FLOMEKO 2019

ID: 1007
Flow Measurement Turn Down Analysis for DP Flow Meter using Multiple Multivariable Transmitters

16:20-16:40, 26th Jun, 2019
Oral Session S8.9: Flow Metering Technology
Room5
FLOMEKO2019
Portugal, Lisbon, LNEC

Akio Ito, Hiromasa Takiguchi, Morokata Aya:
Yokogawa Electric Corporation
Vince Cisar: VERIS Flow Measurement Group,
Armstrong International

Armstrong

YOKOGAWA

Outline

1. INTRODUCTION

2: The motivation of this research

3. Combined flow uncertainty

4. DP uncertainty analysis : L & H range DP comparison with CEESI master meter

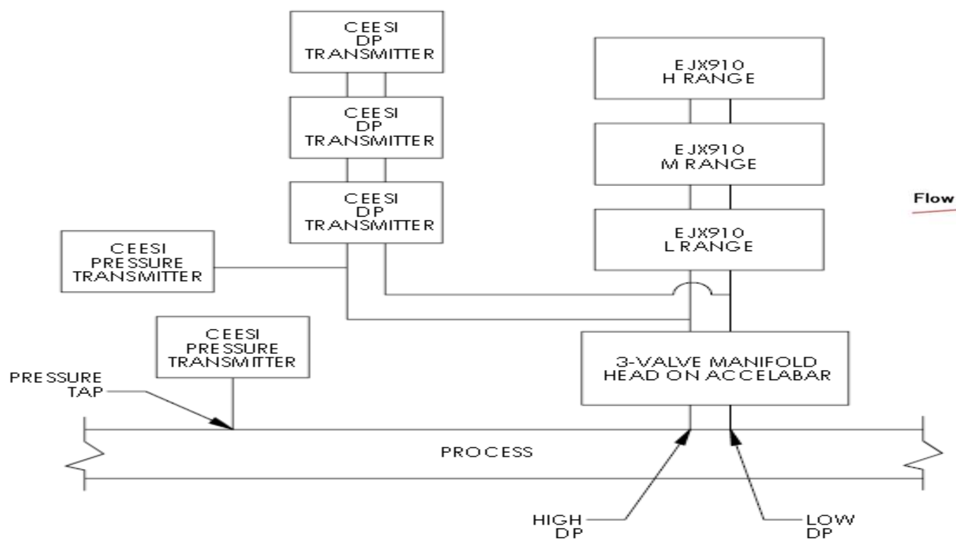
5. Uncertainty analysis at 2.2 inH2O point

6. DP measurement contribution for flow measurement

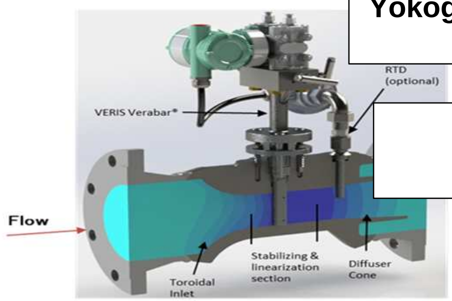
7. CONCLUSION

1. INTRODUCTION: Differential pressure (DP) flow meter calibration at CEESI, reported at ISFFM2018

- We reported at ISFFM2018 that we performed a DP flow meter calibration to determine the combined system accuracy at the CEESI NIST traceable air laboratory located at Nunn, Colorado, USA
  - 4" VERIS Accelabar® flow primary element based on averaging pitot tube technology
    - Combines a unique toroidal nozzle design with the VERIS Verabar® averaging pitot tube
  - Yokogawa EJX® Series multivariable transmitter EJX910 H range (2000inH2O) and M range (400inH2O)
    - Designed with multi-sensing capabilities using built-in silicon resonant sensor technology

