Technical Information

Model DY Vortex Flowmeter

digitalYEWFLO

TI 01F06A00-01E

YOKOGAWA

Yokogawa Electric Corporation

TI 01F06A00-01E

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Model DY Vortex Flowmeter

TI 01F06A00-01E 1st Edition

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1. PREFACE

Generally, a blunt body (vortex shedder) submerged in a flowing fluid sheds the boundary-layer from its surface and generates alternating-whirl in the backward stream called the Karman vortex street. The frequency of this vortex street is directly proportional to the flow velocity within a given range of Reynolds number. Therefore, the flow velocity or flow rate can be measured by measuring the vortex-shedding frequency. Vortex flowmeters work on this principle.

Based on the sales of 200,000 flowmeters around the world and years of experience since developing the world's first commercial vortex flowmeter in 1968, Yokogawa has now developed the digitalYEWFLO.

In addition to the reliability and endurance of former models, the digitalYEWFLO has an on-board SSP amplifier based on the state-of-the-art digital circuit technology to provide high-level stability and accuracy.

■ New Feature, Spectral Signal Processing (SSP) Amplifier

● Spectral Adaptive Filter (Key technology)

The spectral adaptive filter integrated in the DSP amplifier analyzes vortex signals so that the optimum measuring condition can be obtained without any interaction.

● Adaptive noise Suppression (ANS)

Eliminates all possible effects from vibrations, allowing vortex signals to be received precisely and ensuring stable signals, even under environments where piping vibrations inevitably occur.

● Multi-function display

The two-column display allows monitoring of the instantaneous flow rate and sum together. It also displays piping vibrations or fluid fluctuations from the self-diagnostic, allowing for early-stage judgement and/or remedies in the field.

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2. FEATURES

The digital YEWFLO has many unique features in addition to the usual features of conventional vortex flowmeters.

2.1 Features of Vortex Flowmeter

● **High accuracy**

The accuracy of the vortex flowmeter is ±1% (pulse output) of the indicated value for both liquids and gases and is higher compared to orifice flowmeters. For liquids, an accuracy of ±0.75% is available depending on the fluid types and their conditions.

● **Wide rangeability**

Rangeability is defined as the ratio of the maximum value to the minimum value of the measurable range. Its broad rangeability allows YEWFLO to operate in processes where the measuring point may fluctuate greatly.

● **Output is proportional to flow rate**

Since the output is directly proportional to the flow rate (flow velocity), no square root calculation is needed, while orifice flowmeters require square root calculation.

● **No zero-point fluctuation**

Since frequency is output from the sensor, zero-point shift does not occur.

● **Minimal pressure loss**

Since only the vortex shedder is placed in the pipe of the vortex flowmeter, the fluid pressure loss due to the small restriction in the flow piping is small compared with flowmeters having an orifice plate.

2.2 Unique Features of digitalYEWFLO

2.2.1 Features of Sensor Section

● **Sensor is not exposed to process fluid**

The digital YEWFLO uses piezoelectric elements for the sensor; these are embedded inside the vortex shedder and are not exposed to the process fluid.

● **Simple construction with no moving parts**

Only the vortex shedder with a trapezoidal cross section and no moving parts are placed in the flow piping. This gives the digital YEWFLO a solid and simple construction.

● **Operable at high-temperature and high-pressure without any problem**

The digital YEWFLO measures hot fluids up to 450°C (25 to 200 mm, HT remote converter type for high temperature) and high-pressure fluids up to ANSI class 900 flange rating (15 MPa at ambient temperature) as standard.

- **Low cost of ownership**

Compared with other flowmeters, the total cost for YEWFLO (including installation and maintenance cost) is very economical.

2.2.2 Features of Converters

■ New Functions with SSP (Spectral Signal Processing) Technology

SSP is built into the powerful electronics of digitalYEWFLO. SSP analyses the fluid conditions inside digitalYEWFLO and uses the data to automatically select the optimum adjustment for the application, providing features never before seen in a vortex flowmeter.

SSP accurately senses vortices in the low flow range, providing outstanding flow stability.

- **Adaptive noise suppression (ANS) technology**

The full automation of adaptive noise suppression allows for the provision of optimal measurement conditions immediately after turning on the system. Even under environments where piping vibrations are inevitable, it can capture vortex signals without being influenced by vibrations to ensure stable output signals.

- **Improved self-diagnosis**

Improved self-diagnosis enables the detection and displaying of the influences from excessive piping vibrations or fluid fluctuations at an early stage. This allows early determination of the line status.

- **Improved operability for setting parameters**

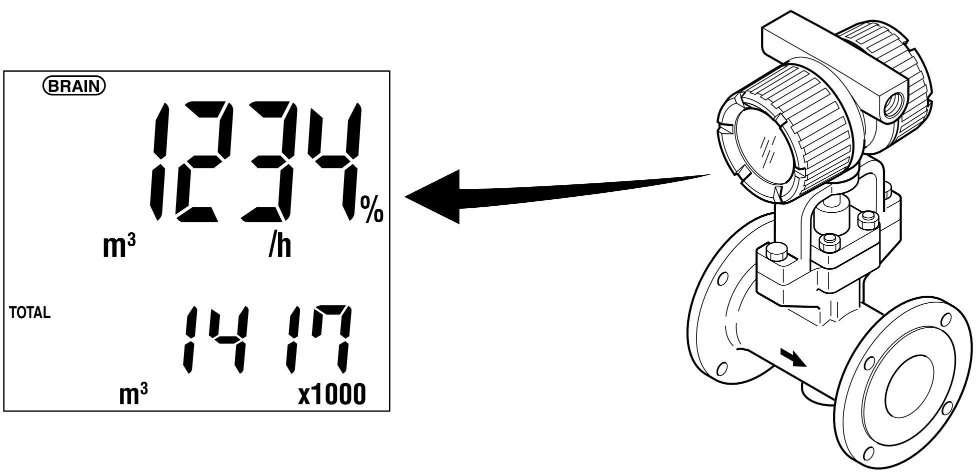
Frequently used parameters are grouped into one block to significantly improve the operability.

- **Multi-function display**

Facilitates monitoring of instantaneous flow rate and total flow rate together in the field.

- **Dual output for Analog/Pulse**

Simultaneous output is available for flow rate and pulse.



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3. PRINCPLE OF MEASUREMENT

When a vortex shedder is placed in a flowing fluid, it generates a Karman vortex street, with alternating whirl vortices on the downstream side of the shedder as shown in Figure 3.1.

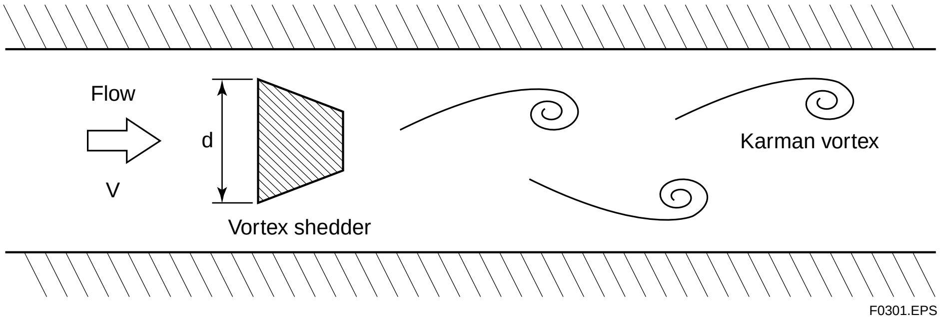

Figure 3.1 Karman Vortex Street

Assuming that the frequency of vortex generated by a shedder is f, the flow velocity is v, and the vortex shedder width is d, the following equation is obtained.

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

This equation also applies to YEWFLO installed in a pipeline.

$$V = \frac{Q}{\frac{\pi \cdot D^2}{4} - dD} \quad \text{.......... (2)}$$

Q: Volumetric flow rate

D: Inside diameter of YEWFLO

St: Strouhal number

From equations (1) and (2), the volumetric flow rate is given by,

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

Strouhal number (St) is a dimensionless number which is a function of the shape and size of the vortex shedder. Therefore, by selecting an appropriate shape, the Strouhal number can be kept constant over a wide range of Reynolds numbers.

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

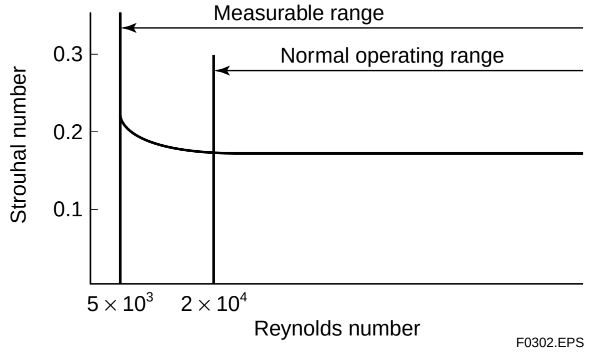

Figure 3.2 Relationship between Strouhal Number and Reynolds Number

Thus, once the Strouhal number is known, the flow rate can be obtained by measuring the vortex shedding frequency. Equation (3) also shows that the flow rate can be measured independently of the fluid pressure, temperature, density and viscosity. However, compensations for temperature and pressure are necessary when measuring volumetric flow and mass flow rate in the reference (standard) state.

