	32243	44268	56172	68005	97489	127058	156854	186978
VY300-0	-	-	Min.	1799	2174	2762	3236	3646	4012	5235	6823	8423	10041
			Max.	19602	28609	46175	63397	80445	97390	139614	181960	224633	267772
VY400-0	-	-	Min.	3381	4086	5187	6078	6848	8002	11472	14957	18468	22003
			Max.	32217	47070	75834	104152	132193	160037	229449	299131	369366	440055

Notes:

- Each pressure reading is the gauge pressure reading at 0°C.
- The maximum value is calculated from the flow velocity of 80 m/s (all within the accuracy specification range).
- The minimum value in parentheses () indicates the lower limit of the accuracy specification range. All others are the same as the lower limit of the accuracy specification range.

Table 9.5 Maximum superheated steam measurement range correction factor K1

Pressure	MPa	0.1	0.2	0.4	0.6	0.8	1	1.5	2	2.5	3
Saturation temperature	°C	120.5	133.7	152	165.1	175.5	184.2	201.5	214.9	226.1	235.7
Density	kg/m ³	1.1362	1.6582	2.6752	3.6731	4.6607	5.6426	8.0891	10.545	13.016	15.518
Overheating temperature	150°C	1.0492	1.5851	2.132	---	---	---	---	---	---	---
	Ratio	0.92	0.96	0.80	---	---	---	---	---	---	---
	200°C	0.9317	1.4022	2.3596	3.3408	4.3485	5.3856	---	---	---	---
	Ratio	0.82	0.85	0.88	0.91	0.93	0.95	---	---	---	---
	250°C	0.8396	1.2612	2.1135	2.9787	3.8576	4.751	7.0549	9.4729	12.026	14.738
	Ratio	0.74	0.76	0.79	0.81	0.83	0.84	0.87	0.90	0.92	0.95
	300°C	0.7648	1.1476	1.9187	2.6978	3.4849	4.2805	6.3083	8.3964	10.551	12.78
	Ratio	0.67	0.69	0.72	0.73	0.75	0.76	0.78	0.80	0.81	0.82
	350°C	0.7025	1.0534	1.7589	2.4696	3.1855	3.9068	5.7342	7.5979	9.5003	11.444
	Ratio	0.62	0.64	0.66	0.67	0.68	0.69	0.71	0.72	0.73	0.74
	400°C	0.6498	0.9738	1.6246	2.279	2.9369	3.5984	5.2684	6.9623	8.6808	10.425
	Ratio	0.57	0.59	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.67

Superheated steam can also be sized by multiplying the measured flow rate of the saturated steam by the correction coefficient K1.

Maximum measurable flow rate of superheated steam = Maximum measurable flow rate of saturated steam (Mmax) x Correction coefficient (K1)

(Example) For 50 A, what is the maximum measurable flow rate when superheated steam is measured at a pressure of 2.5 MPa and the temperature is 250°C?

$$M_{\max} \times K1 = 7688 \times 0.92 = 7073 \text{ kg/h}$$

From these tables and calculation, you can see the maximum measurable flow rate by the pressure and size of the steam you want to measure.

(5) Summary of sizing

For Vortex Flowmeter VY Series devices, the measurable range and normal operating range (range in which accuracy is guaranteed) are determined by the fluid conditions: Select the optimum caliber in consideration of the following conditions.

■ Minimum measurable flow velocity:

The one for which the Reynolds number is 5000 or more and the flow velocity obtained from the relationship between the minimum flow velocity and the density is larger.

■ Normal operating range (guaranteed accuracy) Minimum flow velocity:

The one for which the Reynolds number is 20000 or more (150 mm, 200 mm, 250 mm, 300 mm: 40000 or more) and the flow velocity obtained from the relationship between the minimum flow velocity and the density is larger.

The method for calculating the measurable range and the range in which accuracy is guaranteed is shown in the specifications GS 01F07A00-01.

- When the flow velocity is smaller than the required minimum flow velocity, the output (both analog output and pulse output) indicates zero.

