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(Article begins on next page)

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Flow Rate Test Bench: Automated and Compliant to ISO Standards

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Abstract

The issue of measuring the flow rate through a pneumatic component is a critical one. Several methods exist, each with its own pros and cons regarding the type of gas, measurement range, and accuracy.[1] ISO Standards, however, consider only a few of them: orifice plates, nozzles, Venturi nozzles, Venturi tubes.[2–4] Although amenable to possible criticism, the International Organization for Standardization is an important reference. Designing a test bench according to its Standards is often more than reasonable: advantages include certification, assessment of test methods and accuracy, worldwide recognition. On the other hand, however detailed the Standards may be, they often lack the designer's (and perhaps the user's) point of view. This aspect leads to complicated realizations, low usability or long test execution times. This article proposes a flow rate test bench compliant to ISO Standards allowing a partially automated testing, rational installation, high configurability, user-friendliness, and accuracy.

Introduction

Over 4000 years ago, the Romans measured water flow from their aqueducts to each household to control allocation. The early Chinese measured salt water to control flow to brine pots to produce salt used as a seasoning. In each case, control over the process was the main reason for measurement. Flow measurement for the purpose of determining invoices developed later.

Nowadays, the main reasons for performing flow measurements remain basically the same: process control and/or determination of consumptions. Depending on the application, the process may require a certain accuracy, measurement range and may have additional limitations and constraints. The other side of the coin is the cost of the measuring device and of the measuring process itself.

Moreover, the fluid flow type is crucial in the choice of the flow meter. Several characteristics are involved and the designer should examine each fluid of interest to determine if: (1) it is evaporating or condensing; (2) has well-defined pressure, volume, temperature relationships, or density; (3) has a predictable flow pattern based on Reynolds number; (4) is Newtonian; (5) contains no foreign material that will adversely affect the flow meter performance (e.g., solids in liquids, liquids in gas); (6) has a measurable analysis that changes slowly with time.

The flow should also be examined to see if it: (1) has a fairly constant rate; (2) has a non-swirling pattern entering the meter; (3) is not two-phase or multiphase at the meter; (4) is non-pulsating; (5) is in a circular pipe running full; (6) has provision for removing any trapped air (in liquid) or liquid (in gas) prior to the meter.[5]

Certain meters may have special characteristics that can handle some of these problems, but they must be carefully evaluated to be sure of their usefulness for the fluid conditions. Measurement can usually be accomplished with any one of several meter systems, but certain meters have earned general acceptance for specific applications based on their characteristics. This is an important factor in choosing a meter: reference to industry standards and users within the

industry are key points to review in choosing the best meter for a given application.

There is a wide spread of flow meters to choose from for a specific application. It is estimated[6] that more than a hundred flow meter types are commercially available, and new ones are continuously introduced. Generally speaking, they may be divided into two families: differential producers and linear flow meters.

Differential producing flow meters have a long history and probably still are the most used class of flow meters. They consist in the insertion of a contraction in the fluid flow so to create a pressure drop. According to Bernoulli's streamline energy equation, the pressure difference between the taps located at the full upstream pipe section and in the vicinity of the contraction is related to the difference of the squares of the velocities at those sections, to fluid properties and to the abruptness of the contraction. Since the velocity times the pipe area is the volumetric flow rate, the basic flow equation may be written as:

$$q = k \cdot \sqrt{\frac{\Delta p}{\rho}} \qquad (1)$$

where q is the volume flow rate, Δp the pressure drop between the taps, ρ is fluid density, and k is a constant.

Differential producers include orifice plates, Taylor wedges, Venturi tubes and nozzles, elbows, Pitot tubes, and several other variations.

On the contrary, linear flow meters measure the fluid trying to alter it as little as possible. The turbine flow meter has a rotor speed linearly increasing with flow velocity. The vortex flow meter is based on vortex shedding around a bluff object at a frequency linearly proportional to velocity. Variable-area meters, such as rota meters, consist in a vertical tube through which the fluid moves upward: a conical float creates an annular passage between itself and the wall of the tube; as the flow varies, the equilibrium position of the float changes yielding a measure of the flow rate. Numerous other methods exist, involving such principles as magnetic induction, ultrasounds, Coriolis acceleration, hot-wire fluid heating, etc.