4. METHOD OF DETECTING VORTEX-SHEDDING FREQUENCY

The vortex shedder of YEWFLO has a trapezoidal cross section which provides excellent linearity of the vortex-shedding frequency and generates a stable and strong street pattern. Figure 4.1 shows the vortex flow-pattern forming behind a trapezoidal vortex shedder.

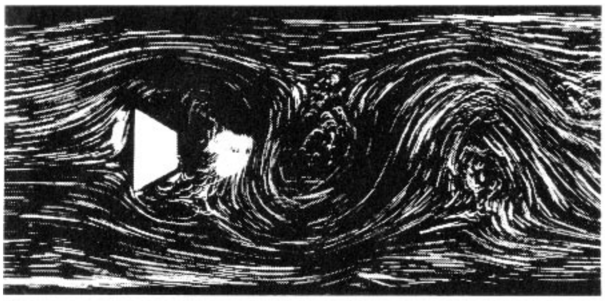

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Figure 4.1 Karman's Vortex Trails Generated by Trapezoidal Columned Object

To transmit the vortex-shedding frequency, YEWFLO uses piezoelectric elements to detect the stress generated by the alternating lift on the whole vortex shedder when vortices are generated. The features of the piezoelectric element method are as follows:

(1) The piezoelectric element sensor can be built into the vortex shedder to avoid direct contact with the process fluid.

(2) Because the method detects stress, the vortex shedder does not need to be displaced far, so the meter construction remains stable and rigid.

(3) Because the piezoelectric element is very sensitive, a wide range of flow rates, from low to high velocity, can be measured.

(4) Wide range of operating temperature and pressure

4.1 Principle of Frequency Detection

Figure 4.2 shows the principle of detecting the vortex-shedding frequency.

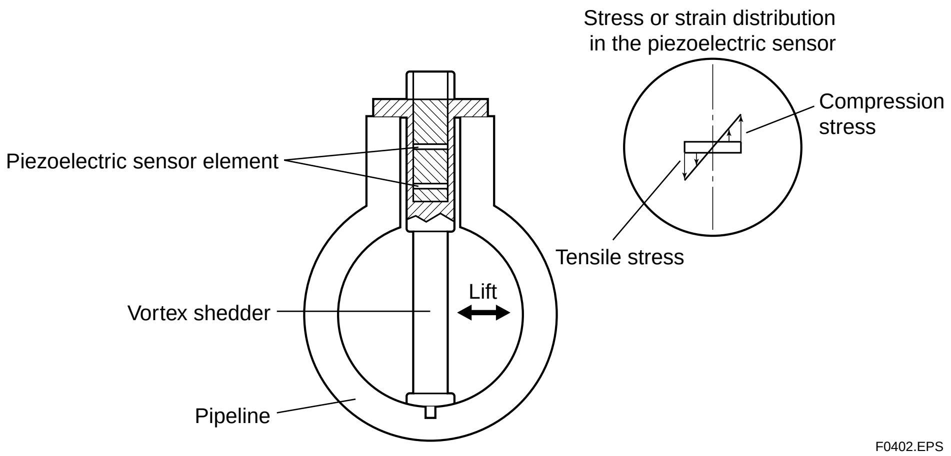


Figure 4.2 Principle of Vortex-shedding Frequency Detection

When the fluid flows directly into the shedder bar pictured in Figure 4.2, vortices are generated from the vortex shedder. The shedder is subjected to alternating lift representing the same frequency as that of vortex-shedding. This alternating lift produces stress changes in the vortex shedder. The frequency of these stress changes, the vortex-shedding frequency, is detected by piezoelectric elements hermetically sealed in the vortex shedder.

The intensity of the alternating lift is proportional to the square of the flow velocity and the density of the fluid. The peak value of lift F_L is given by,

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

where,

C_L: Dimensionless coefficient

V: Flow velocity

D: Inside diameter of pipeline

ρ: Fluid density

d: Width of vortex shedder

The average stress σ_M generated in the piezoelectric element and the electric charge q induced in the element are given by the following equations:

$$\sigma_M = K \cdot F_L$$

$$q = d_0 \cdot \sigma_M \cdot S$$

where,

K: Constant determined by the shape of the vortex shedder and how it is supported.

d_0: Piezoelectric coefficient

S: Surface area of piezoelectric element

The AC electric charge is processed by the electric circuit in the transmitter to obtain the vortex shedding frequency.

4.2 Principle of Operation

4.2.1 Detector Construction

The construction of the detector is shown below.

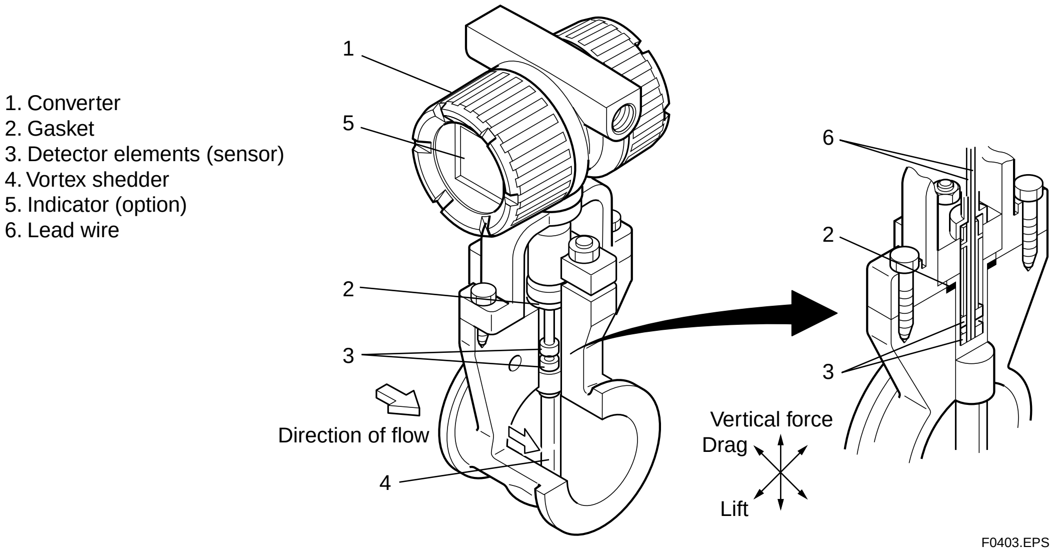


Figure 4.3 Detector Construction

Dual piezoelectric elements fixed on the upper part of the vortex shedder efficiently detect the signal stress caused by the vortex street while eliminating the effects of noise such as pipeline vibration.

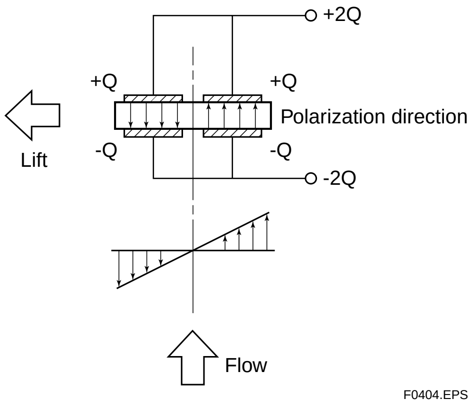


Figure 4.4 Signal Stress

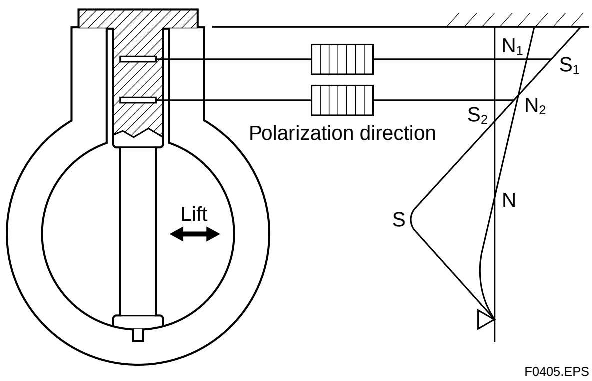


Figure 4.5 Lift Signal and Noise Distribution

As expressed by the arrows in Figure 4.3, stress caused by pipeline vibration can be divided into three components of force: lift, drag, and vertical force. The alignment of the dual piezoelectric elements as shown in Figure 4.4 is set so as not to sense the vibration in the directions of the drag and vertical force. The vibration in the direction of lift, however, is sensed as part of the vortex signal since they appear in the same direction. While in a digital YEWFLO, an effective combination of the proven dual-sensor alignment and spectral signal processing (SSP) technology, eliminates noise caused by pipeline vibration or the like even in this vertical direction.

4.2.2 Spectral Signal Processing (SSP)

The converter circuitry incorporating the SSP technology is shown in the figure below. The SSP, a state-of-the-art technology, effectively rejects the effects of pipeline vibration.

