

An Automated Test and Measurement System for Calibration of Industrial Flowmeters

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Abstract –This paper presents a low-cost test and measurement system that can be used to test and calibrate industrial liquid flowmeters. Different flowmeter types, with different working principles, from different manufacturers, can be easily installed and calibrated in a flexible way. The implemented prototype includes a software component that is tailored for laboratory test and calibration of volumetric or mass flowmeters. The final part of the paper includes several simulation and experimental results.

Keywords –flow measurements, calibration, virtual instruments, linearization

I. INTRODUCTION

Flow measurement is a topic of major importance in every industrial processes, particularly when the transportation of fluids and the evaluation of energy dissipation, associated with eddies in turbulent flows, is required. Only regular calibrations can assure that flowmeters' measurements are accurate. However, calibration of flowmeters cannot avoid errors that result from process conditions, namely fluid characteristics variations, and fluid velocity profile variations inside the pipes. Thus, in every industrial plant, it is very important to assure a regular calibration of flowmeters and to develop laboratory solutions for test and calibration of those devices. The proposed prototype fulfills this aim and provides a flexible platform to test and calibrate different types of flowmeters that can used different normalized communication signals, namely, current loop signals, voltage signals, frequency or PWM modulated signals, HART [1-2] or fieldbus digital signals [3].

II. RELATED RESULTS IN THE LITERATURE

As a matter of fact, there are some commercial solutions to test and calibrate flowmeters [4-6] but those solutions are typically very expensive and, above all, they are turnkey solutions with low flexibility and without access to measurement data for data processing purposes, which is particularly important when the calibration of

different type of flowmeters, from different manufacturers, is required.

III. DESCRIPTION OF THE SYSTEM

The proposed flowmeter test bench includes an orifice based flowmeter, an electromagnetic flowmeter and a Coriolis flowmeter. Combining electro-valves open and close status, several fluid network configurations can be implemented. In the proposed prototype, a number of 11 different associations, between flowmeters, can be implemented.

A. Hardware part

Figure 1 represents the flowmeter test bench that, as previously referred, includes an orifice based flowmeter [7], an electromagnetic flowmeter [8], and a Coriolis flowmeter [9]. The system also includes an hydraulic pump and an inverter that is used to control the flow rate intensity. In order to measure the fluid volume inside the tank, a low cost gauge pressure sensor is used [10]. From the pressure measurement it is possible to obtain the fluid height inside the tank, whose value is given by:

$$h = \frac{p}{\rho \cdot g} \quad (1)$$

where p represents the measured pressure, ρ represents the fluid's specific mass, approximately 1000 kg/m^3 for water, and g represents the gravity acceleration value. Being the geometry of the tank well known, and performing the level measurements within its cylindrical portion, it is possible to obtain the average value of the volumetric flow, during a given interval of time (Δt), using the following relationship:

$$(Q_V)_{av} = \frac{\pi \cdot D^2}{4 \cdot \rho \cdot g} \cdot \frac{\Delta p}{\Delta t} \quad (2)$$

where D represents the tank diameter, Δp represents the tank pressure variation that occurs during Δt , and the other variables have the same meaning that was previously defined.

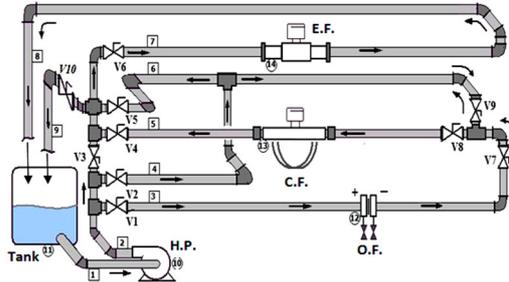


Fig. 1. Flowmeter work bench piping diagram (H.P.- hydraulic pump; O.F.- orifice flowmeter; C.F.- Coriolis flowmeter; E.M.- electromagnetic flowmeter; V- ball valves).

B. Software part

The LabVIEW graphical programming language [11] was used for data processing and HMI purposes. Measurement data from the three flowmeters is filtered and converted to engineering units according to the measurement range of each flowmeter. Conventional 4-20 mA current signals or HART data streams [1] can be used to exchange measuring and configuration data with the different flowmeters. The inverter voltage that controls flow rate is normalized between 0 and 100% that correspond to the minimum and maximum values of the flow rate delivered by the hydraulic pump, respectively. A software implemented PID controller was used to optimize the response of the flow rate variations relatively to different hydraulic pump set-point variations. The proportional, integral and derivative gains of the PID controller can be manually or automatically adjusted according to the dynamic characteristics of the measurement system. Graphical representations of the measurement results are visible in real time and statistical results of measurement errors, for each flowmeter, can be accessed after data processing of the measurement results. Calibration results can be obtained using a reference flowmeter or using the pressure sensor data (1). Figure 2 depicts the LabVIEW front panel of the flowmeter test and calibration system.

