Mass Flow Calculation in digitalYEWFLO Vortex Flow Meter

- Highly Accurate Mass Flow Calculation Using FieldMate FlowNavigator -

Takashi Kawano [*1]   *Shinnosuke Yoshida* [*1]

Yokogawa introduced the world's first vortex flow meter for industrial use in the 1960s, which is now widely used for measuring liquid, gas, and steam. However, Yokogawa's digitalYEWFLO vortex flow meter had limited functions in tracking pressure changes especially in the measurement of gas and steam, for which mass flow measurement is generally required, due to the use of the pressure value as a constant. The newly developed FieldMate FlowNavigator flow configuration software applying Field Device Tool/Device Type Manager (FDT/DTM) technology has made it possible to compensate density using a physical properties database. Combined with FOUNDATION Fieldbus type digital YEWFLO, it can accurately calculate mass flow. This report describes mass flow calculation in the FOUNDATION Fieldbus type digitalYEWFLO, and highly accurate calculation of the mass flow of natural gas by FlowNavigator with actual test data.

INTRODUCTION

Vortex flow meters have been appreciated by users as volume flow meters, which can, in principle, be applied to any flow measurement of liquid, gas, or steam.

Volume flow measurement is enough for substances with small variations in density such as liquid. However, mass flow must generally be calculated for steam and gas because their volumes vary significantly depending on temperature and pressure.

Although the current digitalYEWFLO vortex flow meter (1) in the market is capable of calculating mass flow for liquid, gas and steam, it has limited functions in tracking the pressure changes of measured fluids and providing highly accurate mass flow calculations because it partially regards the pressure value as a constant.

We have developed FieldMate FlowNavigator flow configuration software that runs on the FieldMate Versatile Device Management Wizard (2) which utilizes the Field Device Tool/Device Type Manager (FDT/DTM) technology. Combined with the FieldMate FlowNavigator, Yokogawa's FOUNDATION Fieldbus communication type digitalYEWFLO has resolved the disadvantages mentioned above. In addition, mass flow calculations can be set up interactively, resulting in significant improvement of user's convenience. Figure 1 shows the external view of the digitalYEWFLO and the FlowNavigator medium.

*1 Field Instruments Business Center,
Industrial Automation Business Headquarters

Integral type vortex flow meter

FlowNavigator medium

Figure 1 External View of digitalYEWFLO and FlowNavigator Medium

FEATURES OF MASS FLOW CALCULATION BY THE FLOWNAVIGATOR

Yokogawa's FOUNDATION Fieldbus communication type digitalYEWFLO is capable of providing various mass flow calculations as listed below by configuring it using the information required for mass flow calculation through the FlowNavigator.

- Highly accurate mass flow calculation for general gases, natural gases, and general liquids (accuracy ≤ 1.1% at 35 m/s for natural gas)
- Mass flow calculation for custom fluids of users
- Interactive configuration for conventional mass flow calculation for saturated steam and volume flow calculation under standard conditions using Boyle's Law and Charles' Law

The FOUNDATION Fieldbus communication type digitalYEWFLO can output mass flow rate responding to the varying conditions of the measured fluid by retrieving temperature and pressure data via the fieldbus.

SYSTEM CONFIGURATION

Overall configuration

Figure 2 shows a system configuration example where the FlowNavigator is used with a vortex flow meter and pressure transmitter to provide highly accurate mass flow measurement of general or natural gas.

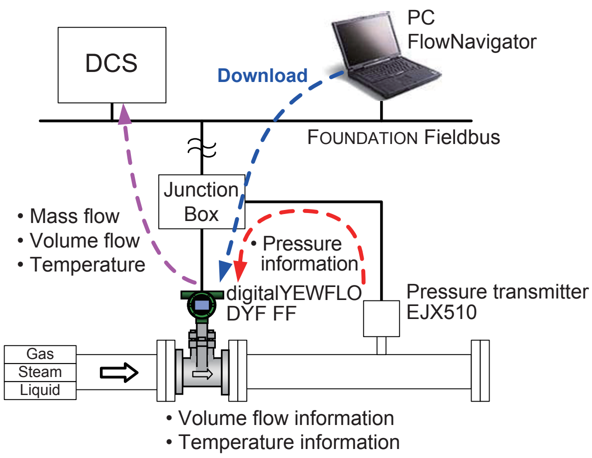


Figure 2 System Configuration Example

Since the multivariable type digitalYEWFLO maintains fluid temperature in addition to volume flow rate, it can calculate mass flow rate by retrieving the pressure value from the pressure transmitter via the fieldbus communication. Data required for measurement, including fluid conditions and unit of mass flow, are set in the FlowNavigator on the PC. Among these data, the density compensation coefficients used for density calculation are downloaded to the digitalYEWFLO via fieldbus communication. The digitalYEWFLO uses downloaded parameters, including density compensation coefficients, to perform mass flow calculation.