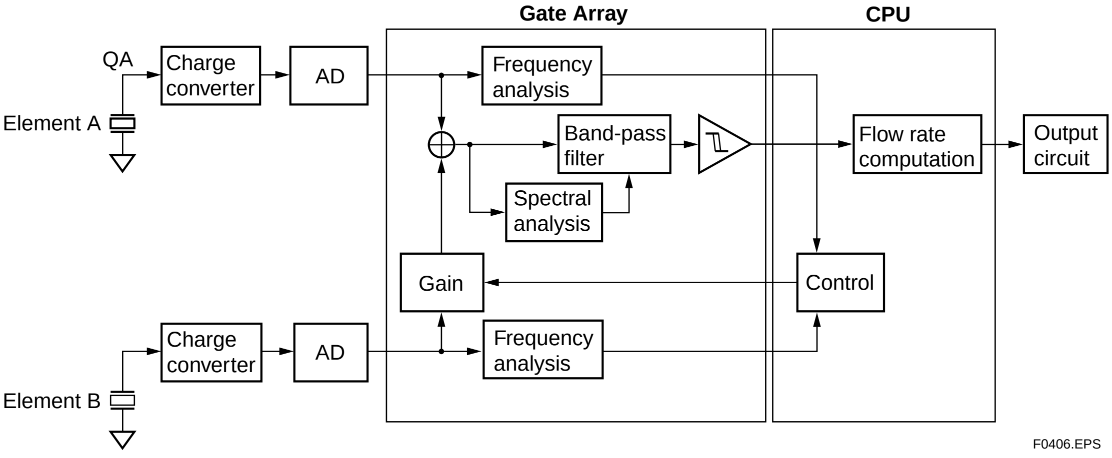


Figure 4.6 Detector Construction

● Adaptive Noise Suppression (ANS)

Catch the vortex signal using two piezo ceramics sensors and suppress the vibration noise.

● Spectral Adaptive Filter (SAF)

Separate vortex signal and vibration noise.

Using these digital technology, the following effects are demonstrated.

(1) Improves vibration performance.

The extensive improvement of the vibration performance wa realized compared with the previous model.

(2) Realize the low-flow measurement.

The output change by the vibration noise is removed and a normal signal is outputted.

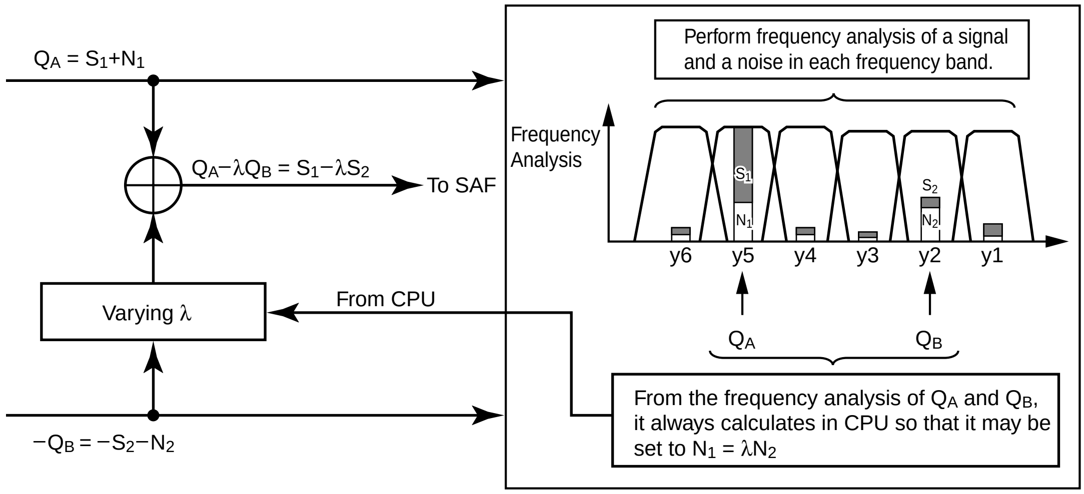
(3) Extend a self-diagnostic function

Since frequency analysis is always performed, alarm can be taken out at the time of abnormalities, such as an unstable flow, and adhesion, vibration.

(1) Adaptive noise suppression (ANS)

The YEWFLO eliminates the effect of pipeline vibration by using the distribution of the signal and noise in the direction of a lift shown in Fig.4.5. This feature, which balances noise in the outputs with each other, is referred to as adaptive noise suppression.

The signals output from two piezoelectric elements are converted into alternating signals by respective charge converters. Each of these alternating signals is then converted into a digital signal through an A/D converter. The SSP filter continuously performs spectral analyses for these digital signals and measures the signal components and noise components in the outputs from the piezoelectric elements. With the results of these measurements, the noise is rejected continuously based on the principle described next.



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Since the two piezoelectric elements, elements A and B, are so aligned as to be polarized in opposite directions, their outputs Q_A and Q_B can be expressed by the respective signal components S_1 and S_2, and noise components N_1 and N_2 as:

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

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

Multiplying the output of element B by a value (from 0.5 to 1.2), λ, obtains:

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

Then, adding this multiplied signal to the output of element A, namely, adding equation (2) to equation (3) obtains:

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

When N_1 is equal to λN_2, equation (4) becomes as follows and only the signal components can be detected:

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

Hence, if the detector can measure the amplitudes of noise components, N_1 and N_2 and can determine the value of λ to offset them, the noise in the direction of lift can be eliminated.

For earlier models, the N_1 and N_2 levels were measured and the value of λ was adjusted during shipment preparations. Therefore, if the noise ratio has changed from the factory-set λ after the flowmeter in question is installed on site, the intended noise rejection result cannot be obtained. While in a digital YEWFLO, the CPU automatically computes the optimum value at all times and sets it in λ, so the signal components can always be extracted no matter if the noise ratio changes.

(2) Spectral Adaptive Filter (SSP)

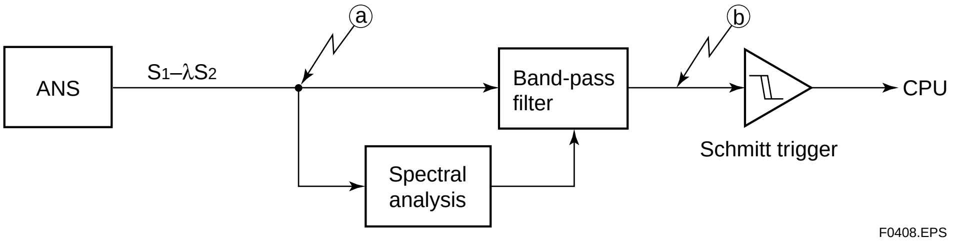

Figure 4.7 Block Diagram of Spectral Adaptive Filter

The Spectral Adaptive Filter (SAF) is shown in the figure above. Two sensor outputs digitized through individual A/D converters are inputted to the band-pass filter after ANS processing. Although noise components are normally removed by ANS, if any level of noise is left such as high frequency noise, the resulting waveform will still carry noise as shown in (a) of Figure 4.8.

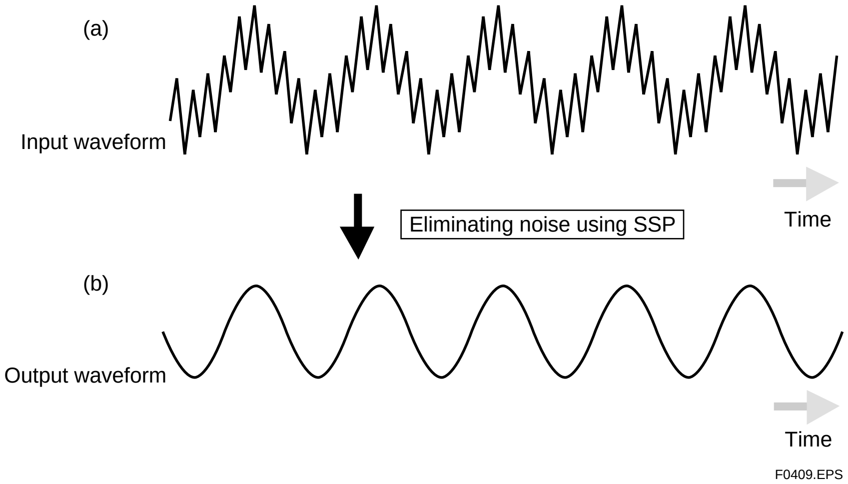

Figure 4.8 Input and Output Waveforms

With previous models, to reject these signals containing a noise component, maintenance people had to make the filter settings manually while monitoring the input waveform (a) using an oscilloscope. In addition, there are limits in the filter settings due to the characteristics of the filter circuit. SAF, however, analyzes the spectral of the signal from which noise could not be removed completely, and makes the optimum filter settings automatically as shown in Figure 4.9.

