The "RCT": two functions integrated in one for pressure Regulation and gas flow metering

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Abstract: Since January 2006, the MESURA company, located in FORBACH France, manufacturer of gas regulators for the distribution networks up to 4 bar, has been developing a design which integrates two functions on the same body, thus optimizing the volume (16 cm or 6.3 inch cubic volume), the pressure regulation and flow metering, and in addition, providing wireless data transmission and remote safety control. The evaluation and the qualification of the complete system and the process (including uncertainties) has been undertaken by the French laboratory LNE-LADG in order to confirm the metering of volume gas (converted with a 0.5% level of uncertainty with the global MPE less than 1% with a known density, and less than 2% with an integrated density corrector between the transitional and the maximal flow rate with the metering scale factor up to 150).

1. Introduction

The new constraints of ecology on the consumption of energy costs are driving R & D work on new concepts for optimizing real-time measurement of and information on energy consumption (whether from fossil fuels or renewable resources), thus decreasing the impact of installations on town planning by substantially reducing their size.

The MESURA company has set itself the goal of offering equipment that satisfies these new constraints and which can be used on natural gas distribution networks to a pressure of 4 bar (absolute), and tanks for LPG, to flow rates up to 200 m3(n).h-1. MPE are expected to 2%, the quantities of gas consumed are converted into volume or mass.

The integration of pressure regulation functions and the flow measurement of gas associated with electronic components with an autonomous power supply, allows additional functions of wireless data communications, driving safety control from a distance, and remote management.

The validated concept has the advantages of the method of flow measurement orifices, while increasing the range of measurement by the continuous variation of the geometry of the orifice according to increasing flow: the well-known mathematical model of the coefficient flow in subsonic flow applies.

The device has the means, because of its concept and its sensors, to take into account and include in the measurement, flow effects induced by the change in gas density

Applying the ratio method of discrete pressure drop on a closed canal at the conditions of the pressure regulator allows the comparison of atmospheric pressure continuously calculated by the device with the local atmospheric pressure to prevent any drift of the measurement.

In the hour of the Smart Meter, the iREGULATOR, the MESURA Regulator Meter Transmitter *(Fig 1)*, in one single device, provides the vital link in the chain of measuring flow-volume and / or the mass of gas, and the installation space is reduced by factor of 5-10, allowing even buried versions, thus solving some town planning constraints.

Fig. 2 - The iREGULATOR, the MESURA REGULATOR METER TRANSMITER

2. The concept of the variable geometry orifice: the tandem pressure reduction valve

2.1. Principle and scheme

With the tandem pressure reduction valve *(see Fig. 2)* making the orifice of variable geometry, the pressure differences Δp created by the displacement X (function of the flow called Q) of the tandem valve are measured, just as the thermodynamic conditions of the fluid are measured by the sensors P and T. Together with the measurement of the pressure difference Δp, the displacement measurement X is performed by the displacement sensor. The dimensional parameters as well as different coefficients enable the flow calculation by the formula (*1*).

The polynomial function $\left(\sqrt{1/\zeta_X}\right)_X$ is defined during the calibration by a matrix function of displacement X for the entire flow range based on physical parameters measured in the flow conditions with : g gravitational acceleration in m.s⁻², Pupstream the absolute pressure upstream of the first valve of the tandem valve in bar, Pdownstream the absolute pressure downstream of the first valve of the tandem valve with Δp equal to the difference between the pressure upstream Pupstream and downstream Pdownstream of the first valve, Tupstream the upstream absolute

temperature of the first valve in degrees Kelvin, X displacement of the tandem valve characterizing the geometry generating the pressure drop in mm, γ isentropic coefficient of gas with Tn = 273.15°K and Pn = 1.01325 bar, $\rho n = \rho$ of gas at Tn and Pn , and D is the diameter of the section upstream of the first valve in m.