ISO Standards

Generally speaking, ISO Standards are a worldwide recognized means of establishing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, in order to ensure that materials, products, processes, and services are fit for their purpose. Although it can be remarked that ISO is very strict in its regulations

and sometimes lacks open-mindedness and rapidity in the acceptance of technical novelties, on the other hand it works on documented agreements, allowing to design certifiable measurement processes, and test benches. This gives the user a provable degree of certainty about the validity of the measurement, permitting them to rely not only on competence and experience but also on established rules and guidelines which may be easily checked.

In the matter of fluid flow measurement, where variables and possibilities are numerous, it can be useful to follow an appropriate ISO Standard if applicable. In particular, ISO 5167: Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full[3]; consisting of four parts, covers the geometry and method of use (installation and operating conditions) of orifice plates, nozzles, and Venturi tubes to determine the flow rate of the fluid flowing in a conduit. It also gives necessary information for calculating the flow rate and its associated uncertainty. ISO 5167 is applicable only to pressure differential devices in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase, but is not applicable to the measurement of pulsating flow. Furthermore, each of these devices can only be used within specified limits of pipe size and Reynolds number.

While those limitations may not suit some industrial applications, they can be fulfilled by a laboratory test bench using dry compressed air for the measurement of flow rate characteristics of pneumatic components. This test bench, including the differential device according to ISO 5167, may be further specified by another Standard: ISO 6358, Pneumatic fluid power—Components using compressible fluids—Determination of flow rate characteristics,[2] which covers the subject of flow measurement specifically for pneumatics and provides a broader look on the test bench design, giving criteria and rules to obtain reliable measurements.

In particular, ISO 6358 specifies a method for testing pneumatic fluid power components which use compressible fluids, that is gases, to enable their flow rate characteristics under steady-state conditions to be compared. It specifies requirements for the test installation, the test procedure, and the presentation of results. It does not apply to components exchanging energy with the fluid (gas), for example cylinders, accumulators, etc.

Practically speaking, ISO 6358 provides guidelines for the design of the test bench as a whole, and

for the analysis of the results in order to evaluate the characteristics of a given component under test. On the other hand, ISO 5167 covers flow meters, providing installation drawings and constraints. It also gives rules and equations for flow rate calculation.

However, it is important to underline that ISO 6358 by itself does not provide any information or requirement for the flow rate measuring device, nor does it make any reference to ISO 5167. This makes it possible to stay within the borders of ISO 6358 while choosing a flow meter different from those covered by ISO 5167, possibly leading to poor accuracy and inadequate results. This article aims at a better integration between the two Standards, making a further step forward towards the automation of the testing process.

In fact, the procedure described in the Standards requires time and care by a trained technician, closely respecting all the constraints in order to obtain reliable results. The intrinsic physical characteristics of flow rate measurement and the number of quantities involved make the process lengthy, complicated, and at risk of error.

In particular, with a manual test set up according to ISO 6358, whose scheme is shown in Fig. 1, the main problem is the fact that the tests should be made keeping the pressure upstream the component G constant, while the pressure regulator B is not immediately upstream of it; therefore every increase of fluid flow destabilizes the proportionality between pressure control and actual pressure upstream of the component, calling for successive regulations as follows:

1. While the downstream flow control valve K is closed, act on the pressure regulator B so that the pressure upstream of the component G, measured through I, is as desired.
2. Slightly open the flow control valve K; a greater fluid flow increases the pressure drop in all components, in particular in those between the pressure regulator B and the component G.

3. Act on the pressure regulator B so that the pressure upstream of the component, measured through I, is again within the tolerance prescribed by the Standards.
4. Record all the quantities involved, in particular those necessary to calculate the flow rate.
5. Repeat from 2 to 5 until the flow control valve K is completely open.
6. In case, repeat with a different upstream pressure.
7. Execute the calculations necessary to evaluate the flow rate and the relative uncertainty for each point acquired.