A formula of density compensation for calculating the mass flow rate of gas is shown below. The digitalYEWFLO performs density compensation calculation using polynomial approximation to obtain highly accurate mass flow rate.

$$\begin{aligned}\rho_f = {} & K_{\rho 0} + K_{\rho 1} \times (1/T_f) + K_{\rho 2} \times (1/T_f)^2 \\ & + K_{\rho 3} \times P_f + K_{\rho 4} \times (1/T_f) \times P_f + K_{\rho 5} \times (1/T_f)^2 \times P_f \\ & + K_{\rho 6} \times P_f^2 + K_{\rho 7} \times (1/T_f) \times P_f^2 + K_{\rho 8} \times (1/T_f)^2 \times P_f^2 \\ & + K_{\rho 9} \times P_f^3 + K_{\rho 10} \times (1/T_f) \times P_f^3 + K_{\rho 11} \times (1/T_f)^2 \times P_f^3\end{aligned}$$

$$M = \rho_f \times Q_f$$

ρ_f : Fluid density after compensation [kg/m^3]
$K_{\rho n}$: Density compensation coefficient (n = 0 - 11)
T_f : Fluid temperature [K]
P_f : Fluid pressure [kPa abs]
M : Mass flow rate measured by digitalYEWFLO [kg/h]
Q_f : Volume flow rate measured by digitalYEWFLO [m^3/h]

Function block configuration of digitalYEWFLO

Figure 3 shows the configuration of the function blocks (FB) of the FOUNDATION Fieldbus communication type digitalYEWFLO which performs the mass flow calculation.

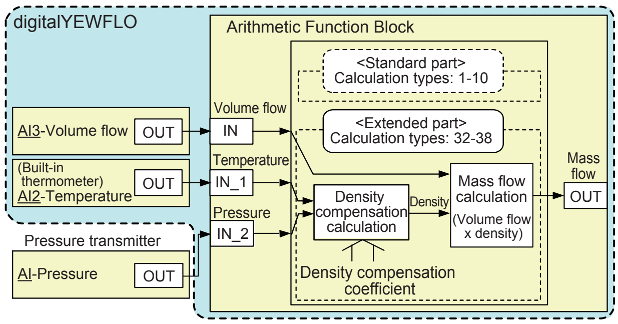
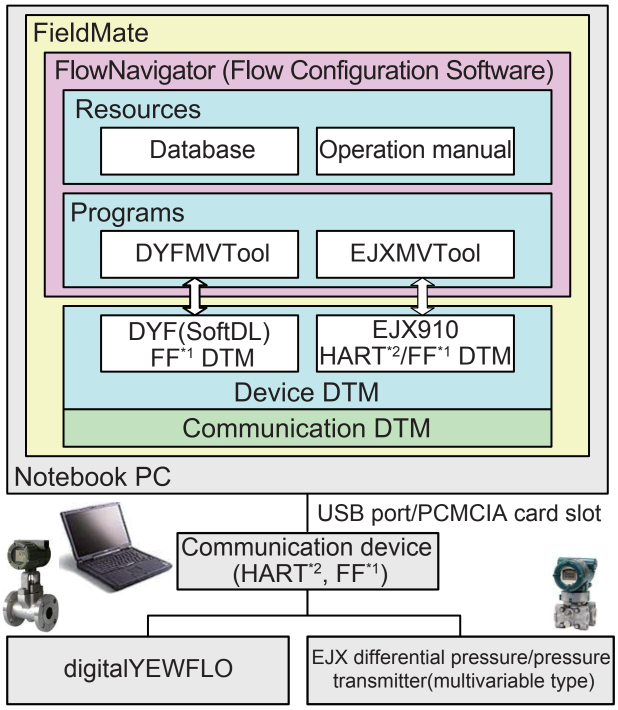


Figure 3 FB Configuration Performing Mass Flow Calculation

Eight FBs are implemented in the digitalYEWFLO. The output from the AI2 (Analog Input 2) FB is temperature, and the output from the AI3 (Analog Input 3) FB is volume flow rate. Both output, together with the pressure measurement from the external pressure transmitter, are connected to INs of the AR (Arithmetic) FB. The AR FB offers extended calculation functions to enable various mass flow calculations as summarized in Table 1.

