17th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2013, Istanbul, Turkey, 10-11 September 2013

CALCULATION OF MEASUREMENT UNCERTAINTY IN PROVING PROCESS OF CORIOLIS FLOW-METER

Emir Baralić
Energoinvest dd Sarajevo
Dr. Fetaha Bećirbegovića 35, 71000 Sarajevo
Bosnia and Herzegovina

Hazim Bašić
Faculty of Mechanical Engineering Sarajevo
71000 Sarajevo
Bosnia and Herzegovina

ABSTRACT
Recently, in the field of flow measurement, the mass flowmeters on the basis of Coriolis force appeared on the market. An everyday flow measurement is known problem of calculation between mass and volumetric flow and it is stressed in fiscal measurement especially in the oil industry. To get accurate mass units from volumetric, beside volumetric meter, it is necessary to include additional measurement apparatus for measurement of temperature, pressure, density and other variables. All mentioned parameters in continual flow process makes calculation harder and in many cases makes uncertainty higher. In this paper, results of proving of mass flow meter, already installed in refinery, are presented. In addition, basic of measurement uncertainty will be presented with the small in numbers of measurement passes. Also, basic information and short description about appearing of Coriolis force and basic information about Coriolis mass flowmeter will be given in.
Keywords: Flow measurement, Coriolis mass flowmeter, Measurement uncertainty.

1. INTRODUCTION
In situ testing means checking and verification of meteorological features (meaning accuracy, repeatability and stability) flowmeters and measuring systems in real work condition. It means, already installed flowmeter will be verified with working fluid and under working exploitation condition (flow, pressure, working and ambient temperature etc). In situ verification is the most desirable method as it proves the meter in its operating location and therefore indicates the meter's installed performance. There are a many different methods of in situ verification and this paper is based on verification of Krohne mass flow meter verified by Compact Prover as a Master meter approved by National Measurement Institution as a working measure etalon. Flow measurement is used for definding the energy and material balance, and acordingly on that basis the productivity of the production process is determined. At the same time, mostly the flow is a basic value used to manage of the production process.

2. CORIOLIS FORCE, SOURCES FOR UNCERTAINTY
Inertial force is a pseudo force (fictitious force), which occurs as a result of the complex motion of particle and is called the Coriolis force. It depends on the value of the transmission movement $\vec{\omega}_p$

and the relative movement $\vec{v}_r$ and is equal to double vector result $[\vec{\omega}_P, \vec{v}_r]$, it is vertical to the plane on which vectors lie, and has direction, seen from the top of the vector $\vec{a}_{cor}$, vector rotation $\vec{\omega}_P$, by the shortest route to the vector $\vec{v}_r$ can be seen in the opposite direction of rotation clockwise. Typical Coriolis meter, shown in Figure 1, consists of [3,4]:

- one or two parallel tubes through which the measured fluid flows,
- housing that protects pipes and strengthens the entire structure,
- impuls generator (electromagnetic exciter) which excites tubes to vibrate,
- two motion sensors which measure the relative velocity between pairs of tubes at two points equidistant from the center-symmetrical.

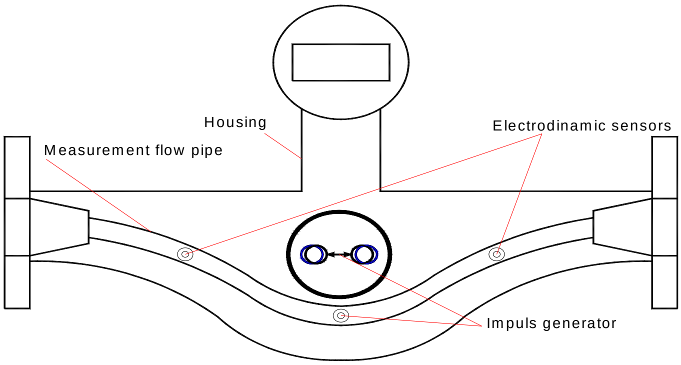

Figure 1. Typical construction of Coriolis flowmeter.

During the flow duration, movement of pipes caused by Coriolis forces $\vec{F}c = -2m[\vec{v}, \vec{\omega}]$, Figure 2, shall result in excitation and shift output sensors A and B which, in contrast to no flow condition, are not in phase with each other. The change in the mass flow will proportionally increase or decrease such shift in stages. Changes in the properties of fluids usually affect the flexibility / elasticity of the oscillating measuring tube. Zero drift between sensors, arisen during the calibration, can be modified by changing the initial parameters. The temperature and the pressure have the most significant effect on the mass flow measurement. The additional factors that may affect the performances criteria can be: the influence of stability of zero meters, gas trapped in the media, external vibration, erosive media properties, coats of paint or dirt inside the measuring tube and the like.