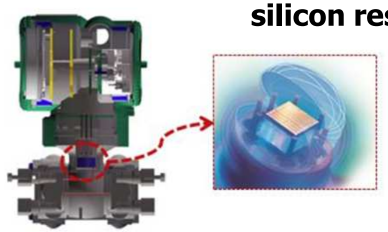


Yokogawa EJX910 multivariable transmitter



VERIS Accelabar® flow primary element

EJX910 multivariable transmitter with silicon resonant sensor

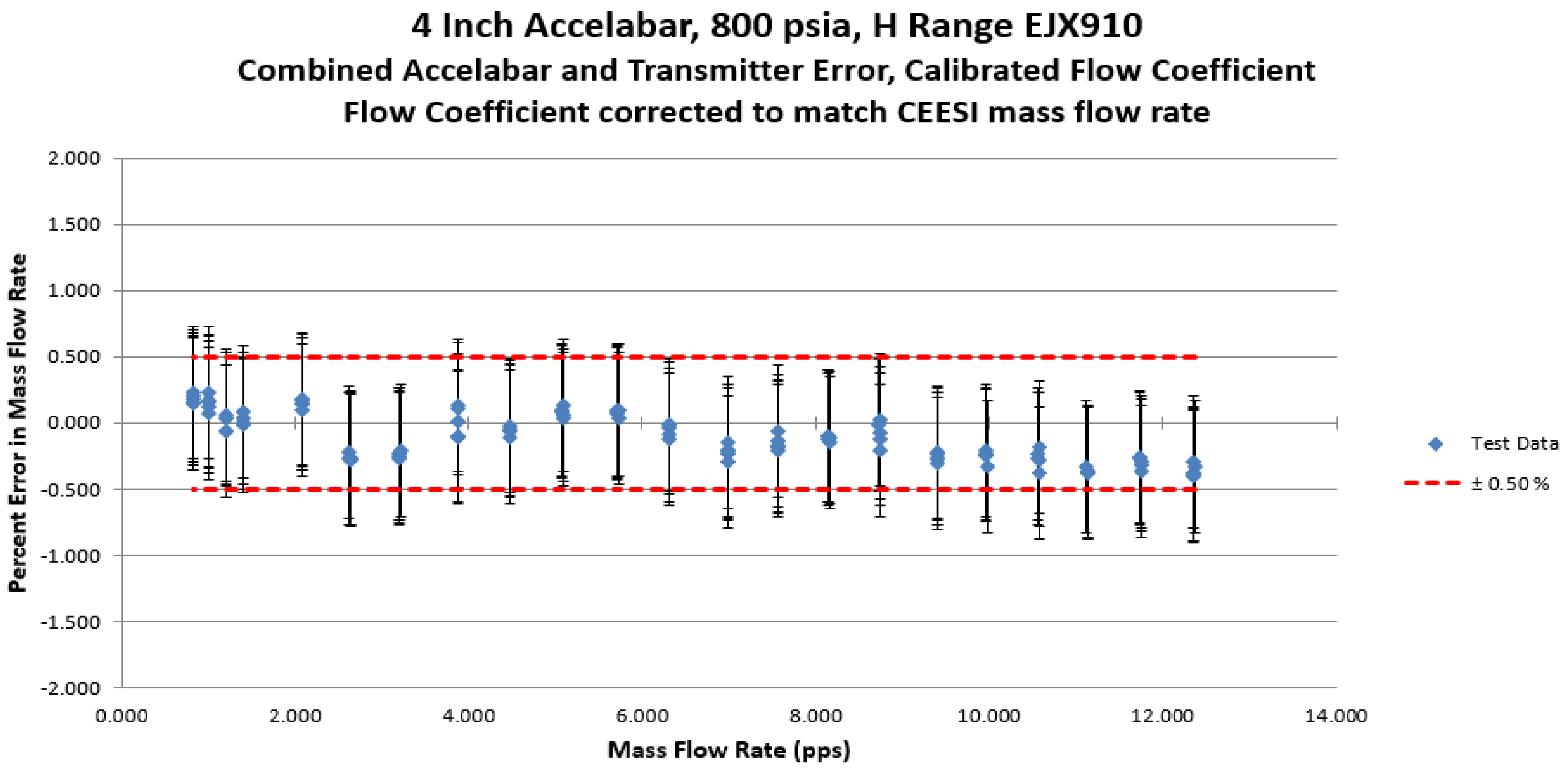


1. INTRODUCTION: Flow measurement result using single multivariable transmitter, reported at ISFFM2018

- For FLOMEKO2019, we focus below
- Flow rate outputs of the EJX910 transmitters were compared to CEESI flow rates determined by CEESI's NIST traceable sonic nozzles
- VERIS Accelabar® flow coefficient (K) value was corrected from EJX910 flow data to match CEESI flow data
  - The best performance was achieved during the 800 psia air tests
  - The result obtained using single EJX910 H range (2000inH2O) was reported at ISFFM2018
    - The combined linearity of VERIS Accelabar® flow primary element and Yokogawa EJX910 DP measurement was 0.5% with 15:1 turndown