$$\text{(1)} \quad Q\,(t)_{Vn} = \left(\sqrt{\frac{1}{\zeta_X \text{ calibrated}}} \right)_X * P_{ups} * \sqrt{ \frac{ \gamma * \left[(P_{dow} / P_{ups})^{2/\gamma} - (P_{dow} / P_{ups})^{\gamma + 1/\gamma} \right] * 2\,g }{ (\gamma - 1) * \left[\dfrac{4}{\pi D^2 * 3600} \right]^2 * \rho n * \dfrac{Pn * T_{ups}}{Tn} } }$$
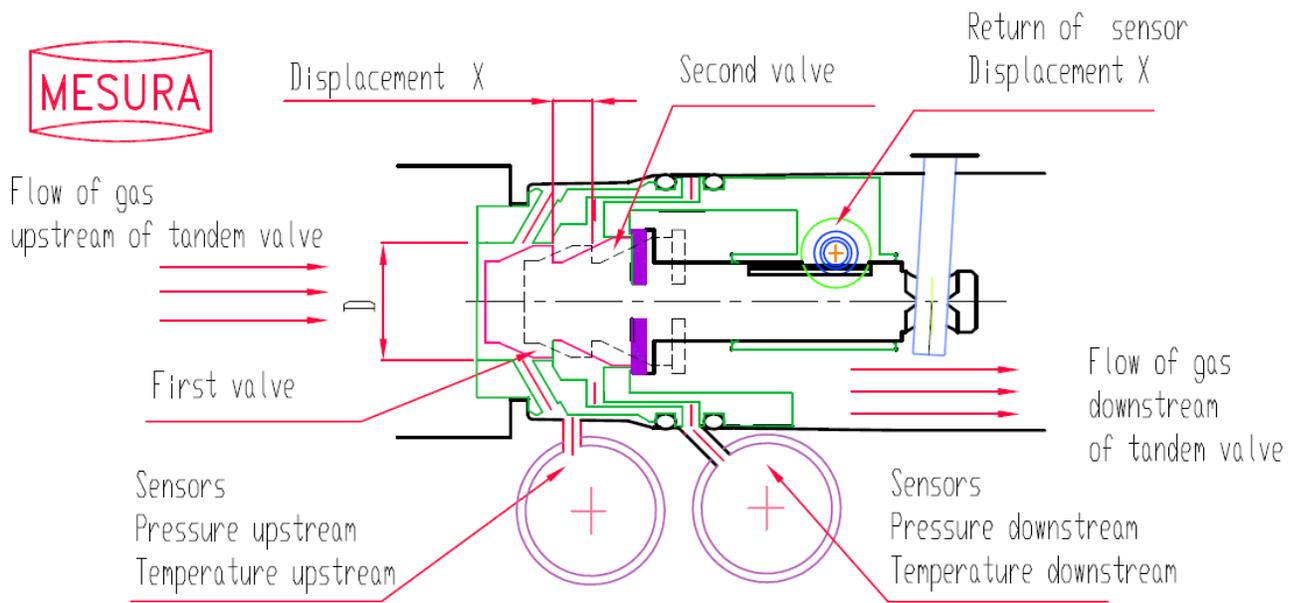

Fig. 2 The concept of tandem pressure reduction valve producing an orifice of variable geometry

The tandem valve comprises two valves forming an intermediate chamber; the pressure difference Δp is measured between the first or second valves according to the location of the seal at zero flow on the second or first valve respectively. The geometry of the external profile of the plunger-type tandem valve creates an amplification of the displacement X based on the returning movement including play which ensures perfect repeatability of the measurement.

With the geometry of the external profile of the tandem valve developed by MESURA, at low flow rates, generally below 5% of a maximum flow rate, the pressure difference Δp is independent of displacement.

2.2. The achievement tests

The tests were conducted in the laboratory tests of the MESURA Company, located at Le Haillan near Bordeaux FRANCE.

The installation conditions, definition of the equipment and classification were performed by metrological LNE-LADG.

The calibration bench shows the structure of Gas pressure regulator test benches Gas: stabilized inlet pressure adjustable from 0.1 up to 5 bar absolute, dry air flow rate being adjusted by a set of downstream valves with reference to calibrated meters.

The pipes were sized to ensure the stabilization of the test temperature from -20 ° C up to +60 ° C during the calibration of the Regulator Meter on the one hand and the ambient temperature at 20 °C of the calibrated rotary meters G16 (Qmax 25 m3 (n). h-1 NG) and G65 (Qmax 100 m3 (n). h-1 NG) on the other hand.