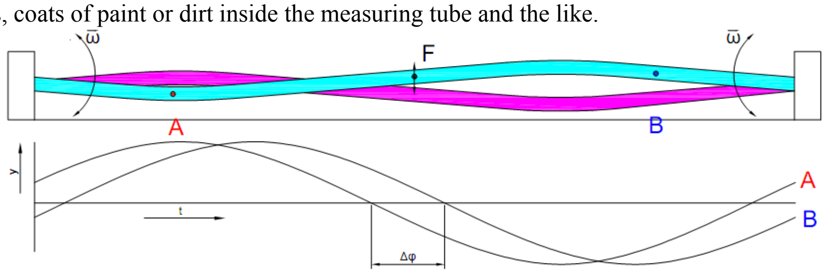

Figure 2. Coriolis meter with flow.

3. IN SITU TESTING AND ANALYSIS OF RESULTS

In the Refinery Pančevo, the new system for transferring LPG are designed, and consists of eight measurement points. Upon the meter is calibrated in the factory, installed in the skid, and then the skid is installed in the system, it is done in situ testing. Test phase, in other words, proving is possible in case when a higher class meter or “Master meter" is connected to the space provided for it. According to the diagram of Figure 3, there are two schemes showing normal measuring mode and proving mode. First one is without connection to the Master meter and the second one is presenting proving mode with schematic flow path through Master meter. When proving, differences can be occurred in the course of converting volume to mass, especially when the Master and main meter are different type of measuring principles (volume or mass flow). Equation which contains members of the meter factor is used for determination of repeatability, [4,7]:

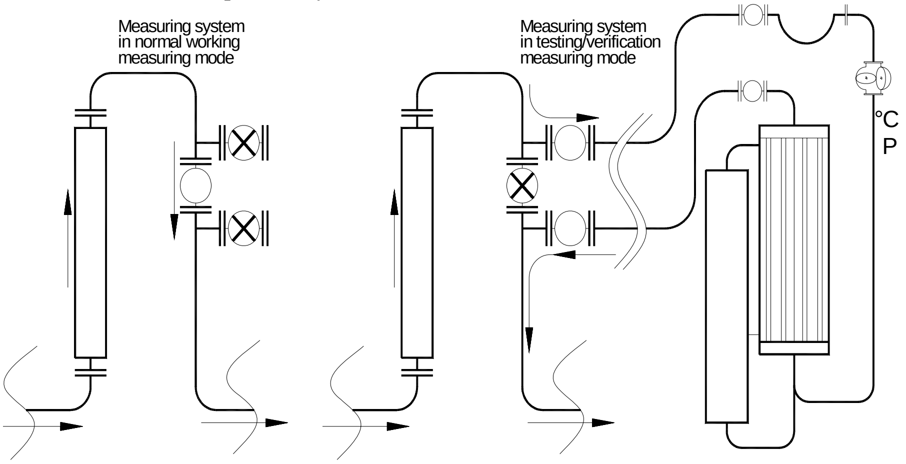

Figure 3.Normal and Proving measuring mode

$$Repeatability(\%) = \frac{MF_{MAX} - MF_{MIN}}{MF_{MIN}} \cdot 100 \tag{1}$$

In order to calculate the mass in a proper manner, it is required to know the density of the fluid. In any case, any prover, even of minimum configuration, has both measurement of pressure and temperature. By knowledge about fluid and its basic characteristics, with influence of pressure and temperature, coefficients that give density are obtained, and after that meter factors criteria is calculated. After that, the coefficients C_{tsp} and C_{psp} are calculated, the factors that depend on the prover material, impact of pressure and temperature, and have an impact on all measurement results. Individual meter factor is then calculated for each passage according to the equation, [4]:

$$MF_m = \frac{BVP \cdot C_{tsp} \cdot C_{psp} \cdot \rho_p}{\frac{Meter\ factor}{K - Faktor}} \tag{2}$$

Measurement uncertainty *E* when proving is calculated according to the equation [2,3,4]:

$$E = \sqrt{(E_{calref})^2 + (E_{prover\ cal})^2 + (E_{prover\ res})^2 + (E_{counter\ res})^2 + (E_{density})^2 + (E_{steel})^2} \tag{3}$$

In addition to the value of the relative error of measurement it is required to get uncertainty of the mean *C* if the number of measurements *n* is less than 25. Uncertainty *C* therefore depends on *t* factor (variable of Student's distribution) and on the number of repeated measurements, while the relative unreliability *c* presents the ratio of unreliability *C* and the mean [1,5]:

$$C_{(P=0,95)} = \pm t \sqrt{\frac{1}{n(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{4}$$

- x_i measured value,
- $\bar{x}$ the arithmetic mean.