1. INTRODUCTION: Flow measurement result using single multivariable transmitter, reported at ISFFM2018

- Achieved accuracy 0.5% with 15:1 turndown
  - EJX910 H range with the 4” VERIS Accelabar®



2. The motivation of this research

- EJX910 has also L range (DP: 40inH2O) transmitter and capability of using for low flow rate measurement
  - We show that adding L range transmitter with H range transmitter, flow measurement turndown will be increased beyond 15:1 until 20:1
- We show that EJX910 has an advantage of low DP measurement under high static pressure (SP) condition

2. The motivation of this research

- Flow rate equation at CEESI flow test

$$q_m = \frac{\pi}{4} K \varepsilon D^2 \sqrt{2 \Delta P \rho_f} \quad \textbf{(1)}$$

Where
K stands for flow coefficient
ε stands for expansibility
D stands for diameter of the conduit
ΔP stands for DP
ρ_f stands for density

- Flow turndown 20:1 flow rate point

	maximum	15:1 flowrate from maximum	20:1 flow rate from maximum
Flow rate (lb/sec)	12.4	0.82	0.62
Dp (InH2O)	890	3.9	2.2

- Analyze 20:1 flow point uncertainty
- Confirm if flow measurement turndown will be increased beyond 0.5% 15:1 until 20:1 in case of adding L range transmitter

3. Combined flow uncertainty: The uncertainty assumption of Flow Primary element and the density

- Combined flow uncertainty

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 + \left(\frac{\partial \Delta P}{2\Delta P}\right)^2 + \left(\frac{\partial \rho}{2\rho}\right)^2} \quad \textbf{(7)}$$

- The uncertainty contribution of Flow Primary element VERIS Accelabar®

$$Uncert_{pe\_as} = \left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 = (0.5\%)^2 \quad \textbf{(10)}$$

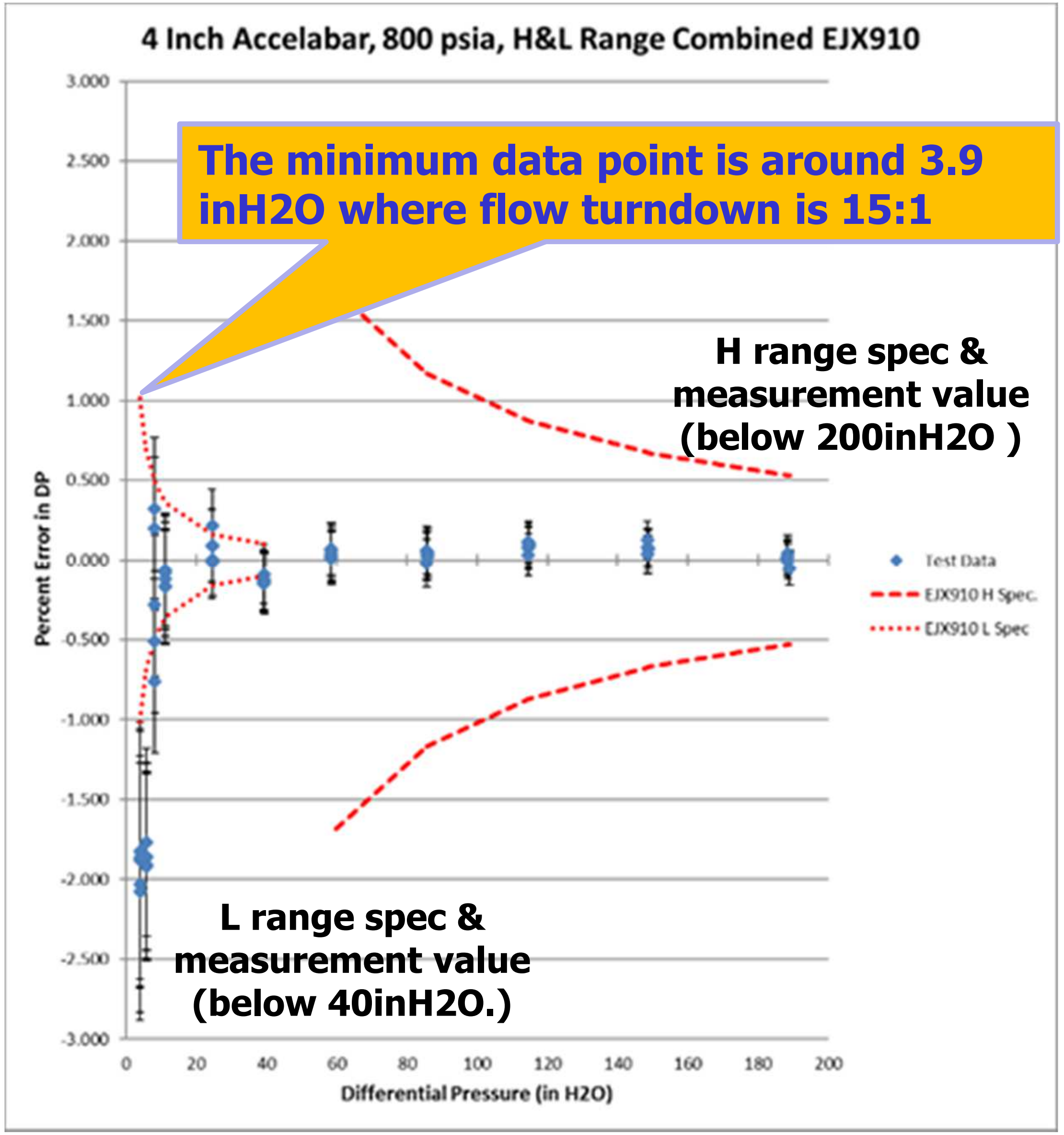
- Assume that VERIS Accelabar® flow uncertainty contribution is 0.5% with 20:1 turndown derived by previous experiments