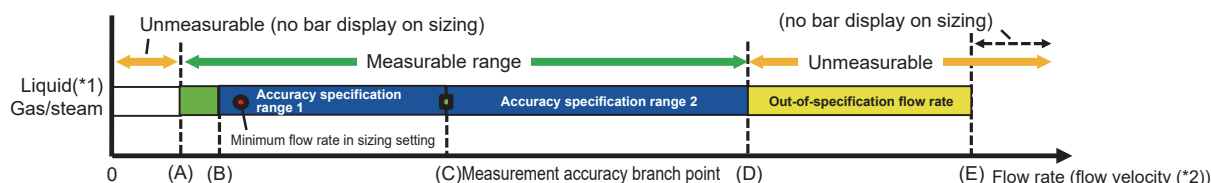
■ Maximum flow velocity:

For liquid, 10 m/s

For gas, 80 m/s

■ Cavitation check (liquid only)

■ Relationship between flow rate / flow velocity and accuracy in vortex flowmeters



*1: It is necessary to consider cavitation due to pressure loss that occurs in the vortex flowmeter when measuring liquid.

Cavitation may be triggered if the line pressure taking the pressure loss into account falls below the saturated steam pressure with the measured fluid used. In that case, it is necessary to take appropriate measures such as increasing the line pressure or reducing the pressure loss (lowering the flow velocity, resizing the vortex flowmeter, etc.). (For details, refer to GS.)

*2: The flow velocity must be obtained from the inner diameter cross-sectional area of the detection section and the flow rate. For details, refer to GS.

Flow velocity point (*2)	(A) Minimum flow velocity in measurable range	(B) Minimum flow velocity in accuracy specification range	(C) Measurement accuracy branch point	(D) Maximum flow velocity within the accuracy specification range and measurable range	(E) Maximum flow velocity that can be specified(*5)
Liquid	Refer to GS (depending on the fluid density). Low Cut factory setting	Refer to GS (depending on the physical characteristics of the fluid).	Refer to GS (depending on the physical characteristics of the fluid).	10 m/s (*3)	15 m/s
Gas/steam			35 m/s	80 m/s (*4)	120 m/s

*3: Density $\rho > 1000 \text{ kg/m}^3$: Max. flow velocity $V = \sqrt{(V_p) \times 10^5}$

*4: Density $\rho > 15.6 \text{ kg/m}^3$: Max. flow velocity $V = \sqrt{(V_p) \times 10^5}$

*5: This is outside the product specifications, but it is the maximum value for which span setting is possible.

Volume flow rate accuracy	Flow rate (A) or less	Flow rate (A) to (B) Measurable range	Flow rate (B) to (C) Accuracy specification range 1	Flow rate (C) to (D) Accuracy specification range 2	Flow rate (D) or more
Liquid	LowCut or less: Flow rate zero output fixed LowCut to (1): Out of measurement accuracy specification	Out of measurement accuracy specification	$\pm 1.0\%$	$\pm 0.75\%$ (*6)	Measurement/use disabled (unspecified flow rate)
Gas/steam			$\pm 1.0\%$	$\pm 1.5\%$	