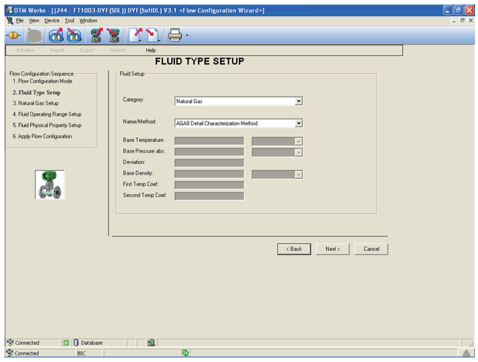
Configuration of FieldMate FlowNavigator

Figure 4 shows the configuration of the FieldMate FlowNavigator. The FlowNavigator runs on the FieldMate, and it comprises programs and resources. The programs include two flow rate calculation programs, DYFMVTool for the digitalYEWFLO vortex flow meter and EJXMVTool for the EJX series differential pressure/pressure transmitters [3]. The resources include the physical properties database etc. The DYFMVTool started by the device DTM calculates density based on interactively set data such as the properties of the fluid, calculation standard, pressure and temperature conditions, gas components, etc. The compensation coefficients required for density calculation are eventually downloaded to the instruments. Figure 5 shows examples of DYFMVTool settings and density calculation results.

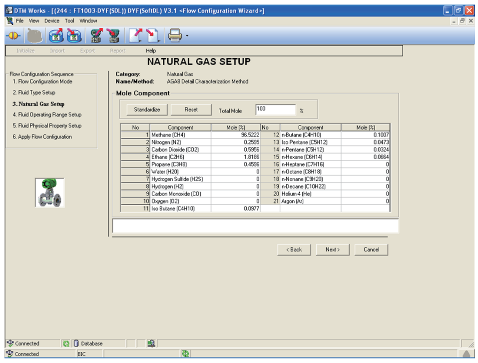


*1: FF (FOUNDATION Fieldbus) protocol
*2: HART (Highway Addressable Remote Transducer) protocol

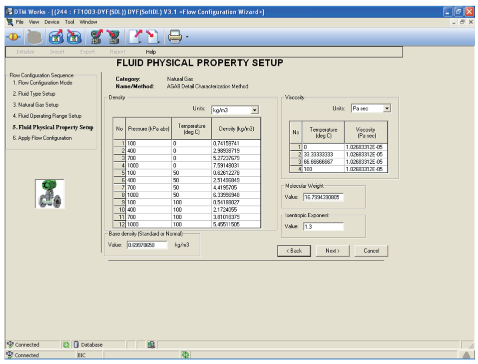
Figure 4 Configuration of the FieldMate FlowNavigator



(a) Fluid-type setup



(b) Natural gas component setup



(c) Density calculation results of natural gas

Figure 5 Examples of the DYFMVTool Settings and Density Calculation Results Display

Table 1 Items of Mass Flow Calculations in the Arithmetic Function Block

Calculation items	Description
a) Calculation for saturated steam based on temperature	Calculates steam density from temperature or pressure based on the equations of IAPWS*1-IF97.
b) Calculation for saturated steam based on pressure	
c) Calculation for superheated steam by temperature and pressure	
d) Temperature/pressure compensation calculation for gas	Calculates gas density with compensation for temperature/pressure based on Boyle's Law and Charles' Law.
e) Temperature compensation calculation for liquid	Calculates liquid densities using compensation formulas described in API*2 or JIS*3 (JIS K 2249).
f) Temperature/pressure compensation calculation for gas (polynominal approximate calculation)	Calculates density using the polynominal approximation defined in the FlowNavigator. General fluids : Utilizes the physical properties database of DIPPR*4 Natural gas : Complies with standard natural gas calculation specifications AGA*5 No. 8 / ISO*6 12213: 1997 First edition
g) Temperature/pressure compensation calculation for liquid (polynominal approximate calculation)	

*1: International Association for the Properties of Water and Steam
*2: American Petroleum Institute
*3: Japanese Industrial Standard
*4: Design Institute of Physical Properties of the American Institute of Chemical Engineers
*5: American Gas Association
*6: International Organization for Standardization

RESULTS OF FIELD TEST

Mass flow tests were conducted at a natural gas test site of Advantica in the UK, which has been certified by the United Kingdom Accreditation Service (UKAS) [4]. Figure 6 shows the test results for two different sizes: 50 mm and 150 mm in diameter. Both have been verified to be within the target ranges of mass flow rate accuracy. Figure 7 shows the system configuration used for the testing.