- The uncertainty contribution of the density

$$Uncert_{\rho\_as} = \left(\frac{\partial \rho}{2\rho}\right)^2 = (0.05\%)^2 \quad \textbf{(13)}$$

- Assume by current EJX910 specification
  - Density uncertainty less than 0.1%

4. DP uncertainty analysis : L & H range DP comparison with CEESI master meter



- The EJX910 L range data difference between the EJX910 H range and CEESI master meter at the point is around 2%
- The EJX910 uncertainty calculated by general specification is around 1%
- The CEESI master mater uncertainty is 0.8%
- The uncertainty of EJX910 and the reference CEESI master meter at the point is relatively bigger than the difference

5. Uncertainty analysis at 2.2 inH2O point: DP reference accuracy influence

- Combined flow uncertainty

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 + \left(\frac{\partial \Delta P}{2\Delta P}\right)^2 + \left(\frac{\partial \rho}{2\rho}\right)^2} \quad \textbf{(7)}$$

  - From reference accuracy defined as ±0.04% of span

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{ref} = \mathbf{0.04\%} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{0.7\%} \qquad \textbf{(15)}$$

  - From L range EJX910 test data at the factory

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{ref\_as} = \mathbf{0.005\%} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{0.09\%} \quad \textbf{(16)}$$

5. Uncertainty analysis at 2.2 inH2O point: SP span effects influence

- Combined flow uncertainty

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 + \left(\frac{\partial \Delta P}{2\Delta P}\right)^2 + \left(\frac{\partial \rho}{2\rho}\right)^2} \quad \textbf{(7)}$$

  - From SP span effects per 6.9 MPa (1000 psi) change defined as ±0.075% of span

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{span} = \mathbf{0.075\%} \times \frac{800\ psia}{1000\ psia} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{1.1\%}\ \textbf{(17)}$$

  - From L range EJX910 test data at the factory

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{span\_as} = \mathbf{0.01\%} \times \frac{800\ psia}{1000\ psia} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{0.15\%} \quad \textbf{(18)}$$

5. Uncertainty analysis at 2.2 inH2O point: Assumed uncertainty at 2.2 inH2O point

- Combined flow uncertainty

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 + \left(\frac{\partial \Delta P}{2\Delta P}\right)^2 + \left(\frac{\partial \rho}{2\rho}\right)^2} \quad \textbf{(7)}$$

  - From Equation 16 (DP reference accuracy influence) and 18 (SP span effects influence)

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{as} = \left(\frac{\partial \Delta P}{\Delta P}\right)_{ref\_as} + \left(\frac{\partial \Delta P}{\Delta P}\right)_{span\_as} = 0.09\% + 0.15\% = 0.24\% \quad \textbf{(19)}$$