If in this case introduce an expanded uncertainty, with a maximum uncertainty of the prover *E* the following equation shall be applied [1]:

$$x = \bar{x} + u = \bar{x} \pm (|C| + |E|) \tag{5}$$

The relative measurement errors, according to the calibration certificates, for the number 1 measuring spot, after typical flow rates are presented in Figure 3, [6]. Green triangles indicate the maximum deviation of the factors scales between passages in one set, and the maximum allowed of 0,05%. Scale factor values are shown in the blue rhombus.

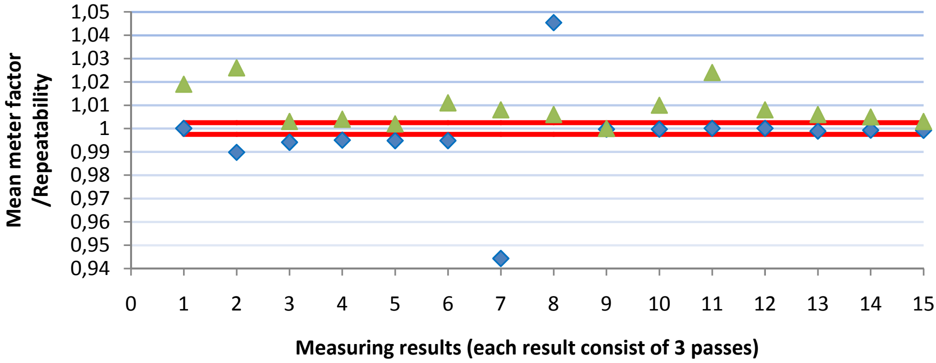

Figure 4. Scale factor / repeatability related to the measurement result.

Based on 15 measurement results, each of them having 3-passes metering piston, satisfactory results that are later taken into account when calculating the uncertainty of measurement scales were got. Measurement results with uncertainty are calculated as:

Mean mass value of three results accepted, (kg)	133,5032
Mean measurement uncertainty of three results accepted, (kg)	0,0969
Result may be expressed in form	133,5032 kg ±0,0969 kg

4. CONCLUSION

This paper shows an example of calculating measurement uncertainty during in situ testing of flowmeters. The most important influences on measurement error, such as changes in temperature and pressure are listed here. In the oil industry, within the measured media a mix of gas and liquid phase may be occurred, which can lead to inaccurate measurements. In addition to these effects, different vibrations may be a common cause of uncertainty measurements. Together with other influences, some inaccurate measures during the measuring can be occurred, and the main goal is to identify the same and to find solutions for their reduction and elimination. To approve using flowmeter in certain measuring system, in situ testing is most accepted method in today praxis. For measurement uncertainty calculation, Student factor is used. Results obtained on this way confirmed producers references that the accuracy is lower than ±0,1% of measured value, as well as requirement of OIML standard with its requirements better than ±0,2%. Basic equation for uncertainty calculation is based on the book issued by Emerson company, one of the leading in production of mass flow meter based on the Coriolis force.

5. REFERENCES

[1] Seferović E., Bašić H.: *"Osnovi metrologije i obrade rezultata mjerenja"*; Mašinski fakultet Sarajevo, 2005, ISBN-9958-601-10-9

[2] BIPM / OIML / IEC / ISO / IFCC: *"Expression of the Uncertainty of Measurement in Calibration",*

[3] Endress+Hauser: *"Flow Handbook"*; Enders+Hauser Flowtec AG, CH/Reinach/BL, 2004, ISBN-3-9520220-4-7,

[4] Micro Motion: *"Proving Coriolis Flowmeters"*; Fisher-Rosemount, Colorado, 1998,

[5] OIML: *"OIML R 117-1 Dynamic Measuring Systems for Liquids Other Than Water"*; 2007,

[6] Baralić E., Bašić H.: *"Istraživanje uticajnih parametara na mjernu nesigurnost Coriolisovih mjerila masenog protoka u eksploatacionim uslovima"*; Magistarski rad, Mašinski fakultet u Sarajevu, 2013,

[7] Diering M., Pajzderski P.: *"The &R&R Index - Proposals and Guidelines on the reference value and acceptance criteria"*; TMT 2012, Istanbul, Turkey