As reference, the mass flow rate was used; the volume flow rate was measured by a UKAS-certified turbine meter and then the mass flow rate was calculated through compensation of temperature and pressure. As for natural gases, gas components must be measured to compensate the density. Thus, gas components were measured using a gas chromatograph and their values were transmitted to the Advantica's host PC and the DYFMVTool. The DYFMVTool performed calculations based on AGA No. 8, a standard for calculating natural gas densities established by the American Gas Association, and downloaded the density compensation coefficients to the digitalYEWFLO under test. The digitalYEWFLO calculated the density using the downloaded compensation coefficients taking the temperature and pressure into account, and then calculated the mass flow rate by multiplying the volume flow rate measured by digitalYEWFLO by the density.

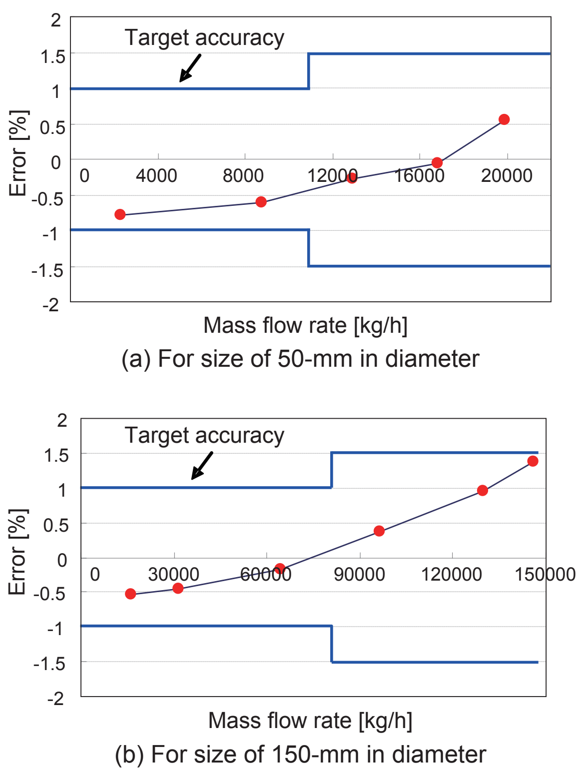


Figure 6 Results of Mass Flow Tests with Natural Gas

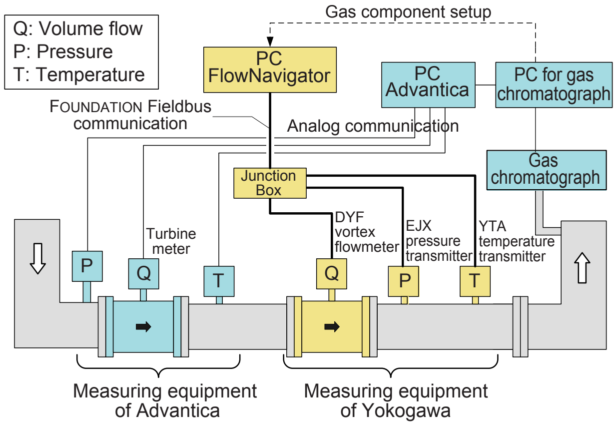


Figure 7 System Configuration of Natural Gas Test Site

CONCLUSION

Combination of the FieldMate FlowNavigator and the FOUNDATION Fieldbus communication type digitalYEWFLO has enabled highly accurate mass flow calculations. In addition, the interactive setup has improved operability. We plan to provide this solution with other protocols than FOUNDATION Fieldbus supported by the FOUNDATION Fieldbus communication type digitalYEWFLOW.

Furthermore, we are continuously enhancing diagnosis-based application software such as impulse line blockage diagnosis, utilizing the FDT/DTM technology. We will continue to create products that contribute to society.

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