5. Uncertainty analysis at 2.2 inH2O point: Assumed uncertainty at 2.2 inH2O point

- Combined flow uncertainty

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 + \left(\frac{\partial \Delta P}{2\Delta P}\right)^2 + \left(\frac{\partial \rho}{2\rho}\right)^2} \quad \textbf{(7)}$$

- DP uncertainty at 2.2 inH2O point (flow turndown 20:1) from equation 19

$$Uncert_{dp\_as} = \left\{\left(\frac{\partial \Delta P}{2\Delta P}\right)^2\right\}_{as} = \left(\frac{1}{2} \times \left(\frac{\partial \Delta P}{\Delta P}\right)_{as}\right)^2 = \left(\frac{1}{2} \times 0.24\%\right)^2 = (0.12\%)^2 \quad \textbf{(20)}$$

5. Combined flow uncertainty: Extending flow turn down to 20:1

- Combined flow uncertainty

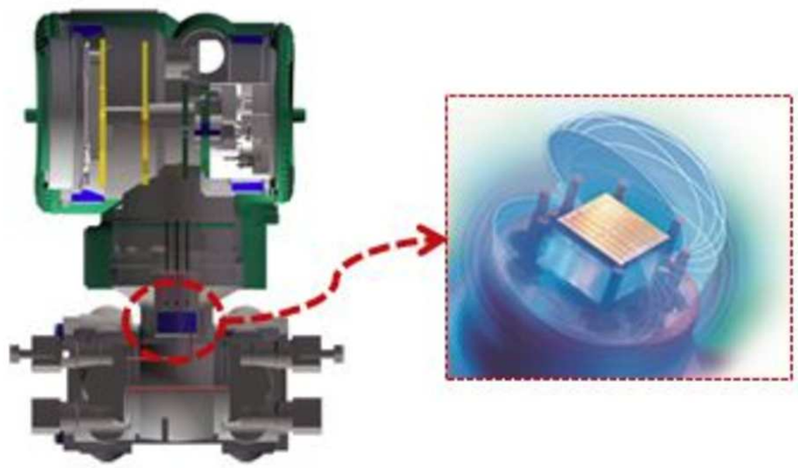
$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\partial K}{K}\right)^2 + \left(\frac{\partial \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\partial D}{D}\right)^2 + \left(\frac{\partial \Delta P}{2\Delta P}\right)^2 + \left(\frac{\partial \rho}{2\rho}\right)^2} \quad \textbf{(7)}$$

$$\left(\frac{\delta q_m}{q_m}\right)_{as} = \sqrt{\left(Uncert_{pe\_as} + Uncert_{\rho\_as} + Uncert_{dp\_as}\right)} = \sqrt{\left((0.5\%)^2 + (0.05\%)^2 + (0.12\%)^2\right)} = \sqrt{(0.25\% + 0.0025\% + 0.0144\%)} = \sqrt{0.2669} = 0.52\% \quad (21)$$

- 0.5 % with flow turn down 20:1 will be achieved using L range transmitter in addition to H range under CEESI test condition

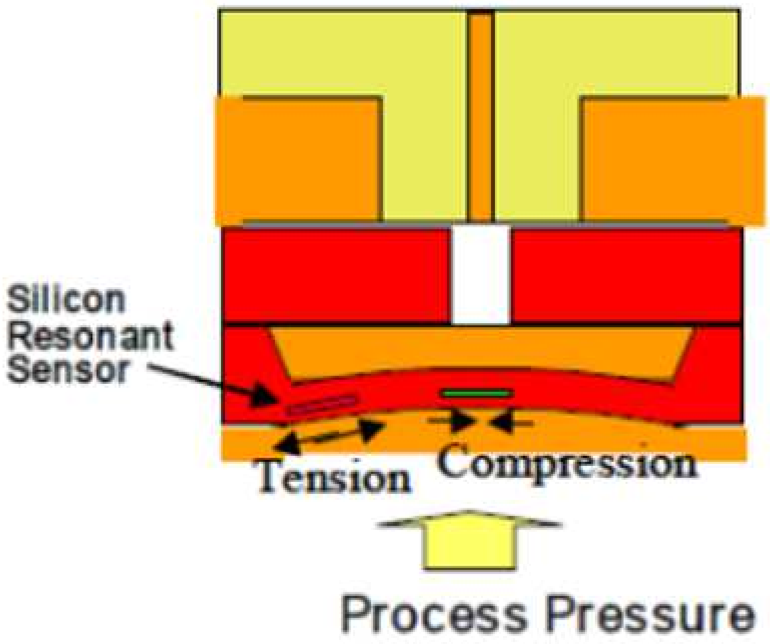
6. DP measurement contribution for flow measurement