It is clear that this procedure would be greatly benefited by a partial automation of the testing sequence, in particular as regards upstream pressure set up and regulation, flow control valve actuation, data acquisition and analysis. In the following, this article will try to provide aid and guidelines towards that goal.

Flow Rate Test Bench

As mentioned before, by measuring flow rates manually it is possible to run into complications and continuous adjustments of the upstream pressure, making it a long process which may even be subject to human error.

In order to make flow rate measurements fast, simple, accurate, and as free as possible from human errors, at the University ''Politecnico di Torino,'' Department of Mechanics, a flow rate test bench has been designed and built. It complies with ISO Standards and it works in a partially automatic way, providing the user with continuous information and visual aids in order to perform data acquisition as efficiently and comfortably as possible. Figure 2 shows the scheme of the test bench, which is composed of the following components:

A: 3/2 valve to supply and vent the system,

F: filter,

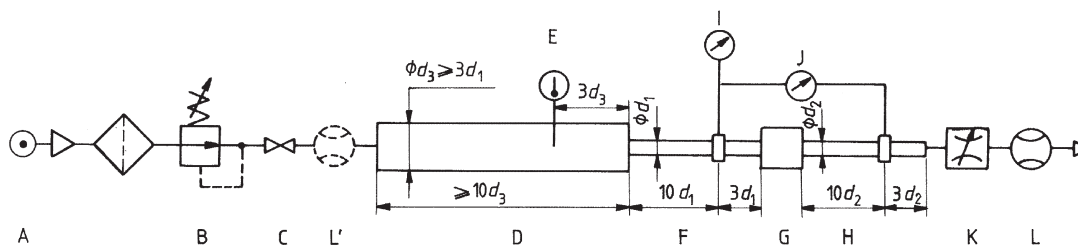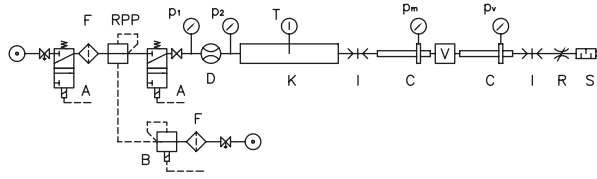RPP: pressure regulator coupled with the pilot electro-valve B,

**Figure 1** Flow rate test circuit according to ISO 6358.

Figure 2 Scheme of the test bench at Politecnico di Torino.

D: orifice plate,

p_1: orifice plate upstream pressure transducer,

p_2: orifice plate downstream pressure transducer,

K: pipe for temperature measurement,

T: air temperature transducer,

I: Cam Lock,

C: pressure measurement tubes (according to ISO 6358),

V: pneumatic component under test,

p_m: transducer for the upstream pressure of the component under test,

p_v: transducer for the downstream pressure of the component under test,

R: flow control valve,

S: silencer/exhaust.

The system is composed of four parts (Figs. 3 and 4): test bench control, air flow measurement system, component under test, and user interface.

The test bench control, shown in Fig. 3, allows the electrical and pneumatic supply and is made of: pneumatic valves (1) (upstream exhaust valve, filter, proportional pressure valve, downstream exhaust valve), the electrical panel (2), the control system for valves and transducers (3).

The flow measurement system consists in a pressure differential device (6) of the orifice plate type (with internal diameter d) inserted into a circular cross-section conduit running full (internal diameter D). By
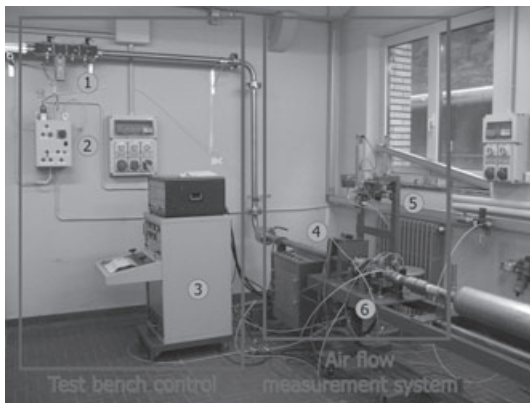
Figure 3 Test bench: upstream part.