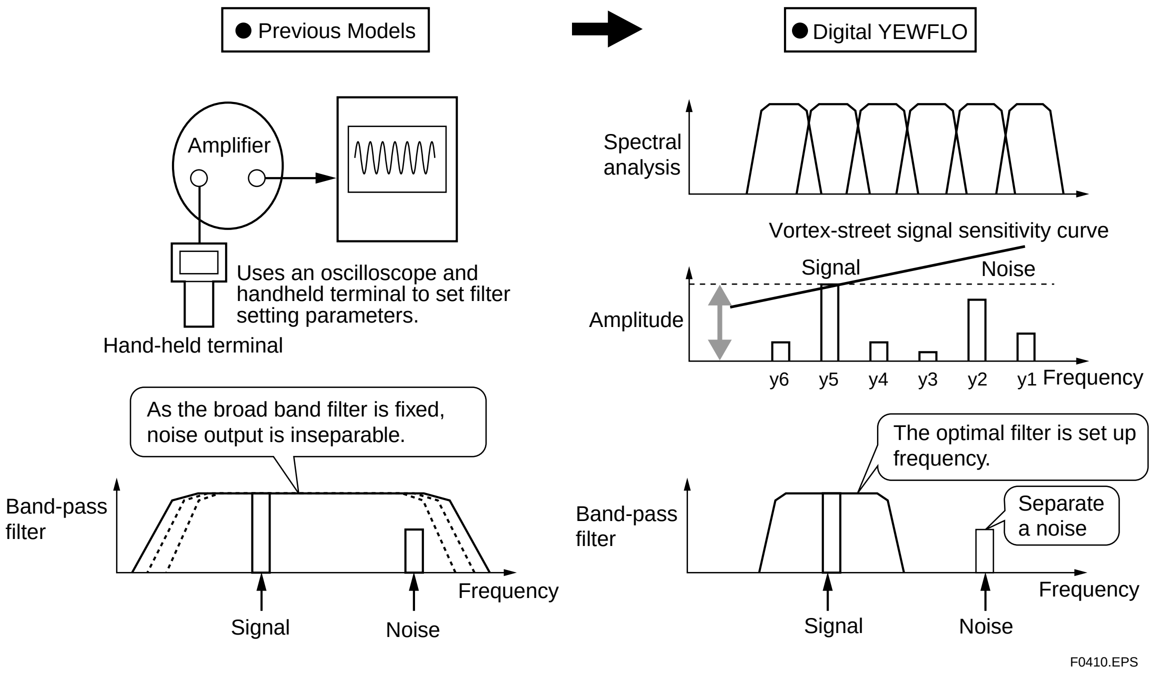

Figure 4.9 Operation of Spectral Adaptive Filter

The SAF contains multiple band-pass filters for divided bands, and performs a spectral analysis on each band for a waveform carrying noise as in (a) of Figure 4.8. Then, the circuit compares the analysis results with the vortex signal sensitivity curve stipulated for each flowmeter size. This comparison allows noise components to be discriminated from the vortex-street signal, and therefore the filter can be optimally set automatically to let only the signal component pass through. Accordingly, a waveform as in (a) of Figure 4.8 can be filtered into a clear waveform as in (b) of Figure 4.8.

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5. FLOW RATE CALCULATION

The flow rate is calculated based on the count number N of generated vortices as follows:

a) Flow rate (actual flow rate unit)

$$RATE = N \cdot \frac{1}{\Delta t} \cdot \varepsilon_f \cdot \varepsilon_e \cdot \varepsilon_r \cdot \varepsilon_p \cdot \frac{1}{KT} \cdot U_{KT} \cdot U_K \cdot U_{TM} \cdot \frac{1}{S_E} \quad \text{(8)}$$

$$KT = KM \cdot \{1 - 4.81 \times (T_f - 15) \times 10^{-5}\} \quad \text{(9)}$$

b) Flow rate (%)

$$RATE\ (\%) = RATE \cdot \frac{1}{F_S} \quad \text{(10)}$$

c) Integrated value

For a scaled pulse

$$TOTAL = N \cdot \varepsilon_f \cdot \varepsilon_e \cdot \varepsilon_r \cdot \varepsilon_p \cdot \frac{1}{KT} \cdot U_{KT} \cdot U_K \cdot \frac{1}{T_E} \quad \text{(11)}$$

For an unscaled pulse

$$TOTAL = \varepsilon_f \cdot \varepsilon_e \cdot \varepsilon_r \cdot \varepsilon_p \cdot N \quad \text{(12)}$$

d) Flow velocity

$$V = N \cdot \frac{1}{\Delta t} \cdot \frac{1}{KT} \cdot U_{KT} \cdot \frac{4}{\pi \cdot D^2} \quad \text{(13)}$$

e) Reynolds number

$$Red = \frac{V \cdot D}{\frac{\mu}{pf} \times 1000} \times 10^6 \quad \text{(14)}$$

where,

- N : Input pulse number (pulse)
- εf : Correction coefficient of instrument error
- εr : Correction coefficient of Reynolds number
- εe : Correction coefficient of expansion for compressible fluid
- εp : Correction coefficient of adjacent pipe
- KM : K factor in 15°C (p/l)
- KT : K factor for operating temperature (P/l)
- U_{KT} : Unit conversion coefficient of K factor
- U_{TM} : Coefficient for flow rate unit time (e.g.: /m (min) = 60)
- S_E : Span factor (ex.: E + 3 = 10^3)

F_S : Flow rate span

μ : Viscosity coefficient (cP)

D : Internal diameter (m)

Δt : Time corresponding to N (second)

U_k : Flow conversion coefficient

T_f : Operating temperature (°C)

T_E : Total factor

pf : Operating density (kg/m^3)

The flow conversion coefficient U_k is automatically calculated just by setting parameters (temperature, pressure and density).

The parameters to be set are sequentially displayed on a hand held BT200 (BRAIN terminal) when the fluid type is specified.

6. CORRECTION FUNCTIONS

The digitalYEWFLO has extensive correction functions to support various applications. These correction functions are outlined below.

6.1 Reynolds Number Correction

In a 3-dimensional flow inside a pipeline, as Reynolds number (≤20000) decreases, the Strouhal number (K factor) gradually increases. The curve of this K factor is corrected using a 5-point line segment approximation.

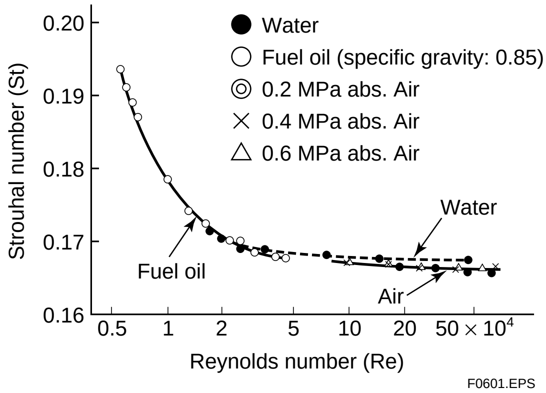

Figure 6.1 Strouhal Number for Low Reynolds Number

6.2 Compressibility Coefficient Correction

Pressure changes and errors are generated, as the compressible fluid flow becomes faster. Assuming that the fluid changes state adiabatically, the vortex-shedding frequency of the compressible fluid is given by the following equation.

$$f = A \cdot \left(\frac{P1}{P2}\right)^{1/\kappa} \cdot St \cdot \frac{V_2}{d} \quad \text{..........} (15)$$

where

- V_2 : Local average flow velocity at position 2.5D downstream of the vortex shedder
- P1 : Pressure at position 1D upstream of the vortex shedder
- κ : Ratio of specific heat of gas
- A : Coefficient indicating the influence of flow velocity distribution and area ratio
- P2 : Pressure at position 2.5D down stream of the vortex shedder
- St : Strouhal number
- d : Internal diameter

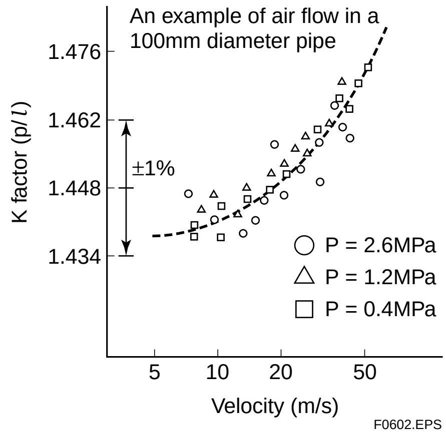

Figure 6.2 K Factor of Compressible Fluid

Ordinarily, temperature and pressure are corrected by providing a pressure tap at positions 2D to 6D, where the pressure is stable, downstream of the vortex shedder. However, the pressure actually decreases most near position 0.5D. As Figure 6.2 shows, if the measuring point to obtain P2 of equation (15) is changed, errors will occur in the K factor as the flow becomes faster. By approximating these errors as a secondary order function of flow velocity, errors due to the difference of measuring points can be corrected.

7. SELF-DIAGNOSIS FUNCTION

The digitalYEWFLO provides the following self-diagnosis functions:

Indication	Diagnostic Message	Error Name	Problem Cause	Current Output	Pulse Output	% Output	Engineering Unit Output	Totalizing Output	How to recover
Err-01	OVER OUTPUT	Over range output signal	Output signal is 110% or more	Fixed at 110%	Normal Operation	Fixed at 110%	Normal Operation	Normal Operation	Change parameters or over ranged flow input
Err-02	SPAN SET ERROR	Span Setting Error	Span setting parameter is more than 1.5 times of max flow velocity	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Change parameters span factor is outside the acceptable limits
Err-06	PULSE OUT ERROR	Pulse output error	Pulse output frequency is more than 10kHz	Normal Operation	Fixed at 10KHz	Normal Operation	Normal Operation	Normal Operation	Change parameters (ItemC, ItemE)
Err-07	PULSE SET ERROR	Pulse setting error	Pulse output frequency setting is more than 10kHz	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Change parameters (ItemC, ItemE)
CHECK Vibration	Transient noise	Error of Vibration	Transitional disturbance	Hold	Normal Operation	Hold	Hold	Normal Operation	CHECK the vibration
CHECK Vibration	High Vibration	Error of Vibration	High vibration	Fixed at 0%	Stop Output	Fixed at 0%	Fixed at 0	Stop the total	CHECK the vibration
CHECK Flow	Fluctuating	Error of Flow	Fluctuating	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Normal Operation	CHECK the clogging
CHECK Flow	Clogging	Error of Flow	Clogging	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Normal Operation	CHECK the clogging
Err-20	PRE-AMP ERROR	PRE-AMP is failed		Normal Operation	Normal Operation	Normal Operation	Normal Operation	Normal Operation	Replace the AMP. unit
Err-30	EE PROM ERROR	EEPROM is not functioning correctly		Over 110% or -2.6% below	Halt	Fixed at 0%	Fixed at 0	Halt	Replace the AMP. unit
	CPU FAULT	CPU is failed	All operations are Dead. Display and self dignostic function is also dead.g	Over 110% or -2.6%	Halt	Halt	Halt	Halt	Replace the AMP. unit

Note. Normal Operation : Operation continues without relation to error occurrence.
Retain Operation : Calculation continues with relation to error occurrence.