- The EJX910 is designed with multi-sensing capabilities using built-in silicon resonant sensor technology
- The pressure sensor based on advanced silicon resonant sensor structure contributes to the flow measurement performance which realizes uncertainty 0.5% turn down 20:1 by multiple multivariable transmitters



6. DP measurement contribution for flow measurement: Pressure sensor structure

- Two resonators are incorporated into one sensor tip inside EJX910 using MEMS technology at the location of the silicon diaphragms
- Two resonators are located where tensile strain and compressive strain occur
- SP is simultaneously measured along with the DP by this one sensor tip



6. DP measurement contribution for flow measurement: Pressure sensor signal

- Changes (Δf^2) in resonance frequencies f1 and f2 of the two resonators due to the pressure

$$\Delta f_1^{\,2} = \Delta f_{01}^{\,2} \cdot G_{f1}(+\varepsilon_{dp1} + \varepsilon_{sp1}) \qquad (22)$$

$$\Delta f_2^{\,2} = \Delta f_{02}^{\,2} \cdot G_{f2}(-\varepsilon_{dp2} + \varepsilon_{sp2}) \qquad (23)$$

where

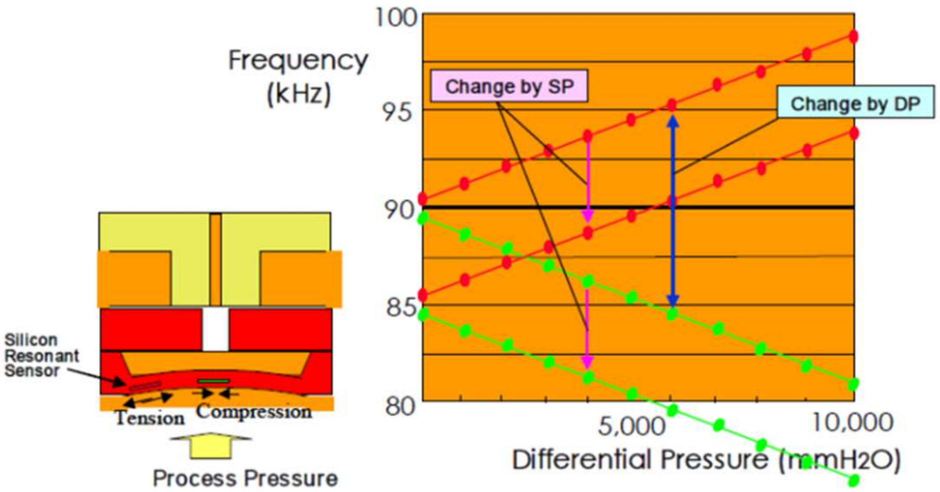
f_0 stands for the resonance frequency when the tensile force is zero

G_f stands for the squared sensitivity of the resonator (=0.2366・$(1/h)^2$)

h stands for thickness of the resonator

ε_{dp} stands for change in the tensile force due to DP

ε_{sp} stands for change in the tensile force due to SP



6. DP measurement contribution for flow measurement: Pressure sensor signal

- DP and SP change from equation 22 and 23

$$\Delta\mathrm{DP} = \Delta {f_1}^2 - a \cdot \Delta {f_2}^2 \quad \textbf{(24)}$$

$$\Delta\mathrm{SP} = \Delta {f_1}^2 + b \cdot \Delta {f_2}^2 \quad \textbf{(25)}$$

where

ΔDP stands for DP change

ΔSP stands for SP change

- DP and SP signals can be calculated by previously determining each coefficient from actual measured appropriate data
- EJX910 dynamically & continuously minimize the effect of SP fluctuation inside the transmitter

6. DP measurement contribution for flow measurement: Pressure sensor signal

- Provides precise DP measurement under real conditions which is explained
  - in equation (15): DP reference accuracy influence
    - From reference accuracy defined as ±0.04% of span

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{ref} = \mathbf{0.04\%} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{0.7\%} \qquad \mathbf{(15)}$$

    - From L range EJX910 test data at the factory

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{ref\_as} = \mathbf{0.005\%} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{0.09\%} \qquad \mathbf{(16)}$$