*6: Reduced bore type: $\pm 1.0\%$

F0902.ai

10. Various Fluid Data

(1) Liquid density and viscosity

Table 10.1 Liquid viscosity

Liquid substance	Viscosity (Centipoises)				
	0°C	10°C	20°C	40°C	80°C
Acetone 100%	0.395	0.356	0.322	0.268	
Acetone 35%	3.2	2.4	1.80	1.070	0.41
Aniline	10.2	6.5	4.40	2.300	1.10
Amil alcohol	8.0	6.0	4.50	2.580	0.94
Sulfur dioxide	0.42	0.37	0.34	0.290	0.22
Ammonia 100%	0.15	0.13	0.115	0.088	
Ammonia 26%	1.9	1.54	1.27	0.850	0.44
Isobutyl alcohol	7.8	5.7	4.20	2.320	0.80
Ethyl alcohol 100%	1.84	1.46	1.20	0.829	0.435
Ethyl alcohol 80%	3.69	2.71	2.01	1.200	
Ethyl alcohol 30%	6.94	4.05	2.71	1.370	0.57
Ethylene glycol	48.00	33.50	23.50	11.800	3.40
Ether	0.292	0.263	0.24	0.200	0.141
Ethyl chloride	0.335	0.300	0.27	0.230	0.165
o - Chlortoluene	1.38	1.20	1.06	0.820	0.52
Chlorobenzene	1.18	1.01	0.88	0.670	0.41
Hydrochloric acid 31.5%	3.10	2.7	2.40	1.870	1.21
Octane	0.71	0.63	0.56	0.450	0.305
Sodium hydroxide 50%			110.00	42.500	6.70
o - Xylene	1.06	0.94	0.84	0.670	0.45
Glycerin 100%	12100.00	3950	14.99		
Glycerin 50%	12.5	9.0	6.05	3.500	1.20
Chloroform	0.70	0.63	0.57	0.466	
Acetic acid 100%			1.22	0.900	0.56
Acetic acid 70%	5.13	3.57	2.66	1.630	0.78
Ethyl acetate	0.578	0.507	0.449	0.360	0.248
Methyl acetate			0.381	0.312	0.217
Vinyl acetate	0.56	0.50	0.45	0.370	0.26
Carbon tetrachloride	1.35	1.13	0.97	0.740	0.472
Diphenyl	4.15	3.50	3.00	2.290	1.34
Mercury	1.685	1.615	1.554	1.450	1.298
Carbolic acid			11.60	4.770	1.59
Carbon dioxide	0.10	0.085	0.074		
Turpentine	2.10	1.76	1.50	1.100	0.62
Kerosene	3.65	3.00	2.42	1.660	0.82
Toluene	0.768	0.667	0.586	0.466	0.319
Naphthalene					0.967
Nitrobenzene	3.09	2.46	2.01	1.440	0.87
Carbon disulfide	0.433	0.396	0.366	0.319	
Calcium chloride (CaCl ₂ 25%)	4.83	3.450	2.45	1.320	0.42
Butyl alcohol	5.19	3.870	2.95	1.780	0.76
Hexane	0.397	0.355	0.320	0.264	
Heptane	0.517	0.458	0.409	0.332	0.231
Benzene	0.910	0.760	0.65	0.492	0.316
Pentane	0.283	0.254	0.229		
Water	1.79	1.310	1.01	0.650	0.36
Methyl alcohol 100%	0.86	0.720	0.62		
Methyl alcohol 60%	2.85	2.100	1.59		
Methyl alcohol 30%	3.63	2.440	1.76		
Sulfuric acid 111%	90.00	66.000	59.00	28.000	9.60
Sulfuric acid 98%		39.000	27.00	14.000	5.50
Sulfuric acid 60%	10.00	7.500	5.70	3.710	2.21

Table 10.2 Liquid density

Liquid name	T°C	pg/cm ³	Vm/s
Acetone	20	0.7905	1190
Aniline	20	1.0216	1659
Alcohol	20	0.7893	1168
Ether	20	0.7135	1006
Ethylene glycol	20	1.1131	1666
n - Octane	20	0.7021	1192
o - Xylene	20	0.871	1360
Chloroform	20	1.4870	1001
Chlorobenzene	20	1.1042	1289
Glycerin	20	1.2613	1923
Acetic acid	20	1.0495	1159
Methyl acetate	20	0.928	1181
Ethyl acetate	20	0.900	1164
Cyclohexane	20	0.779	1284
Dioxane	20	1.033	1389
Heavy water	20	1.1053	1388
Carbon tetrachloride	20	1.5942	938
Mercury	20	13.5955	1451
Nitrobenzene	20	1.207	1473
Carbon disulfide	20	1.2634	1158
Promo form	20	2.8904	931
n - Propyl alcohol	20	0.8045	1225
n - Pentane	20	0.6260	1032
n - Hexane	20	0.654	1083
Light oil	25	0.81	1324
Transformer oil	32.5	0.859	1425
Spindle oil	32	0.905	1342
Oil	34	0.825	1295
Gasoline	34	0.803	1250
Water	13.5	1	1460
Seawater (35% salt)	16	1	1510

(Note) T: Temperature, p: Density, V: Sound velocity

<Reference: Ultrasonic Technology Handbook Nikkan Kogyo Shimbun>

(2) Gas density

Molecular weight of typical gas and density in the standard state (1 atm, 0°C)