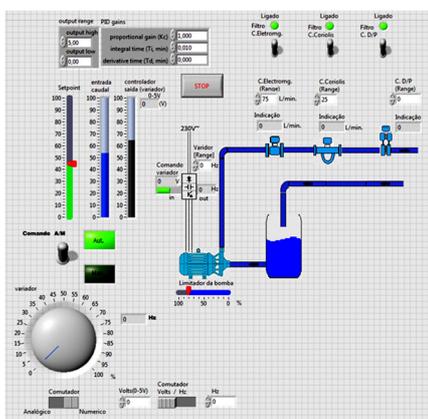


Fig. 2. LabVIEW front panel of the flowmeter test and calibration system.

The system software also includes a set of HART routines that are used to configure and extract measurement data from the flowmeter devices. The communication with the HART transmission line is supported by a low cost HI311 interface [12].

IV. EXPERIMENTAL RESULTS

Several tests were performed in order to test the performance of the proposed measurement and calibration system. In the final version of the paper additional results will be included for the electromagnetic and Coriolis flowmeters.

A. Orifice

In order to characterize the orifice flowmeter, the differential pressure, between its high and low pressure taps, for different flow rates, was measured. The differential pressure transmitter was calibrated for an upper range value (URV) equal to the upper range limit (URL) and to an URV equal to URL/2, being the turn down factor equal to 1:15 for both measuring ranges. Figure 3 represents the experimental results that were obtained when the flow rate varies between 2.5 and 30 l/min with increments of 0.5 l/min.

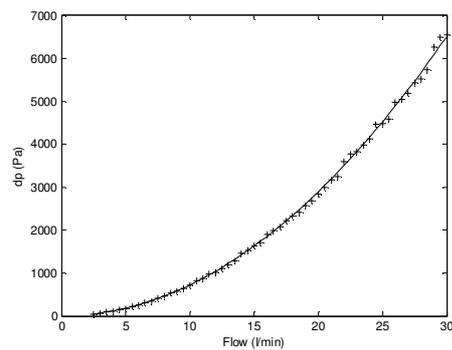


Fig. 3. Variation of the pressure loss in the flowmeter orifice as a function of flow rate.

Using the MATLAB least mean square (LMS) nonlinear curve-fitting function, the following orifice parameters were obtained: $C_F=0.73$ and $A_0=0.3$ square inches, being the evaluated specific mass of the fluid (ρ) equal to 1032 kg/m^3 . The maximum deviation between experimental and expected theoretical values of the flow rate is lower than 2% and the estimated orifice area is almost 5% lower than its theoretical value. The deviation between experimental results and theoretical expectations are acceptable considering the errors of the measurement instruments, the variations of the fluid Reynolds number and also the errors caused by the variations of the position of the orifice vena contracta relatively to orifice pressure taps that are always associated with flow rate instabilities.

B. Calibration results

The calibration procedure is based on the average value of volumetric flow measurements, during a time interval of 10 minutes. The fluid volume that crosses the flowmeters is evaluated using the pressure sensor measurement data (1). The main characteristics of the pressure sensor includes a pressure measuring range that varies between -50 to +50 mm Hg, a nominal sensitivity of 40.0 mV/mm Hg, a linearity error of 0.80 % and a hysteresis plus repeatability errors lower than 0.15 % relatively to the span measuring range. For a series association of the three flowmeters, figures 4 and 5 represent the flow measurements results and the absolute measurement error, respectively, when the inverter frequency varies between its minimum and maximum values. Regarding measurement results, it can be underlined that the maximum value of the absolute error is lower than 0.25 l/min which corresponds to a relative error lower than 2 % of the maximum flow rate. The maximum error value, that is associated with the orifice based flowmeter, is within the typical error range values that are associated with this type of flowmeters [13-16], plus other additional errors such as the ones that are caused by fluid profile distortions, upstream and downstream piping bends and flow rate instabilities.

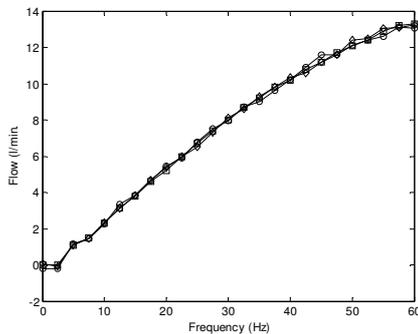


Fig. 4. Flowmeter measurement results as a function of the inverter frequency (square symbol- electromagnetic flowmeter; diamond symbol- Coriolis flowmeter; circular symbol- orifice based flowmeter).