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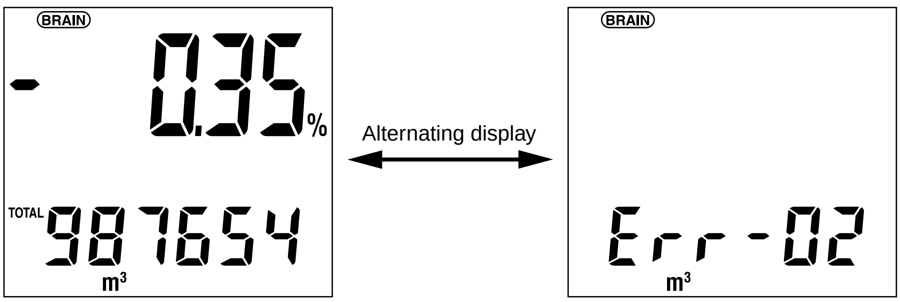

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8. BASIC DATA

8.1 Effects of Spectral Adaptive Filter

● Purpose

This test determines the effects of the spectral adaptive filter, one of the key technologies of the digital YEWFLO.

● Method

Apply vibrations to a fluid (air) at a low flow rate to see the effect of the spectral adaptive filter.

● Specifications

(1) Applying vibrations (equivalent to 1 G) should not influence the vortex waveform or vortex pulses.

(2) Applying vibrations (equivalent to 1 G) should not influence 4 to 20 mA output.

● Actual measurements

(1) No vortex pulse was generated.

(Test data)

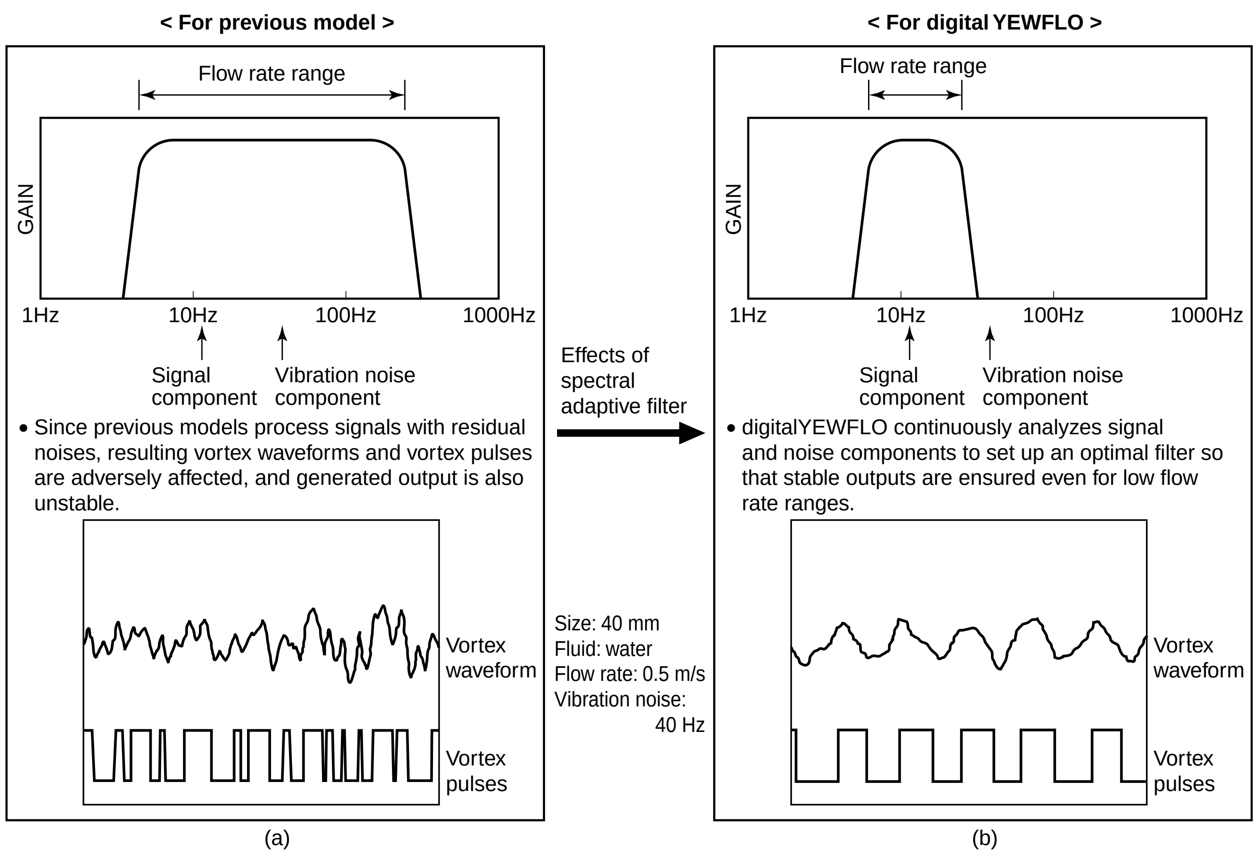

Figure 8.1

(Description)

Figure 8.1 shows the effects of the "spectral adaptive filter." The test data for earlier models in Figure 8.1 (a) shows that the vibration noises influence the vortex waveform to cause vortex pulses and adversely influence the output. The test data for the digital YEWFLO with a spectral adaptive filter in Figure 8.1 (b) shows that vortex signals and noise components are continuously being analyzed, meaning the existence of vibration noises does not influence the output.

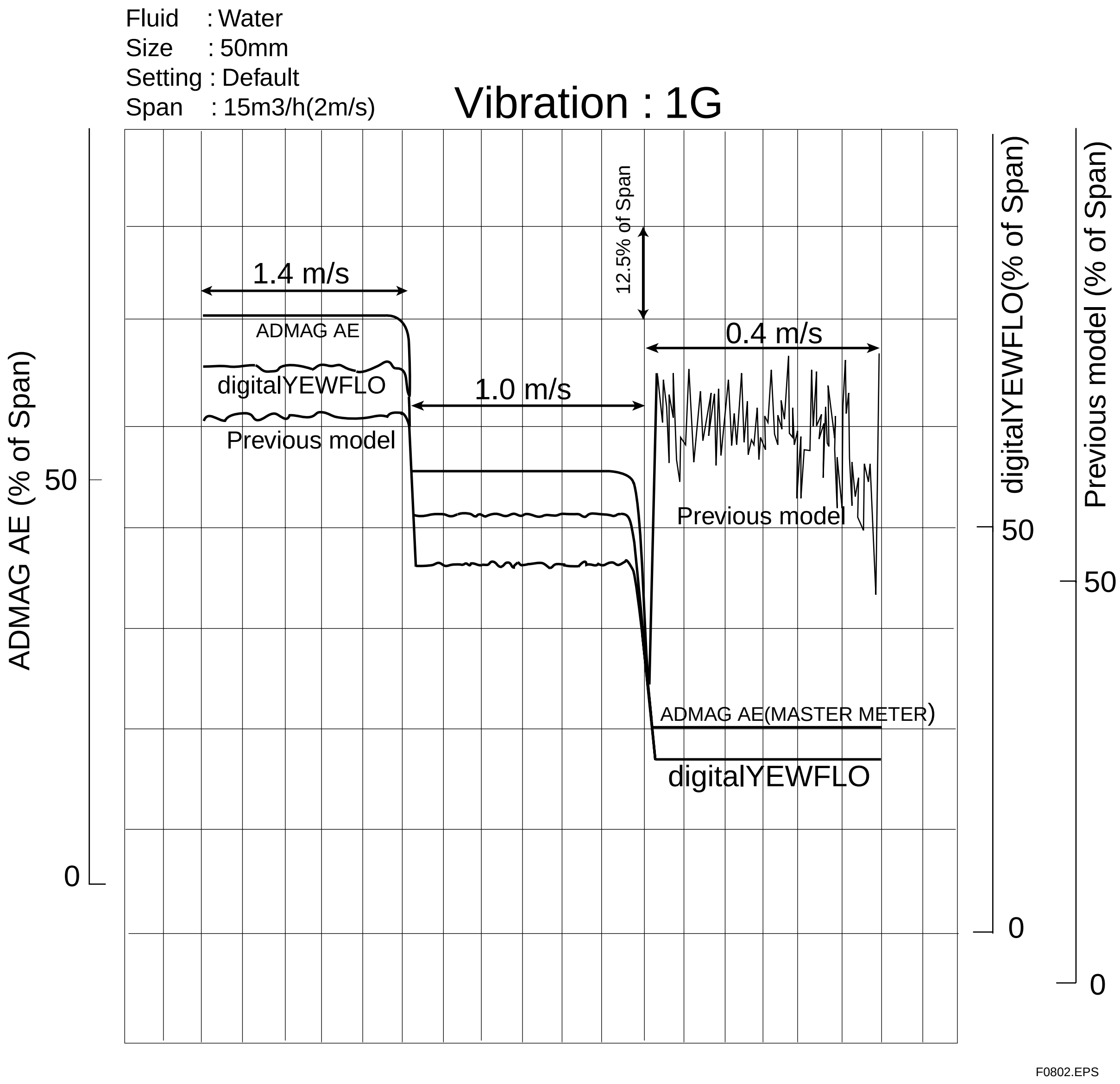

Figure 8.2

Figure 8.2 shows output result of flow rate when giving vibration noise 1G. In zero flow rate, earlier model carry out the incorrect output by vibration noise. However digitalYEWFLO carry out the output always stable.