Gas name	Chemical formula	Molecular weight	Density g/l
Sulfurous acid gas	SO ₂	64.07	2.9268
Argon	Ar	39.94	1.7828
Ammonia	NH ₃	17.03	0.7708
Carbon monoxide	CO	28.01	1.2501
Hydrogen chloride	HCl	36.47	1.6394
Chlorine	Cl ₂	70.91	3.2204
Air		28.97	1.2928
Oxygen	O ₂	32.00	1.4289
Hydrogen	H ₂	2.016	0.0898
Carbon dioxide gas	CO ₂	44.01	1.9768
Nitrogen	N ₂	28.02	1.2507
Neon	Ne	20.18	0.8713
Helium	He	4.003	0.1769
Hydrogen sulfide	H ₂ S	34.08	1.5392
Isobutane	C ₄ H ₁₀	58.12	* 2.081
Ethane	C ₂ H ₆	30.07	* 1.048
Ethylene	C ₂ H ₄	28.05	* 0.976
Methyl chloride	CH ₃ Cl	50.49	2.3044
Butane (n)	C ₄ H ₁₀	58.12	* 2.094
Butadiene (1.3)	C ₄ H ₆	54.09	(2.301)
I - Butene	C ₄ H ₈	56.11	* 2.013
Freon 12	CCl ₂ F ₂	120.9	(5.533)
Freon 13	CClF ₃	104.5	(4.762)
Propane	C ₃ H ₈	44.10	* 1.555
Popylene	C ₃ H ₆	42.08	* 1.480
Methane	CH ₄	16.04	* 0.555

Based on "Handbook of Chemical Engineering".

Calculated after considering the compression coefficient in ().

* JIS K2301 (2011) value in the actual state

(3) Viscosity of gas

Gaseous substance	Viscosity (10 ⁻⁶ poise)					
	0°C	20°C	50°C	100°C	200°C	
Nitrous oxide	137	146	160	183	225	
Acetylene	96	102	111	126		
Acetone	71	77	83	95	119	
Sulfur dioxide	116	126	140	163	207	
Argon	212	222	242	271	321	
Ammonia	93	100	111	128	165	
Carbon monoxide	166	177	189	210	247	
Isobutane	69	74		95		
Ethane	86	92	101	115	143	
Ethyl alcohol	75			109	140	
Ethyl ether	68	101	110	96	120	
Ethylene	94	97	107	126	140	
Ethyl chloride	90	143		124	157	
Hydrogen chloride	131	132	145	183	230	
Chlorine	123	181	195	168	210	
Air	171	78	86	218		
Acetic acid	72	75.5	83	101	133	
Ethyl acetate	70	188	204	95	120	
Nitric oxide	179	203	218	227	268	
Oxygen	192			244	290	
Cyan	93	99	108	127		
Hydrogen cyanide	94	70	77	121	148	
Cyclohexane	66	139	148	87	109	
3H ₂ + 1N ₂	132			162	190	
Hydrogen bromide	170	153	94	234		
Bromine	146	88	162			
Hydrogen	84	147	76	103	121	
Carbon dioxide	138	69	107	185	229	
Toluene	65	97	83	88	110	
Carbon disulfide	89	76	250	126	162	
Butylene	71	224	91	95	119	
Fluorine	205	84	116	299	396	
Butene	79	109	121	105	130	
Freon 11 (CCl ₃ F)	130	113	88	130	154	
Freon 21 (CHCl ₂ F)	107	80	96	134	159	
Propane	75	84	71	101	125	
Popylene	78	65	208	107		
Hexane	60	196	82	82	104	
Helium	186	74		229	270	
Benzene	68		118	96	121	
Water		108	106	128	166	
Methane	102	95	202	133	147	
Methyl alcohol	89	186		122	155	
Hydrogen iodide	173	124			293	
Hydrogen sulfide	117			159		
Viscosity of gas (1 atm or more)						
Gaseous substance	Temperature °C	Viscosity (10 ⁻⁶ poise)				
		1 atm	40 atm	60 atm	80 atm	200 atm
Air	16 to 20	170	180	187	198	330
Carbon dioxide gas	20	148	166	700	810	
Carbon dioxide gas	40	157	176	187		
Hydrogen	30	90	96	97	99	110
Hydrogen	70	98	102	103	104	113
Nitrogen	30	179	194	202	207	241
Nitrogen	70	196	210	215	222	256