Flow rate control is automated to ensure reproducibility of measurement cycles and acquisitions: flow rate variation - stabilization - measures and acquisitions.

Defined by LNE-LADG the test program below *Table 1* was used to evaluate the metrological performance of the device.

These tests were conducted with all measuring devices previously calibrated in accredited laboratories.

2.3. The test program

The tests have evaluated the errors of flow rates and quality regulation according to the flow rate expressed in NG according to conditions in *Table 1*.
This traces the error curves versus flow rates by determining the influence of inlet pressure at the Regulator Meter ranging from 1.5 to 5 bar absolute and the ambient temperature and of the gas ranging from -10 ° C to + 40 ° C.
The error curve at J + 0 days at 20 ° C and 3.2 bar is the curve of the reference test.
The reproducibility of the measurements is determined after testing temperatures at J+14 days and J+22 days compared to the reference curve.

The repeatability is determined at the conditions of the reference curve, at rates of 20 and 70% of Qmax, for each flow rate value, 10 measurement steps are produced and the average error and standard deviation is calculated.
The scale and the values of flow rate Q is expressed in m3 (n).h-1 NG (Natural Gas).

Test type	Table	Fig	Parameters	Date	Inlet pressure	Room temperature	Dry air Flow rate	Variation of flow rate
Influence of inlet pressure	2	5	Regulation Flow rate Error %	J+0	1.5, 3.2 and 5 bar absolute	+20 °C (293°K)	Qmini ; 3 Qmini ; 10% 20% 40% 70% de Qmax ; Qmax	decreasing and increasing
Influence of temperature	-	6	Regulation Flow rate Error %	J+1 J+2 J+3 J+4	3.2 bar absolute	+5°C (278°K) -10°C (263°K) +30°C (303°K) +40°C (313°K)	Qmini ; 3 Qmini ; 10% 20% 40% 70% of Qmax ; Qmax	decreasing and increasing
Repeatability	-	3; 4	Average error % Standard deviation	J+6	3.2 bar absolute	+20°C (293°K)	20% and 70% of Q max	constant
Reproducibility	3	-	Flow rate error %	J+14	3.2 bar absolute	+20°C (293°K)	Qmini ; 3 Qmini ; 10% 20% 40% 70% of Qmax ; Qmax	decreasing and increasing
Reproducibility	4	7	Flow rate Error %	J+22	3.2 bar absolute	+20°C (293°K)	Qmini ; 3 Qmini ; 10% 20% 40% 70% of Qmax ; Qmax	decreasing and increasing

Table . 1 Regulator Meter Test Program

2.4. Reference curve

The curve is represented *Fig 5*.

2.5. Influence of inlet pressure

The inlet pressure device on a distribution French network (scenario chosen) are typically 1.5 to 5 bar (absolute), average pressure is set at 3.2 bar absolute.

All the curves (*Fig 5)* are clustered around the average value within a range of ± 0.5% in the extent of a rotary piston meter G16 (from 0.5 up to 25 m3.h-1); below the flow rate of 0.5 m3.h-1 the dispersions are larger (± 2% at a flow rate of 0.160 m3.h-1, Qmin of the range of a diaphragm meter).

Average error % Prototype RCT Zeta 2 Inlet pressure 1,5 ; 3,2 ; 5 bar absolute Temp. 20°C				
Average Qv(n) GN Calibrated [m3 / h]	Aver Qv(n) GN RCT [m3 / h]	E aver %	E aver sup (+) %	E aver inf (-) %
25,63	25,59	-0,165	0,229	-0,472
18,01	17,97	-0,239	-0,020	-0,423
10,28	10,27	-0,138	0,346	-0,364
6,42	6,42	-0,111	0,223	-0,387
5,11	5,13	0,415	0,519	0,147
3,85	3,86	0,227	0,686	-0,404
2,61	2,61	-0,017	0,086	-0,166
1,27	1,27	-0,185	0,239	-0,550
0,512	0,510	-0,322	-0,119	-0,613
0,156	0,155	-0,320	1,654	-2,589

Table. 2 Influence of the inlet pressure, T. = 20°C constant

2.6. Influence of the temperature

The complete unit (mechanical and electronic) was subjected to ambient and fluid temperature, at the same value. Input pressure: 3.2 bar absolute and temp. -10° C, 5 °C, 30° C, 40°C.