Figure 4 Test bench: downstream part.

using orifice plates of different diameters, it is possible to improve the measurement accuracy through the flow rate range of the bench. Moreover, the test bench allows automatic substitution of the orifice plate (5). Figure 4 shows the point where the component under test must be positioned, before the silencer.

The International Standard ISO 5167 establishes the allowed ranges of diameters d and D, pipeline length L, diameter ratio β $(\beta = d/D)$ and Reynolds number Re_D (referred to diameter D) in order to achieve correct working conditions for the flow rate measurement device.

The control system allows the test bench management, thanks to an input/output digital/analogue board coupled with a personal computer. This permits data acquisition from the transducers (orifice plate upstream and downstream pressure; temperature; component upstream and downstream pressure) and provides the reference pressure value to the upstream proportional valve.

A data acquisition board (National Instruments PCI 6035E), connected to the personal computer is the interface between the transducers and the bench control system. Calibration of the sensors is possible through the software of the board.

Flow Rate Calculations

The acquisition system developed performs automatic calculation of the flow rate. It may be useful to recall the associated equations. In particular, the mass flow rate q_m is:

$$q_m = \frac{C}{\sqrt{1 - \beta^4}} \cdot \varepsilon \cdot \pi \frac{d^2}{4} \cdot \sqrt{2 \cdot \rho \cdot \Delta p} \qquad (2)$$

where $\Delta p = p_1 - p_2$ is the pressure drop through the orifice plate, ρ the air density (as a function of p_2 and T), $\beta = d/D$ the diameter ratio, C the parameter that is a function of the Reynolds number and the system geometry, and ε is the expansion factor, function of β, p_1 and p_2.

Through the following equation, it is possible to calculate the volume flow rate q_v:

$$q_V = q_m/\rho \qquad (3)$$

while the volume flow rate q_N in standard reference conditions ANR[7] is:

$$q_N = q_m/\rho_N \qquad (4)$$

where ρ_N is the density referred to standard reference conditions (20°C, 101325 Pa, 65% relative humidity). The flow rate is calculated in an iterative way because the associated formula is not linear.

Test Procedure

The connection of the component under test is made through a Cam Lock system realized according to Standard A-A-59326 (former MIL-C-27487).[8] It is also suitable for large components thanks to flexible connecting pipes.

The acquisition/control program requires to set the ambient pressure and to verify the choice of the orifice plate. It has been conceived and realized in order to allow the operator to interact with an intuitive, rapid, and almost automatic system.

Figure 5 shows the graphical interface for the data acquisition procedure. First, with the switch positioned on ''Setup'' the operator establishes all variables and parameters for the test, starting from the reference pressure upstream of the component under test (1); this pressure is automatically regulated by a closed-loop control, compensating flow effects. When the desired pressure is reached within 2% tolerance the indicator (2) turns green and data acquisition is enabled. This automatic check prevents the operator to collect inconsistent data, guaranteeing that the acquisition is performed at the pressure desired, within the tolerance defined by the Standards.

Two displays show upstream p_m (3) and downstream p_v (4) pressures referred to the component. Also the upstream pressure of the orifice plate p_1 (5) and the relative pressure drop Δp (6) are continuously monitored and measured. The button (7) allows the reset of the flow rate. On the bottom of the figure, it is possible to see the air temperature (8), needed
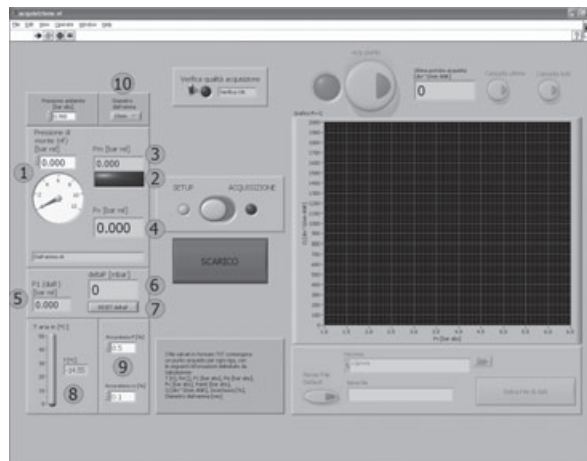

Figure 5 Setup screen of the measurement system.

for flow rate calculation, and the accuracy settings of the transducers, in case they are substituted (9).