8.2 Effects of Adaptive Noise Suppression

● Purpose

This test determines the effects of "auto noise balancing," one of the key technologies of digital YEWFLO.

● Method

Apply vibrations to a fluid (air) at zero flow rate to compare the auto noise balancing features of an previous model and the digital YEWFLO.

● Specifications

(1) Applying vibrations (equivalent to 1 G) should not cause vortex pulses.

(2) Applying vibrations (equivalent to 1 G) should not influence 4 to 20 mA output.

● Actual measurements

(1) No vortex pulse was generated.

(2) No effect on the output was found.

(Test data)

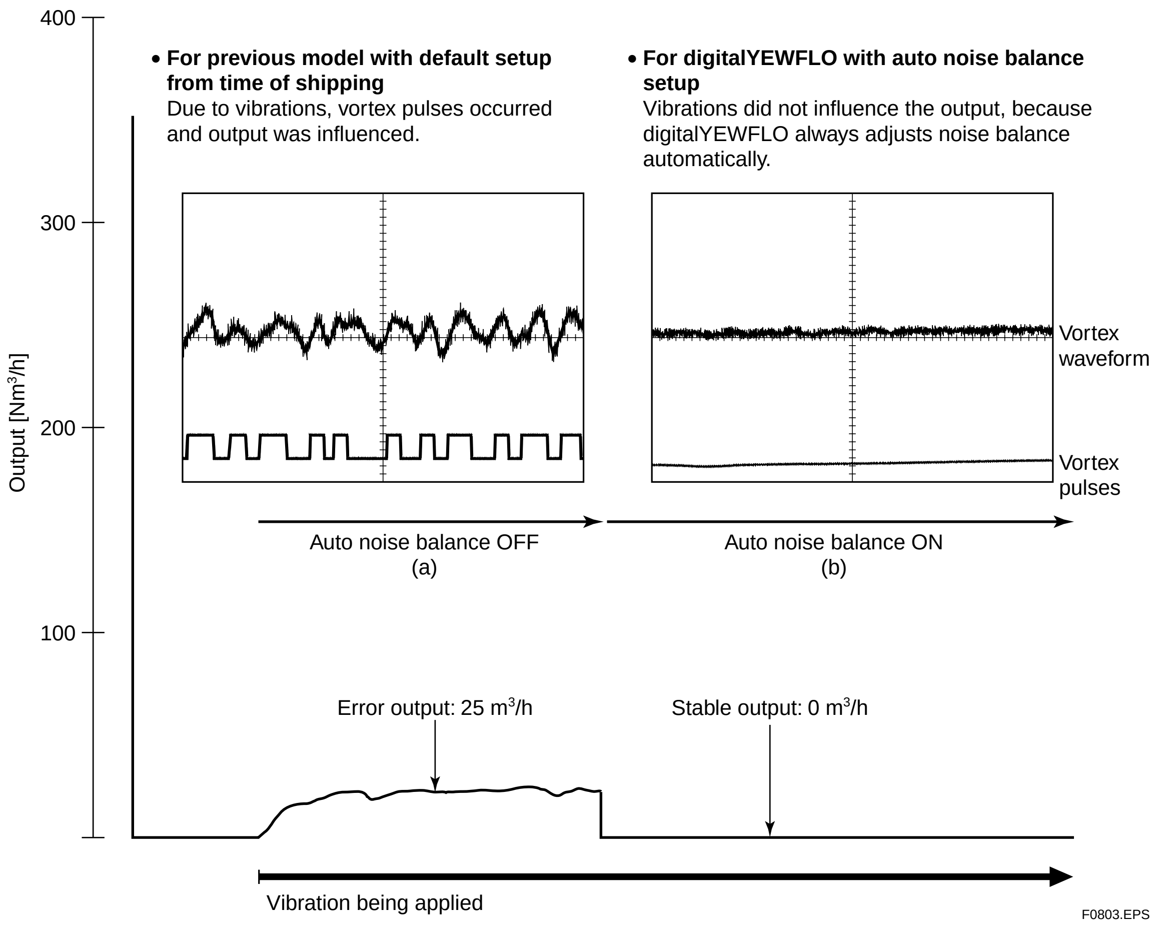

Figure 8.3

(Description)

Figure 8.3 shows the effect of the auto noise balance. For the previous model in Figure 8.3 (a), the influences from vibration noises appeared on the vortex waveform, vortex pulses occurred and the output was influenced. Figure 8.3 (b) shows the effect of digitalYEWFLO with the auto noise balance turned on. The same noises which were applied to the previous model were automatically canceled, and no vortex pulse was generated. This means the vibrations did not influence the output.

8.3 Measurement in Low Flow Rate

● Purpose

This test determines the effects of Low flow measurement comparing with previous model.

● Method

As compared with Magnetic Flowmeter (ADMAG AE), measurement of low flow rate is performed conventionally.

(Test data)

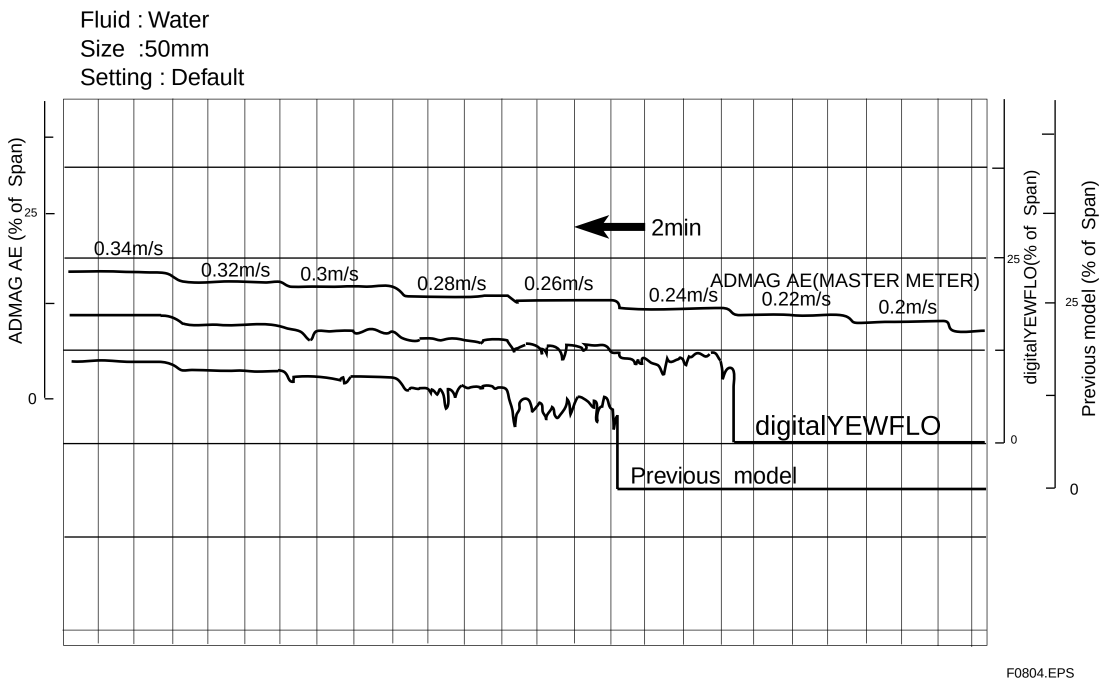

Figure8.4

(Description)

Figure 8.4 shows the measurement result of low flow rate.

According to the SSP, digitalYEWFLO had the low flow region expanded.

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9. SIZING

This section outlines the sizing for various fluids for check purposes. For details on sizing, refer to GS 01F6A00-01E.

(1) Liquid

● Maximum measurable flow rate check

Table 9.1 Maximum Measurable Flow Rate Range for Each Flowmeter Size

Maximum measurable range [m³/h]										
Nominal diameter	1/2 in. (15 mm)	1 in. (25 mm)	1.5 in. (40 mm)	2 in. (50 mm)	3 in. (80 mm)	4 in. (100 mm)	6 in. (150 mm)	8 in. (200 mm)	10 in. (250 mm)	12 in. (300 mm)
Maximum measurable range [m³/h]	6	18	44	73	142	248	544	973	1506	2156

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(1) With reference to 15°C, except for ammonia which references to -40°C

(2) Maximum flow rate was calculated from a flow rate of 10 m/s.