All the curves (*Fig 6)* are clustered around the average value within a range of ± 0.75% in most of the extent of a rotary piston meter G16 from 0.5 up to 25 m3.h-1; for the minimum flow rate, 1.26 and 0.51 m3.h-1 the influence is stronger, resulting in errors in ± 1.5% and ± 3% at Qmin.

2.7. Repeatability

We performed measurements at 20 and 70% of Q max of the device at 5 m3.h-1 (*Fig 3*) and 17.5 m3-h-1 (*Fig 4)*. The flow rate having been stabilized, we conducted a series of 10 measuring points, each point being composed of three separate measures, which are represented on the curves below. The average value is represented for each point. The average of 10 points and the corresponding standard deviation are calculated using 30 measurements.

 The different measurements carried out at 20% and 70% of Q max (equivalent to the size G16) or 5 and 17.5 m3.h-1 (NG) showed small deviations calculated on a total of 30 points, respectively, 0.014% and 0.034 %.
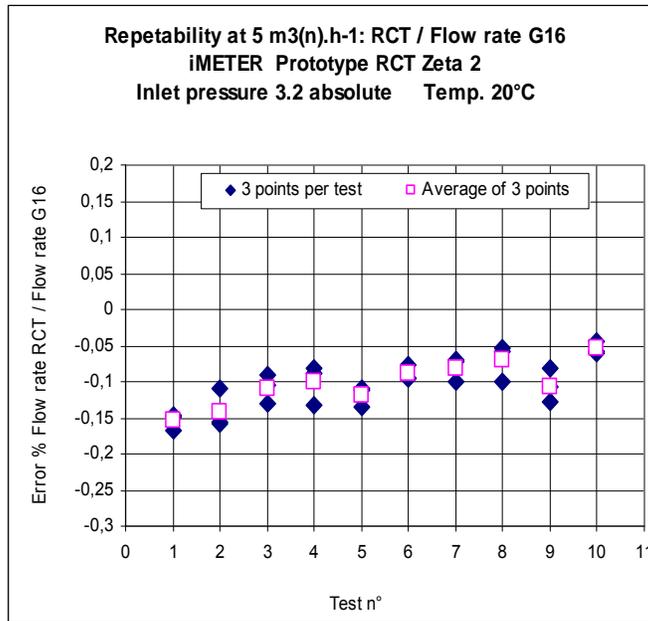
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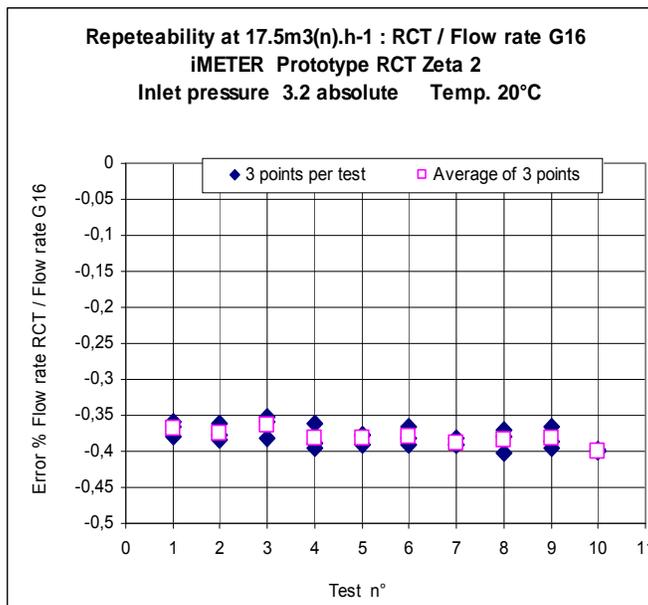*Fig.3 Repeatability at 5m3.h-1, Inlet pressure 3.2 bar absolute, Temp +20°C*

Fig. 4 Repeatability at 17.5m3.h-1, Inlet pressure 3.2 bar absolute, Temp +20°C

2.8. Reproducibility

The average errors obtained on J+14 days is compared to the average obtained during the reference curve to J+0 days (before the test temperature).