To start the acquisition process, the operator changes the middle switch to ''Acquisizione'' position (acquisition). During this phase, all the ''Setup'' controls are greyed out to keep the test conditions constant.

By opening the flow control valve (R in Fig. 2), the component upstream pressure decreases, therefore the test bench control system automatically regulates the upstream pressure keeping it at the predefined setup value. The opening of the flow control valve must be gradual, step by step: only when all pressures and the flow rate are steady it is possible to acquire the measure by pressing a button. In this way, keeping the upstream pressure constant, the flow rate is a function of the downstream pressure.

In Fig. 6, it is possible to notice: the acquisition button (1), the graph showing the acquired flow rate values (2), and the led indicating the ''quality'' of the measurement (3), turning green and allowing acquisition when the following conditions are satisfied:

- $p_2/p_1 \geq 0.75$, otherwise a warning appears asking to substitute the orifice plate (from ISO requirements),
- the statistical control on the variance of the pressure drop through the orifice plate is below a defined threshold (from ISO requirements),
- regulated upstream pressure is within 2% of the desired value (from ISO requirements),
- $\Delta p > 70$ mbar, otherwise a ''substitute orifice plate'' warning appears because the differential pressure transducer limit is reached.
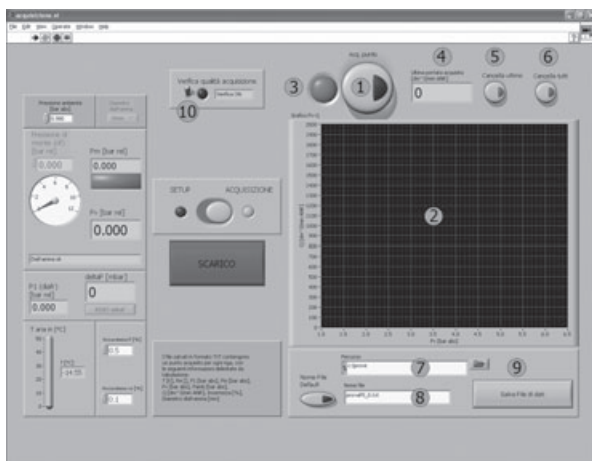
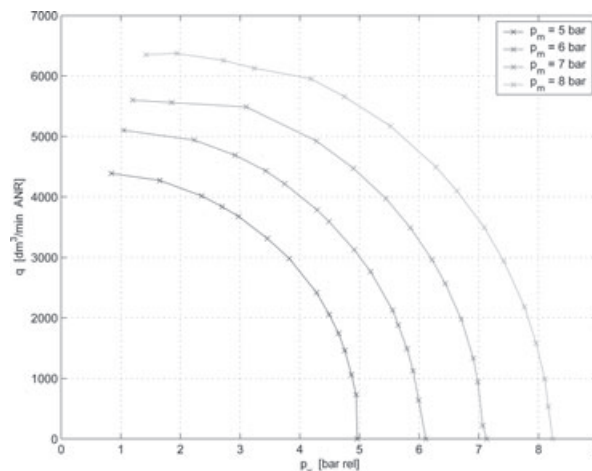**Figure 6** Graphical user interface for data acquisition.

Figure 7 Example of the flow-rate curves.

In case of particular tests, by activating the switch (10), it is possible to inhibit those checks and proceed to the acquisition in any case.

Next to the acquisition button there is a display showing the last measured value (4), a button to delete it (5), and a button to delete all acquired data (6).