● Minimum measurable flow rate check

Table 9.2 Minimum Measurable Flow Rate Ranges for Various Liquids

Minimum measurable range [m³/h]										
Nominal diameter / Fluid type	**1/2 in. (15 mm)**	**1 in. (25 mm)**	**1.5 in. (40 mm)**	**2 in. (50 mm)**	**3 in. (80 mm)**	**4 in. (100 mm)**	**6 in. (150 mm)**	**8 in. (200 mm)**	**10 in. (250 mm)**	**12 in. (300 mm)**
Water (H_2O)	0.3	0.65	1.3	2.2	4.3	7.5	17	34	60	86
Methanol (CH_3OH)	0.4	0.7	1.5	2.5	4.8	8.4	18	38	67	97
Ethanol (C_2H_5O)	0.5	0.9	1.5	2.5	4.8	8.4	18	38	67	97
Aniline (C_6H_5N)	0.8	1.5	2.4	3.1	4.3	7.3	16	33	59	85
Acetone (CH_3)	0.34	0.73	1.5	2.5	4.7	8.3	18	38	67	96
Carbon bisulfide (CS_2)	0.26	0.58	1.2	2.0	3.8	6.6	15	30	54	77
Carbon tetrachloride (CCl_4)	0.24	0.51	1.1	1.8	3.4	5.9	13	27	48	68
Ammonia (NH_3)	0.34	0.74	1.5	2.5	4.8	8.4	18	37	65	93

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(1) For sizes of 2 inches or less, the above table shows the lower limit of the normal operation range.

● Cavitation check

When using a YEWFLO with the same nominal diameter as the process piping and the minimum flow rate during operation becomes lower than the lower limit of the measurable range, perform a cavitation check for a YEWFLO one or two sizes smaller than the process pipe. If it is confirmed that this smaller YEWFLO may not cause cavitation, install it to the piping using reducers.

Cavitation occurs when the flow line pressure is low and flow verosity is high during measurement, preventing correct measurement of flow rate. Please be sure to perform a cavitation check.

(2) Pressure Loss and Cavitation

● Pressure loss

For water with a flow velocity of 10 m/sec, use 108 kPa (1.1 kgf/cm^2)

For atmospheric pressure with a flow velocity of 80 m/sec, use 9 kPa (910 mmH_2O)

The pressure loss can be obtained from the following equation:

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

or

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

where

ΔP : Pressure loss (kgf/cm^2)

ρ : Fluid density at operating conditions (kg/m^3)

V : Flow velocity (m/s)

Q : Volumetric flow rate at operating conditions (m^3/h)

D : Flowmeter tube inner dia. (mm)

Figure 9.1 shows a graph based on the above equation.

When the nominal size is within 15mm to 50mm and the adjacent pipe is Sch40, and when the nominal size is within 80mm to 300mm and the adjacent pipe is Sch80, pressure loss will be approx. 10% smaller than the calculated value.

● Cavitation (minimum line pressure)

In liquid measurement, a low line pressure and high flow velocity condition can cause cavitation and measuring flow velocities may fail. Minimum line pressure causing no cavitation can be obtained from the following equation:

$$P = 2.7 \times \Delta P + 1.3 \times P_O \quad \text{.......... (3)}$$

P : Downstream 2 to 7 D line pressure, from the flowmeter downstream side end surface [kPa abs {kgf/cm^2 abs}]

ΔP : Pressure loss [kPa{kgf/cm^2}]

Po : Saturate vapor pressure of liquid at operating conditions [kPa abs {kgf/cm^2 abs}]

(Example) Pressure loss calculation example

If water with a temperature of 80°C and a flow rate of 30 m^3/h is measured within a nominal size of 2 inches (50mm), how much is the pressure loss?

(1) Since water with a density of 80°C is 972 kg/m^3, from Equation (2) the following equation can be derived:

$$\Delta P = 135 \times 971.8 \times \frac{30^2}{51.1^4}$$
$$= 17.3\text{kPa } (0.176\text{kgf/cm}^2)$$

(2) From Equation (1), the flow velocity at a flow rate of 30 m^3/h is

$$V = \frac{354 \times Q}{D^2} = \frac{354 \times 30}{51.1^2} = 4.07\text{m/s}$$
$$\Delta P = 108 \times 10^{-5} \times 971.8 \times 4.065^2$$
$$= 17.3\text{kPa } (0.176\text{kgf/cm}^2)$$

(3) From Figure 10.1 the following equation can be derived:

Since C = 18.5, $\Delta P = 98.1 \times 18.5 \times 972 \times 10^{-5} = 17.6$kPa (0.18kgf/$cm^2$)

(Example) Cavitation confirmation

Suppose line pressure is 120 kPa abs (1.22 kgf/cm^2) and the flow rate scale is 0 to 30 m^3/h under the same conditions as above. Since confirmation at only the maximum flow rate is needed, saturated vapor pressure of 80°C water can be Po = 47.4 kPa{0.483 kgf/cm^2}.

From Equation (3)

$$P = 2.7 \times 17.3 + 1.3 \times 47.4$$
$$= 108.3\text{kPa abs. } \{1{,}106\text{kgf/cm}^2 \text{ abs}\}$$

Thus, line pressure (120 kPa {1.22 kgf/cm^2G}) higher than the minimum line pressure (108.3 kgf/cm^2 abs) shows that no cavitation will occur.

Pressure loss factor of liquid (C)   Pressure loss factor of gas/steam (C)

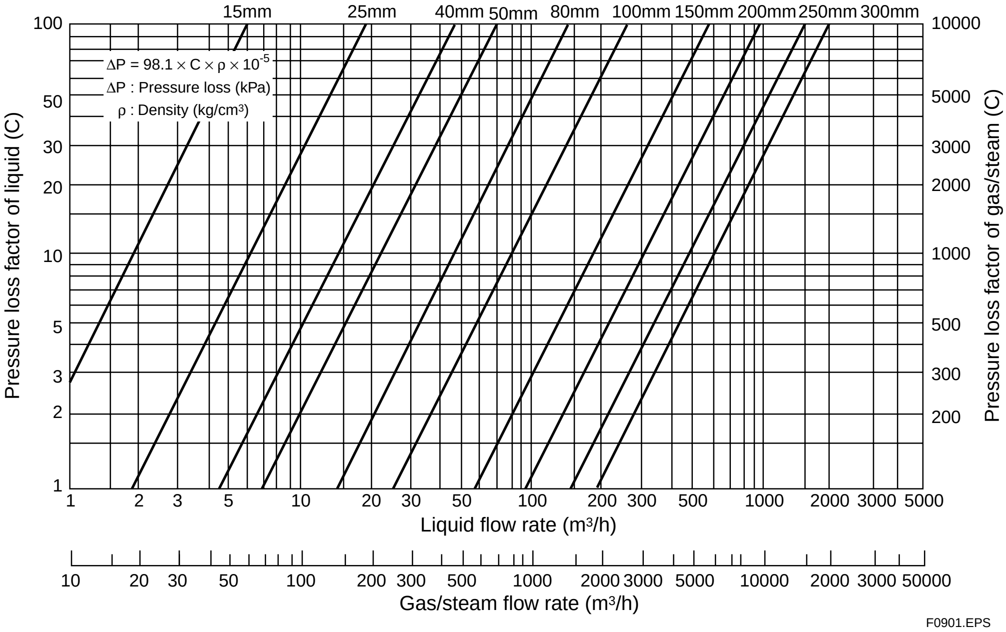

Figure 9.1 Relations between Pressure Loss and Flow Rate (operating conditions)

(3) Gas

● Minimum/maximum measurable flow rate check

Table 9.3 Measurable Range for Gas

Nominal Size	Flow Rate Limits	Minimum and Maximum Measurable Flow Rate in Nm^3/h									
		0 MPa	0.1 MPa	0.2 MPa	0.4 MPa	0.6 MPa	0.8 MPa	1 MPa	1.5 MPa	2 MPa	2.5 MPa
15 mm	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
25 mm	min.	11.0(19.5)	15.5(19.5)	19.0(19.5)	24.5	29.0	33.3	40.6	59.0	77.5	95.9
	max.	149	297	444	739	1034	1329	1624	2361	3098	3836
40 mm	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
50 mm	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
80 mm	min.	70.1	98.4	120	155	197	254	310	451	591	732
	max.	1140	2266	3391	5642	7892	10143	12394	18021	23648	29274
100 mm	min.	122	172	211	272	334	442	540	786	1031	1277
	max.	1990	3954	5919	9847	13775	17703	21632	31453	41274	51095
150 mm	min.	268	377	485	808	1131	1453	1776	2583	3389	4196
	max.	4358	8659	12960	21559	30163	38765	47365	68867	90373	111875
200 mm	min.	575	809	990	1445	2202	2599	3175	4617	6059	7501
	max.	7792	15482	23172	38549	53933	69313	84693	123138	161591	200046
250 mm	min.	1037	1461	1788	2306	3127	4019	4911	7140	9370	11600
	max.	12049	23939	35833	59611	83400	107181	130968	190418	249881	309334
300 mm	min.	1485	2093	2561	3303	4479	5756	7033	10226	13419	16612
	max.	17256	34286	51317	85370	119441	153499	187556	272699	357856	443017

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(1) The pressures shown above represent gauge pressures at 0°C.

(2) Each flow rate in the table represents the flow rate to the rate under the reference conditions (0°C, 101.325 kPa [1 atm]).

(3) Each value within parentheses is the lower limit value of the normal operation range. Unless otherwise followed by a value in parentheses, the lower limit of the normal operation range is the same as that of the measurable range.

(4) 1 kgf/cm^2 = 98.0665 kPa

(5) The maximum flow rate indicates the rate when the flow velocity is 80 m/s.