Error % Prototype RCT Zeta 2

Inlet pressure 3,2 bar absolute   Temp. 20°C

Average Qv(n) GN Calibrated [m3 / h]	Initial Error J+0 days %	Error J+ 14 days %
24,98	0,229	0,025
17,92	-0,020	-0,380
10,02	-0,256	-0,172
5,02	0,457	-0,102
2,57	-0,036	-0,101
1,28		-0,973
0,166		-1,199

Table. 3 Reproducibility, Inlet pressure 3.2 bar absolute, Temp +20°C to J+0 days and J+14 days

Error %
Prototype Zeta 2
Inlet pressure 3,2 bar
Temp. 20°C
J + 22 days

Average Inlet pressure RCT [Bar]	Aver Temp. Inlet RCT [°K]	Aver Qv(n) GN Calibrated [m3 / h]	Aver Qv(n) GN RCT [m3 / h]	E aver %	E aver sup (+) %	E aver inf (-) %
3,19	293,0	**25,58**	25,55	-0,10	0,09	-0,29
3,21	293,1	**17,94**	17,92	-0,11	0,00	-0,22
3,21	293,1	**10,28**	10,26	-0,17	-0,13	-0,20
3,21	293,1	**6,42**	6,42	0,06	0,07	0,04
3,21	293,1	**5,09**	5,10	0,31	0,58	0,05
3,20	293,2	**3,83**	3,82	-0,13	0,30	-0,56
3,20	293,2	**2,57**	2,57	-0,05	-0,03	-0,07
3,21	293,2	**1,29**	1,28	-0,67	-0,29	-1,05
3,21	293,2	**0,515**	0,511	-0,58	-0,58	-0,58
3,20	293,2	**0,160**	0,156	-1,88	-1,41	-2,35

Table. 4 Reproducibility, Inlet pressure 3.2 bar absolute, Temp +20°C and J+22 days

Readings were conducted and compared with initial readings J+0 days (P input (absolute) 3.2 bar and T = 20 ° C), the table (14 days) *Table 3* provides a comparison with a small size deviation and a maximum deviation on one point of 0.5%.

The curve *Fig 7* and table *Table 4* together show the values obtained 22 days after the reference curve, after testing at 20 ° C for inlet pressures of 1.5, 3.2 and 5 bar absolute and testing temperature -10 ° C, 5 ° C, 30 ° C and 40 ° C for an inlet pressure of 3.2 bar absolute.

The curve at J+22 days also has at the low flow (2 points) deviations of 0.7 and 1.4%; for these points the uncertainty of the calibrated meter is higher (Mass flowmeter).

2.9. Regulation

The regulating pressure in different test configurations were performed:

- Outlet pressure regulator, for inlet pressure conditions of between 1.5 and 5 bar (absolute) on the extent of the flow rate Q shows changes of ± 1 mbar around the setpoint,
- A variation of ± 1 mbar around the average value of the output pressure for the temperature of -10 ° C to +40°C.
It is observed that the flow rate measurement is independent of outlet pressure the pressures being measured upstream of the pressure-reduction valve.
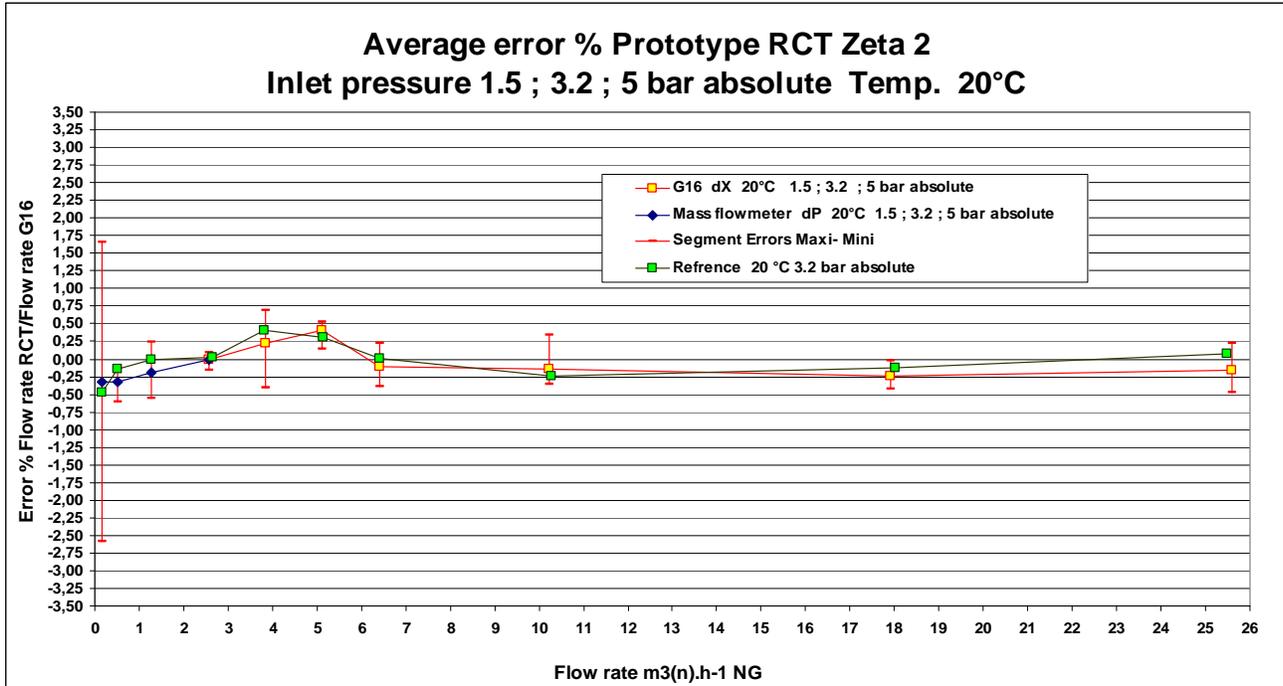