  - in equation (18): SP span effects influence
    - From SP span effects per 6.9 MPa (1000 psi) change defined as ±0.075% of span

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{span} = \mathbf{0.075\%} \times \frac{800\ psia}{1000\ psia} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{1.1\%}\ \mathbf{(17)}$$

    - From L range EJX910 test data at the factory

$$\left(\frac{\partial \Delta P}{\Delta P}\right)_{span\_as} = \mathbf{0.01\%} \times \frac{800\ psia}{1000\ psia} \times \frac{40\ inH2O}{2.2\ inH2O} = \mathbf{0.15\%} \qquad \mathbf{(18)}$$

6. DP measurement contribution for flow measurement: Pressure sensor characteristics

- a) EJX910 silicon resonant sensor is made of single crystal which is tetrahedral structure with strong bonding. It reacts ideal elastic deformation from outside force
- b) EJX910 pressure whole range measurement is conducted under elastic deformation state.
  - The deformation is proportional and uniform
  - The hysteresis is small
  - The two resonators deformation precisely match the theoretical Equation (22) and (23)
- c) Two resonators are incorporated into one sensor tip and the compensations (24) and (25) are achieved precisely

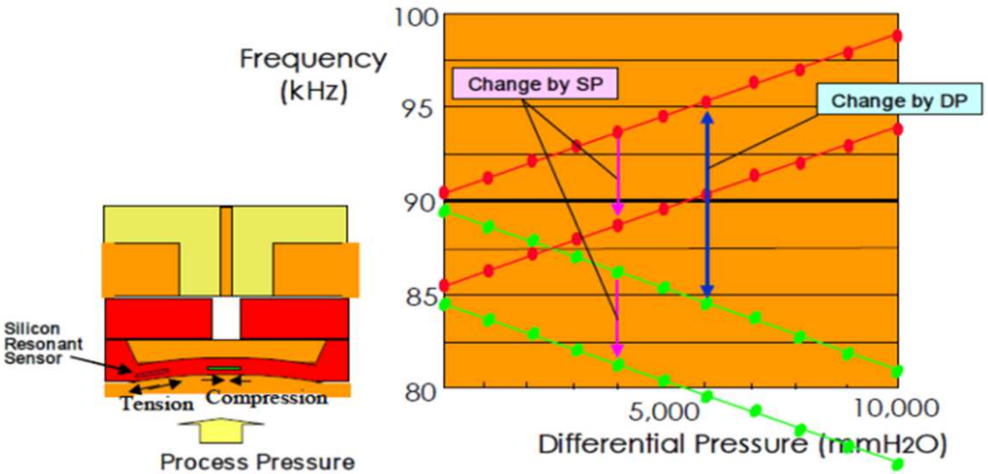
$$\Delta \mathrm{DP} = \Delta {f_1}^2 - a \cdot \Delta {f_2}^2 \quad \textbf{(24)}$$

$$\Delta \mathrm{SP} = \Delta {f_1}^2 + b \cdot \Delta {f_2}^2 \quad \textbf{(25)}$$

- d) The silicon resonant sensor is inside the vacuum cavity and the resonance is robust from outside disturbance

6. DP measurement contribution for flow measurement: Low DP measurement under high SP condition

- The two resonators signals are influenced by the DP and the SP
  - The resonators frequency shifts according to the DP and the SP changes
  - Keeping two resonators frequency relation
- The changes are proportional and uniform and the hysteresis is small
  - SP compensations of DP signal for whole ranges are achieved precisely
  - The uncertainty of the DP is small even at the condition of low DP under high SP
- EJX910 has an advantage of low DP measurement under high SP condition



7. CONCLUSION

- Combined DP flow meter VERIS Accelabar® flow primary element and Yokogawa EJX910 multivariable L range transmitter are analyzed
  - Adding EJX910 L range transmitter with H range transmitter, combined flow measurement turndown will be increased beyond 15:1 until 20:1 under 0.5% linearity with reference flow rate.
- EJX910 is designed with multi-sensing capabilities using built-in silicon resonant sensor technology
  - EJX910 dynamically & continuously minimizes the effect of SP fluctuation with two resonators incorporated into one sensor tip
  - Provides precise DP measurement under real conditions
  - EJX910 has an advantage of low DP measurement under high SP condition with built-in silicon resonant sensor technology
- These indicate the latest progress of DP flow meter technology
  - DP flow meter has still big potential for use in industry widely

- Thank you for your kind attention.