Opening the flow control valve step by step, a certain number of points are acquired. Finally, the condition in which the flow control valve is completely open is reached. Then, if it is necessary for the specific test being run, the operator proceeds by gradually closing the flow control valve and performs the acquisition again. In this way, the hysteresis of the component under test can be observed.

Following this procedure, it is possible to obtain the points describing flow rate as a function of the downstream pressure for a given upstream pressure; an example of those data is shown in Fig. 7 for four different upstream pressures p_m.

The experimental data can be saved on a text file by using the commands (7), (8), and pushing (9) of Fig. 6. The file saves tab-delimited data to allow elaboration using other programs.

Another graphical interface (Figs. 8 and 9) allows a built-in post-processing of the data, providing:

- the visualization of the flow rate acquired curves, which can also be compared with one another,
- the normalization of the acquired curves,
- the calculations of the sonic conductance C and critical pressure ratio b,
- an HTML file with graphs and results selected by the user.

The buttons from (1) to (5) allow selecting and opening up to eight files in order to visualize the
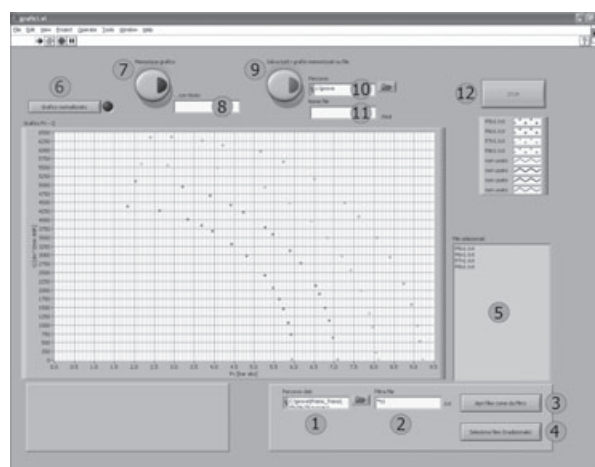

Figure 8 Post-processing user interface.

curves in the same graph to make comparisons. On the right, a legend identifies the different curves.

The button ''Normalized graph'' (6) allows showing no longer the flow rate q_N as a function of the downstream pressure p_v, but the normalized flow rate defined as:

$$\tilde{q}_N = \frac{q_N}{p_m\sqrt{\frac{T_N}{T}}} \tag{5}$$

as a function of the pressure ratio:

$$\tilde{p}_v = \frac{p_v}{p_m} (6) \tag{6}$$

where $T_N = 293.15$ K is the absolute reference temperature ANR.[7]

The normalized flow rate allows to separate flow characteristics such as upstream pressure and
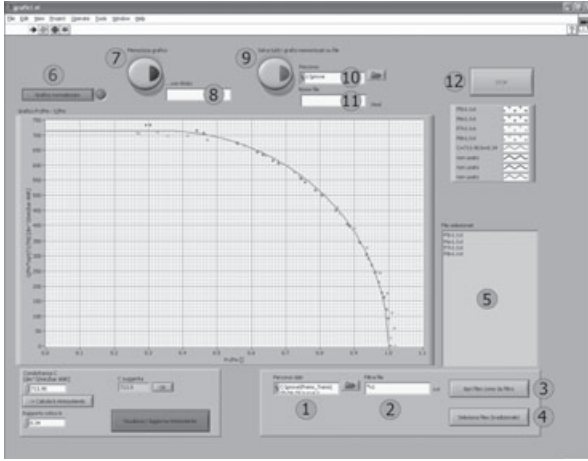
Figure 9 Normalized curves with flow coefficients C and b.