Fig. 5 Average curve, influence of the upstream Pressure, Temp. = 20 ° C constant at J+0 days Nb. For measurement of low flow rates we used a calibrated mass flowmeter for which uncertainty is ± 1%
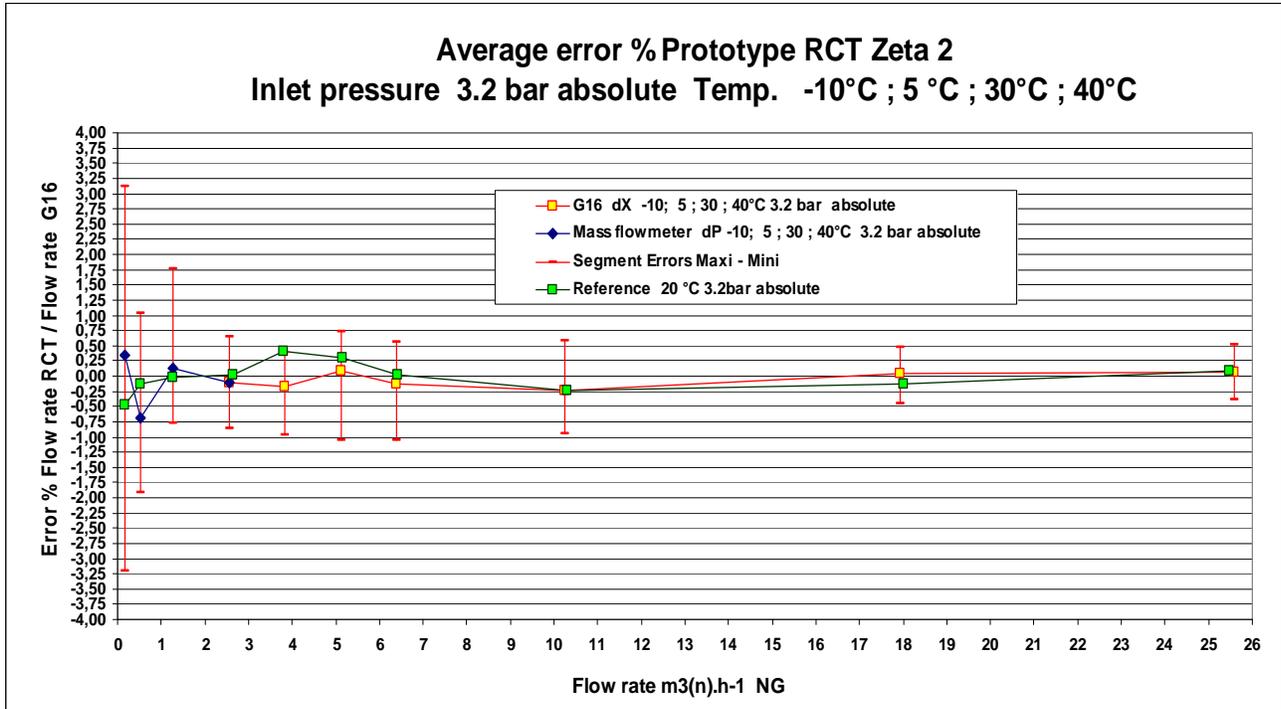
Fig.6 Average curve, influence of temperature ranging -10 °C to +40 °C, Inlet Pressure = 3.2 bar(absolute)
Nb. For measurement of low flow rates we used a mass flowmeter calibrated
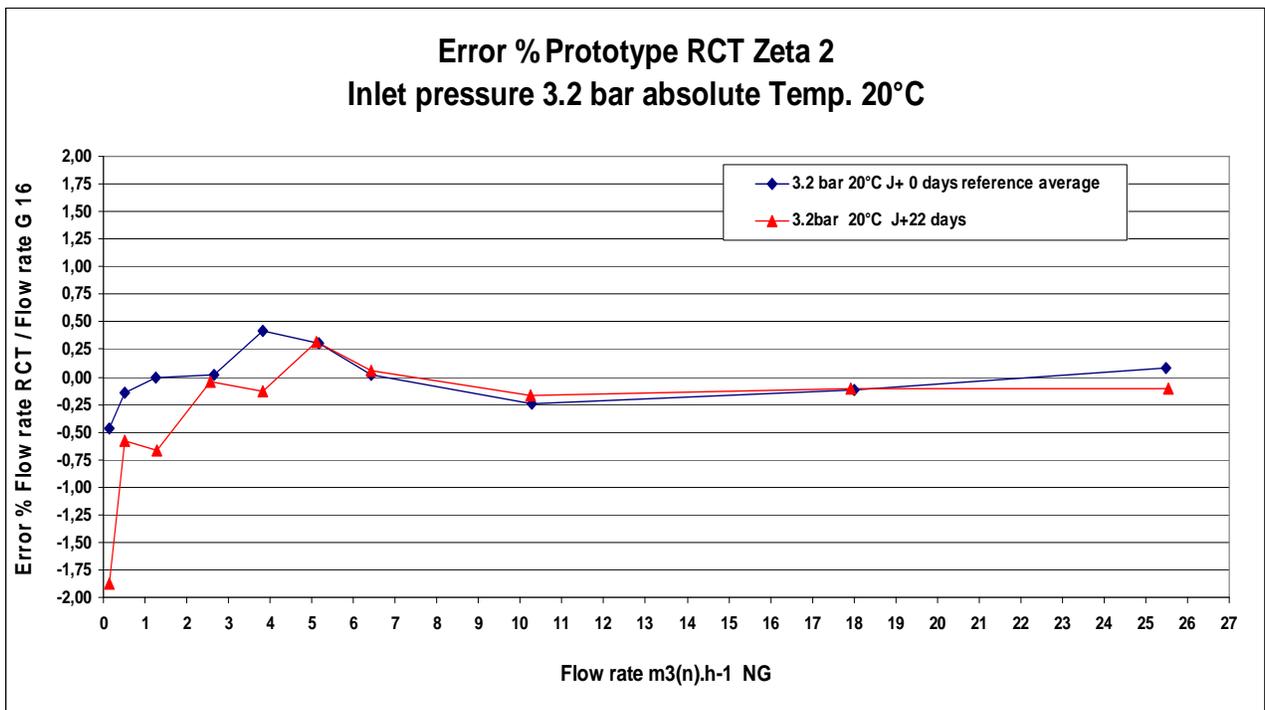*which uncertainty is ± 1%*

