

Calculations for Sensor and Laminar Flow Element Linearization

Introduction

The contents of this paper are the result of extensive research and vastly improve the linearity of the 400-I Series mass flow meters. Linearity becomes important especially when measuring different gases than the calibration gas. Because of differences in densities of gases, there are differences in the fluid characteristics when exposed to the same environment, such as a flow splitter or a laminar flow element.

This becomes important for applications that might use one mass flow meter for measuring different gases such as hydrogen, helium, propane and nitrogen. This also gives an improved accuracy for the more difficult to measure gases like hydrogen and ethylene, if the high flow rate instrument was calibrated in air and uses a gas conversion factor to calculate the mass flow rate.

This article references commands that are defined in the HFM 400-I Series Software manual and the tutorial on Status/Configuration Word.

Calculation of the Flow Reading

The flow reading starts with acquiring a value (AD) from the sensor A/D. This value will be in counts (16 bits signed, -32768 - 32767 corresponds to -2.048 volts - 2.047 volts). This value is converted to a voltage reading and is available via the s40 command. The zero flow sensor output value (AD0) in volts (available via s16 command and set using the "zro" command) will be subtracted from this. The result is divided by the sensor output value when flowing 5 sccm of nitrogen (SFS) in volts (see "s 45" command) the resultant value will be a floating point number between -2 and +2 typically between 0 and +1.

$$\frac{AD - AD0}{SFS} = S$$

This resultant sensor value is linearized with a normalized polynomial with a linear and a 3rd order component. The coefficients of this polynomial have been calculated such that the sum total of the coefficients is 1.00. The 3rd order value (B) is set for nitrogen with the "s 43" command, the 5th order value (C) is set for nitrogen with the "s 44" command. The linear value (A) is calculated from the fact that A + B + C = 1 and can be read with the "s 42" command. Since each gas creates a different non-linear response in the flow sensor each gas must be linearized using a different polynomial. Each gas has two factors which are used to correct the for the varying gas sensitivities of the sensor. The linear part is called the gas correction factor GCF (available via the G9 command, from GasDataTables.xls) and the coefficient that multiplies the higher order term is referred to as the gas "z" multiplier (Gz, available with the g3 command).

$$B' = B \cdot Gz, C' = C \cdot Gz$$

The resultant (SL) is also a floating point value typically (but not always) between 0 and 1.

$$[A(S) + B'(S^3) + C'(S^5)]GCF = SL$$

This resultant linear sensor value is adjusted with another gas dependent normalized polynomial to correct for the non-linearity of the laminar flow element. This polynomial has a linear and a 2nd order component. The coefficients of this polynomial have been calculated such that the sum total of the coefficients is 1.00. The 2nd order value (E) is set with the "g10" command and the 4th order value (F) is set with the "g11" command. The linear value (D) is calculated from D + E + F = 1. It cannot be set or read. The resultant (SHL) is also a floating point value typically (but not always) between 0 and 1. Changing the active gas will select a different set of coefficients. Any gas dependent values will have a different value stored in each gas record.

$$D(SL) + E([SL]^2) + F([SL]^4) = SHL$$

This linearized shunt value is multiplied by the following factors: a shunt factor (ShF, "s46", nominal nitrogen equivalent range of the laminar flow element), a time correction factor for the flow unit (TcF, "g5"), a volume correction factor for the flow unit (VcF, "g8"), a gas dependent calibration span adjust factor (SpF, "g14") and if the flow unit is volumetric ("g15") then a

reference temperature correction factor (T_c , calculated from "g19"). The end result is the flow rate in engineering units that is reported when the "f" command is received.

$$(SHL)[(ShF)(TcF)(VcF)(SpF)(Tc)] = f$$

Six different multiplication steps could be performed on each data reading or alternatively an internal factor could be maintained that is the product of the six factors. This internal factor could be updated whenever one of the other factors is changed.

The T_c value is calculated as follows:

$$\frac{T + 273.15}{273.15} = T_c$$

Resultant Linearized Analog Output

The resultant flow value ("f") is divided by the full scale flow value (FSF, "g2"). This dividend is multiplied by the DAC full scale code in counts (DFS, "s 52"). The resultant counts value then has the DAC zero code (DA0, "s 51") added to it. This final result (DAC) can be sent to the analog output Digital to Analog converter.

Analog Set point Input

$$\frac{f}{FSF} DFS + DA0 = DAC$$

The flow reading starts with acquiring a value (AD4) from the set point A/D. This value will be in counts (16 bits signed, -32768 - 32767 corresponds to -2.048 volts - 2.047 volts). The input voltage that corresponds to a zero flow command (4Z, available via s69 command) will be subtracted from this. The result is multiplied by the full-scale factor (FS4) (see "s24" command) to generate a full scale input range equal to the full scale analog output value.

$$(AD4 - 4Z)FS4 = Sp$$

If the original analog input signal was a 4-20 mA or 1-5 VDC signal the zero flow command value is not numerically equal to 0.00 in these cases the value reported back for the s26 command is the Sp value plus 1.00 or 4.00 dependent on the value stored in the Product Configuration word s64.