temperature from those that are intrinsic to the component under test, which can be studied, for instance through the flow coefficients: sonic conductance C and critical pressure ratio b as defined in ISO 6358. The effect is that by using the normalized flow rate all acquisitions, even at different pressures and temperatures, tend to lay on the same curve, because of[2]:

$$q_m = C{\cdot}p_m{\cdot}\rho_N{\cdot}\sqrt{\frac{T_N}{T}} \text{ for } \frac{p_v}{p_m} \leq b \tag{7}$$

$$q_m = C{\cdot}p_m{\cdot}\rho_N{\cdot}\sqrt{\frac{T_N}{T}}{\cdot}\sqrt{1 - \left(\frac{\frac{p_v}{p_m} - b}{1 - b}\right)^2} \text{ for } \frac{p_v}{p_m} \geq b \tag{8}$$

From which, through Eqs. 4 and 5:

$$\tilde{q}_N = C \text{ for } \frac{p_v}{p_m} \leq b \tag{9}$$

$$\tilde{q}_N = C{\cdot}\sqrt{1 - \left(\frac{\frac{p_v}{p_m} - b}{1 - b}\right)^2} \text{ for } \frac{p_v}{p_m} \geq b \tag{10}$$

The final effect is that of a graph providing a clear, immediate indication of the flow parameters C and b. The new screen obtained by pressing the button ''Grafico normalizzato'' (6) (normalized graph) is shown in Fig. 9. It is also possible to calculate automatically, by a statistical approach, the flow coefficients: sonic conductance C and critical pressure ratio b.

Buttons from (7) to (11) allow saving the graphs in an HTML file. By pressing the button (12) the program stops.

Evaluation of Uncertainties

Whenever a measurement of fluid flow is made, the value obtained is simply the best estimate that can be obtained of the flow rate or quantity. In practice, the flow rate or quantity could be slightly greater or smaller than this value: the uncertainty characterizes the range of values which the flow rate or quantity is expected to lie within, with a specified confidence level.

Coupled with ISO 5167, the Standard ISO 5168[9] focuses on the evaluation of uncertainties. ISO 5167 itself also covers the subject in a simplified way. For its purposes, uncertainty is defined as an interval about the result of a measurement that may be expected to encompass approximately 95% of the distribution of values that could reasonably be attributed to the measuring. For convenience, a distinction is made between the uncertainties linked to measurements made by the user and those linked to quantities. The latter uncertainties are on the discharge coefficient and the expansion factor; they give the minimum uncertainty with which the measurement is unavoidably tainted, since the user has no control over these values. They occur because small variations in the geometry of the device are allowed and because the investigations which the values have been based on could not be made under ''ideal'' conditions, or without some uncertainty.

The practical working formula for the uncertainty of the mass flow rate is given by the following equation:

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\delta C}{C}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2\beta^4}{1 - \beta^4}\right)^2 \left(\frac{\delta D}{D}\right)^2}$$
$$+ \sqrt{\left(\frac{2}{1 - \beta^4}\right)^2 \left(\frac{\delta d}{d}\right)^2 + \frac{1}{4}\left(\frac{\delta \Delta p}{\Delta p}\right)^2 + \frac{1}{4}\left(\frac{\delta \rho_1}{\rho_1}\right)^2} \tag{11}$$

Once all parameters are set and all the characteristics of components and sensors of the test bench are known, the control computes automatically the uncertainty associated with each measurement through Eq. 11.

A Test Example

To demonstrate the performances of the test bench presented in this article, a set of test results are presented and analyzed as an example. The component under test is a manual pressure regulator. In this case, the test requires additional actions by the operator because the component must be tested in

a combination of different upstream pressures (like any other component) and of different regulation (downstream) pressures. This applies both to manual tests and to automated tests (Table 1).

The 13 data points shown were collected in less than 4 min, while the same test performed manually would have taken a much longer time. For instance, notice how the regulation pressure p_1 must be raised as the flow rate increases, in order to keep p_m constant: in a manual test, this would require the operator to act on the pressure regulator at every acquisition step, while the test bench performs this operation automatically and with the required accuracy. In fact, with p_m set at 7.25 bar, the actual pressure is always within the 2% tolerance stated in ISO Standards. The actual overall uncertainty of each flow rate measurement is also shown, comprising the accuracy of all instruments and the uncertainty coming from the iterative calculations. As can be seen from Table 1, the uncertainty has very little variation and stays well below 1%. Different orifice plates at different pressures yield different values of uncertainty, depending on the variables specified in Eq. 11. The worst accuracy ever registered by the test bench so far is 1.19%, in a combination of high pressure, very low flow rate, and large orifice.