When using an YEWFLO with the same nominal diameter as the process piping and the maximum flow rate under the operating condition is larger than the upper limit of the measurable range, use a YEWFLO one or two sizes smaller. If the smaller size YEWFLO can measure the specified maximum and minimum flow rates, install it to the piping using reducers.

(4) Steam

● Minimum/maximum measurable flow rate check

Table 9.4 Measurable Range for Saturated Steam

Nominal Size	Flow Rate Limits	Minimum and Maximum Measurable Flow Rate in kg/h									
		0.1 MPa	0.2 MPa	0.4 MPa	0.6 MPa	0.8 MPa	1 MPa	1.5 MPa	2 MPa	2.5 MPa	3 MPa
15 mm	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
25 mm	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
40 mm	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
50 mm	min.	44.0	53	67.3	79	89	98	119	156	192	229
	max.	671	979	1580	2170	2753	3333	4778	6228	7688	9166
80 mm	min.	84.9	103	130	152	171	189	231	300	371	442
	max.	1295	1891	3050	4188	5314	6435	9224	12024	14842	17694
100 mm	min.	148	179	227	267	300	330	402	524	647	772
	max.	2261	3300	5326	7310	9276	11232	16102	20986	25907	30883
150 mm	min.	324	392	498	600	761	922	1322	1723	2127	2536
	max.	4950	7226	11661	16010	20315	24595	35258	45953	56729	67624
200 mm	min.	697	841	1068	1252	1410	1649	2364	3081	3803	4534
	max.	8851	12918	20850	28627	36325	43976	63043	82165	101433	120913
250 mm	min.	1256	1518	1929	2260	2546	2801	3655	4764	5882	7011
	max.	13687	19977	32243	44268	56172	68005	97489	127058	156854	186978
300 mm	min.	1799	2174	2762	3236	3646	4012	5235	6823	8423	10041
	max.	19602	28609	46175	63397	80445	97390	139614	181960	224633	267772

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(1) Each value within parentheses is the lower limit value of the normal operation range.

(2) Unless otherwise followed by a value in parentheses, the lower limit of the normal operation range is the same as that of the measurable range.

(3) The pressures shown above represent gauge pressures

(4) 1 kgf/cm^2 = 98.0665 kPa

(5) The maximum flow rate indicates the rate when the flow velocity is 80 m/s.

Table 9.5 Measurable Range for Hot Steam

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
Superheated 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

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Sizing for superheated steam is also available by multiplying the measured flow rate of saturated steam by the correction factor K1 as follows:

Max. measurable flow rate of superheated steam = Max. measurable flow rate of saturated steam (Mmax) x correction factor (K1)

(Example)

If superheated steam with a pressure of 2.5 MPa and a temperature of 250°C is measured within a nominal size of 2 inches, what is the measurable flow rate?

$Mmax \times K1 = 7688 \times 0.92 = 7073kg/h$

These tables and equations can be used to calculate the maximum measurable flow rate of steam by pressure and size.

(5) Summary

The measurable and normal operation ranges for this flowmeter depend on the conditions of liquid to be measured. Choose an optimum diameter in consideration of the following conditions:

■**Minimum measurable flow rate:** With a Reynolds number of 5000 or more and a larger flow rate that can be calculated from the relation between the minimum flow rate and density.

■**Normal operation range (assured accuracy) minimum flow rate:** With a Reynolds number of 20000 or more (40000 for 150, 200, 250, 300 mm) and a larger flow rate that can be calculated from the relation between the minimum flow rate and density. For the measurable range and assured accuracy range, refer to General Specifications sheet GS 01F06A00-01E.

- For flow rates smaller than the lower value that can be derived from the conditions, the outputs (both of the analog and pulse outputs) show zero.

■**Maximum flow rate:** 10 m/s for liquid; 80 m/s for gas

■**Check the cavitation**

10. FLUID DATA

(1) Density and viscosity of liquid

Table 10.1 Viscosity of Liquid

Liquid substance	Viscosity (cP)				
	0˚C	10˚C	20˚C	40˚C	80˚C
100% Acetone	0.395	0.356	0.322	0.268	
35% Acetone	3.2	2.4	1.80	1.070	0.41
Aniline	10.2	6.5	4.40	2.300	1.10
Amyl alcohol	8.0	6.0	4.50	2.580	0.94
Sulfur dioxide	0.42	0.37	0.34	0.290	0.22
100% Ammonia	0.15	0.13	0.115	0.088	
26% Ammonia	1.9	1.54	1.27	0.850	0.44
Isobutyl alcohol	7.8	5.7	4.20	2.320	0.80
100% Ethyl alcohol	1.84	1.46	1.20	0.829	0.435
80% Ethyl alcohol	3.69	2.71	2.01	1.200	
30% Ethyl alcohol	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-chlorotoluene	1.38	1.20	1.06	0.820	0.52
Chlorobenzene	1.18	1.01	0.88	0.670	0.41
31.5% Hydrochloric acid	3.10	2.7	2.40	1.870	1.21
Octane	0.71	0.63	0.56	0.450	0.305
50% Sodium hydroxide			110.00	42.500	6.70
o-xylene	1.06	0.94	0.84	0.670	0.45
100% Glycerin	12100.00	3950	14.99		
50% Glycerin	12.5	9.0	6.05	3.500	1.20
Chloroform	0.70	0.63	0.57	0.466	
100% Acetic acid			1.22	0.900	0.56
70% Acetic acid	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 oil	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	
Brine (25% $CaCl_2$)	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
100% Methyl alcohol	0.86	0.720	0.62		
60% Methyl alcohol	2.85	2.100	1.59		
30% Methyl alcohol	3.63	2.440	1.76		
111% Sulfuric acid	90.00	66.000	59.00	28.000	9.60
98% Sulfuric acid		39.000	27.00	14.000	5.50
60% Sulfuric acid	10.00	7.500	5.70	3.710	2.21

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Table 10.2 Density of Liquid

Liquid name	T˚C	ρg/cm³	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-xylol	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
Bromoform	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
Petroleum	34	0.825	1295
Gasoline	34	0.803	1250
Water	13.5	1	1460
35% sea water	16	1	1510

Legends:
T: temperature; ρ: viscosity; V: sound speed
(Bibliography: Supersonic Waves Technology Handbook published by The Nikkan Kogyo Shimbun Ltd.)

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(2) Density and viscosity of gas

Molecular Weight and Densities of Typical Gases under Standard Conditions (1 atm, 0°C)

Gas name	Chemical formula	Molecular weight	Density (g/l)
Sulfur dioxide	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	HCI	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
Carbonic acid 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_2S	34.08	1.5392
Isobutane	C_4H_{10}	58.12	*2.081
Ethane	C_2H_6	30.07	*1.048
Ethylene	C_2H_4	28.05	*0.976
Methyl chloride	CH_3Cl	50.49	2.3044
Butane (n)	C_4H_{10}	58.12	*2.094
Butadiene (1.3)	C_4H_6	54.09	(2.301)
l-butene	C_4H_8	56.11	*2.013
Freon 12	CCl_2F_2	120.9	(5.533)
Freon 13	$CClF_3$	104.5	(4.762)
Propane	C_3H_8	44.10	*1.562
Propylene	C_3H_6	42.08	*1.480
Methane	CH_4	16.04	*0.555

Based on “Chemical Industry Handbook”
The value within parentheses was calculated in consideration of a compression coefficient.

The value with an asterisk (*) indicates density in which the gas is in the real state according to JIS K 2301 (1992).

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(3) Viscosity of gas

Gas substance	Viscosity (10^{-6} poise)				
	0˚C	20˚C	50˚C	100˚C	200˚C
Dinitrogen monoxide	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			96	120
Ethylene	94	101	110	126	140
Ethyl chloride	90	97	107	124	157
Hydrogen chloride	131	143		183	230
Chlorine	123	132	145	168	210
Air	171	181	195	218	
Acetic acid	72	78	86	101	133
Ethyl acetate	70	75.5	83	95	120
Nitrogen oxide	179	188	204	227	268
Oxygen	192	203	218	244	290
Cyanogen	93			127	
Hydrogen cyanide	94	99	108	121	148
Cyclohexane	66	70	77	87	109
$3H_2+1N_2$	132	139	148	162	190
Hydrogen bromide	170			234	
Bromine	146	153			
Hydrogen	84	88	94	103	121
Carbon dioxide	138	147	162	185	229
Toluene	65	69	76	88	110
Carbon disulfide	89	97	107	126	162
Butylene	71	76	83	95	119
Fluorine	205	224	250	299	396
Butene	79	84	91	105	130
Freon 11 (CCl_3F)	130	109	116	130	154
Freon 21 ($CHCl_2F$)	107	113	121	134	159
Propane	75	80	88	101	125
Propylene	78	84	96	107	
Hexane	60	65	71	82	104
Helium	186	196	208	229	270
Benzene	68	74	82	96	121
Water				128	166
Methane	102	108	118	133	147
Methyl alcohol	89	95	106	122	155
Hydrogen iodide	173	186	202		293
Hydrogen sulfide	117	124		159	

Viscosity of gas (1 atm min.)

Gas substance	Temperature (˚C)	Viscosity (10^{-6} poise)				
		1atm	40atm	60atm	80atm	200atm
Air	16 to 20	170	180	187	198	330
Carbonic acid gas	20	148	166	700	810	
Carbonic acid 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

T1004.EPS

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