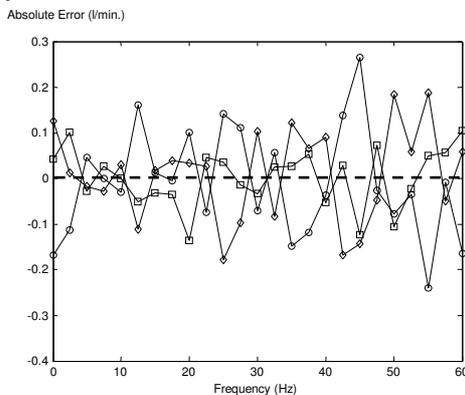


Fig. 5. Calibration errors results (square symbol- electromagnetic flowmeter; diamond symbol- Coriolis flowmeter; circular symbol- orifice based flowmeter).

Calibration can also be performed using the comparative method taking one of the three flowmeters, previously calibrated, as a reference meter.

C. Post-processing of calibration data

From the calibration results it is possible to perform the linearization of the flowmeters' characteristics as well as to compensate offset and gain errors. Regarding linearization, a typical linearization requirement in flow measurements is related with the square root dependence that exists between flow rate and pressure drop in orifice flowmeters. The software routines that were developed can perform easily this linearization using the inverse function linearization method [17-18]. Using the experimental results that were obtained with the orifice flowmeter, namely the relationship that exists between pressure drop and flow rate, it is possible to linearize the orifice flowmeter characteristic using the following relationship:

$$Q_V = 14.81 \cdot \sqrt{V_T - 0.873} \quad (3)$$

where Q_V represents the volumetric flow in liters/min and V_T represents the voltage drop in a 250 Ω resistor inserted in the current loop of the pressure transmitter, whose output current varies between 4 and 20 mA when the orifice pressure drop varies between 200 and 6500 Pa, respectively.

It is important to underline that this software linearization procedure avoids the usage of the well-known square-root extractor and associated signal conditioning circuits.

D. Measurement uncertainty

Regarding measurement uncertainty, it is important to underline that the main influence factors that affect its value include not only the uncertainties associated with the flowmeter, itself, but also the influence factors caused by fluid compression, errors associated with flow volume evaluation, based on level measurements, variations of fluid density and fluid rate stability during the calibration runs. In order to evaluate the uncertainty of flow rate measurements, the statistical distribution of flow was obtained from a series of measurements (type A evaluation of measurement uncertainty) [19]. Using, for instance, the electromagnetic flowmeter, configured for the measuring range between 5 and 50 l/min, and adjusting the inverter frequency to obtain a constant flow of 25 l/min, figure 6 represents the histogram of a series of 256 flow measurements.

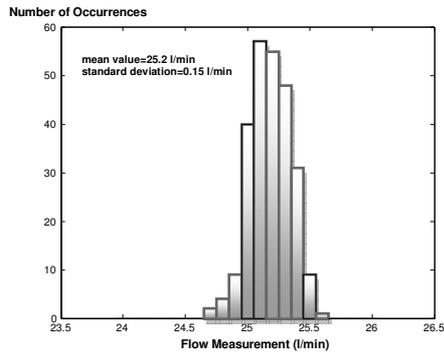


Fig. 6. Electromagnetic flowmeter uncertainty for a series of 256 measurements with a nominal flow rate of 25 l/min.

From the measurement results, it is possible to conclude that the expanded uncertainty of the measurements is almost three times the standard uncertainty of the flowmeter measurements ($\pm 0.25\%$ of velocity rate) and that the mean value of the flow rate has a relative offset deviation of 0.8% from the nominal flow rate.

V. NOVELTIES IN THE PAPER

As main novelties of the proposed automated test and measurement system for calibration of industrial flowmeters, it can be underlined its flexibility and capability to define different calibration and test procedures. The testing configuration can be easily modified using remotely controlled electro valves and the dynamic response of each flowmeters can be analyzed applying different voltage profile variations to the input of the inverter that controls the hydraulic pump. A large number of software routines can be developed to extend the basic features of the flowmeters, without additional costs. These routines can include, for example, filtering of measurement data, engineering units conversions, totalization of flow measurements, and compensation of influence variables effects.

VI. CONCLUSIONS

This paper presented a low cost automated and measurement system for the calibration and testing of industrial flowmeters. Since the system includes a hydraulic pump controlled by an inverter, different flow profile variations can be tested in order to obtain the dynamic characterization of the devices under test. The testing and calibration results, based on pressure measurement or previously calibrated flowmeters, presented low deviations between theoretical expectations and experimental results, being these deviations acceptable considering flowmeters' measuring errors and flow stability conditions.

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