The data presented, although a mere example, show the validity of the automated test bench, allowing accurate and rapid data acquisition.

Conclusions

The test bench presented is in service at the Department of Mechanics of Politecnico di Torino.

It is not just a flow rate measuring device conforming to ISO Standards, but was realized in such a way to obtain:

- Versatility of use with a wide range components different in size and pneumatic characteristics.
- Automation of the acquisition and calculation processes.
- Rapidity to execute a complete test campaign, thanks to closed-loop regulation of upstream pressure, data quality checks and one-button acquisition.
- High accuracy.
- Easiness of use and user friendliness, by providing numerically and graphically all the information the operator needs to keep under control.

It allows executing a big amount of tests in a short time, for prototypes and commercial components, calculating their flow characteristics guaranteeing accurate and reliable results. Its scheme and the concepts lying behind its realization can be a useful starting point for engineers willing to design their own flow rate test bench obtaining characteristics and usability going beyond the scopes of ISO Standards, but nonetheless staying faithful to their indications.

In particular, testing time is greatly improved thanks to a partially automated test bench such as this. Acquisition of a single data point with the manual procedure can take up to 30 s, due to the necessary successive regulations of the upstream pressure, while the automated test bench can give the green light for acquisition to the operator in as little as 5 to 10 s, depending on the upstream reference pressure. Moreover, the internal programmatic checks assure

Table 1 An example of the output from the acquisition program containing both data from the sensors and results from calculations

T (K)	Re	p_1 (bar abs)	Δp (bar)	p_m (bar abs)	p_v (bar abs)	q_N (dm^3/minANR)	Uncertainty (%)
294.72	26583	7.3113	1.4761 e-3	7.2692	6.4965	999.95	0.71871
294.69	35169	7.3001	2.5999 e-3	7.2508	6.3772	1322.8	0.71871
294.66	42212	7.3145	3.7477 e-3	7.2681	6.2692	1587.6	0.71871
294.64	49711	7.314	5.2092 e-3	7.2597	6.1768	1869.5	0.71871
294.64	55597	7.3123	6.527 e-3	7.2449	6.0996	2090.9	0.71871
294.6	60813	7.3115	7.8167 e-3	7.2596	6.0346	2286.8	0.71872
294.6	69388	7.324	10.175 e-3	7.266	5.9314	2609.3	0.71872
294.6	77011	7.3199	12.558 e-3	7.2432	5.8408	2896	0.71872
294.58	82937	7.3254	14.564 e-3	7.2419	5.7622	3118.7	0.71873
294.59	90737	7.3195	17.466 e-3	7.2419	5.6673	3412.1	0.71874
294.52	100040	7.3229	21.235 e-3	7.2599	5.5391	3761.4	0.71875
294.53	104110	7.3339	22.972 e-3	7.2543	5.4639	3914.1	0.71875
294.49	108900	7.3399	25.119 e-3	7.2579	5.402	4093.8	0.71876

T, gas temperature; Re, Reynolds number; p_1, pressure upstream of the orifice plate; Δp, differential pressure at the orifice plate; p_m, pressure upstream of the component; p_v, pressure downstream of the component; q_N, volume flow rate in standard reference conditions ANR; uncertainty of the mass flow rate (%).

that the data are consistent with the constraints from the ISO Standards, while in manual mode it is always possible that the operator may mistakenly acquire points in uncontrolled conditions.

Also the post-processing phase allows saving time and effort, providing a powerful tool to analyze the results one by one or in batches, interpolating acquired data and computing the flow coefficients. Of course, it is still possible to save acquired data for independent analysis through external data sheets.

Hopefully, this article will serve as a guideline to design and build automated flow rate test benches as regards both hardware and software, for those engineers who aim at practical usability while keeping an eye to certification according to ISO Standards.

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