Fig.7 Mean curves compared, refrence J+0 days and J+22 days after the tests influence of temperature of -10 ° C to +40 ° C, Inlet pressure = 3.2 bar absolute, temperature = 20 ° C

2.10. Uncertainties

The calculations shown in tables *Table 5*, *6 and 7* are calculated from the best uncertainty (0.35%) of the calibration bench; for the desired approach validation RCT we assigned this value to RCT, provided that the calculation from the device components (P and T sensors, size, displacement) resulted in a value similar (0.3%) to the flow rate calibrated.

The uncertainties were calculated from data provided by the calibration laboratories and experimental measurements made during testing. These data apply for a stable gas of known density.

Estimates for use with Natural Gas gas type networks are made from settings and density values measured by a French distributor.

   - Uncertainty on the intrinsic flow rate of the device in reference calibration conditions (density known and constant) is shown in *Table 5*.

   - Uncertainty on the flow rate delivered by the device for a constant gas density (d), in operating conditions, table is shown in *Table 6*.

   - Uncertainty about the flow rate delivered by the device for a natural gas (NG) of the settings and density (d) variables (determined by calculation, report Air / NG, the measurement principle allows the evaluation with a guarantee in accordance with the metrological requirements for the range presented) is shown in *Table 7*.

3. Results : Extending the measurement range

The different calibers achievable differ only by their size. This similarity should allow for an extension of flow rate measurement in the sizes considered.

The prototype tested is compared to, in terms of flow meter, a meter-gauge G 16 which is Qmax 25 m3.h-1 and Qmin 0.5 m3.h-1, a perfectly acceptable measurement range and comparable to meters which are the same caliber of the volumetric-type rotary piston.

The desired range of "Regulator Meter Transmitter" could extend the caliber G4 up to caliber G65 possibly G100.

Discussion and conclusions

The Regulator Meter is validated by different tests (in principle and in realization).

The qualities and strengths identified are expected to classify this device at the level of rotary piston meters, in the related MPE.

The use of metering for a billing (according to the International Organisation for Legal Metrology, the OIML) is possible but remains, for now, linked to a fluid that is by nature and composition stable (e.g. air, pure gas). For use on a network in which the gas varies in composition, causing variations in density *(see Table 7)*, it is necessary to be aware of this.

But if one compares the uncertainty without accurate knowledge of ρn table (*Table 7)*, to one delivered by a set of counting converters (P & T), the assessment becomes different.

The result will be optimized by measuring changes in gas density with the densitometer integrated, the differential pressure generated by the pressure regulator and sensors being available.

The density correction is in the course of being validated metrologically, early results showing a resolution lower than 1% with an incidence of 0.5% on the measuring flow rate volume and/or mass of gas.

The classification of the device must be determined in collaboration with metrological organizations, as it is both a pressure regulator, gas meter volume and rate converter (apart from providing the facilities of transmission and other communications devices).

Acknowledgements

Ref	Uncertainty Cause	Uncertainty U(xi) en %	Distribution law		Uncertainty type	Sensibility Coefficient	Contribution to the overall Uncertainty (in %)
			Type	Divisor	u(xi) en %	ci	[ci * u(xi)]^2
A.1	Repeatability of the measurement	Nome				1	
B.1	External calibration	3,00E-01	Normal	2	1,50E-01	1	2,25E-02
B.2	P upstream calibrated	1,40E-01	Normal	2	7,00E-02	1	4,90E-03
B.3	T upstream calibrated	1,20E-01	Normal	2	6,00E-02	-1	3,60E-03
	Combined uncertainty	$u_c = \sqrt{\sum_i C_i^2 Ui^2}$	**1,76E-01**	%			
	Expanded uncertainty	$U_E \left(K = 2 \right)$	**3,5E-01**	%			

Table . 5 The values of uncertainties in the table are derived from calibration data supplied by accredited laboratories. The overall uncertainty is the best value possible uncertainty of the current calibration bench at the MESURA Company.

Ref	Uncertainty Cause	Uncertainty U(xi) en %	Distribution law Type	Divisor	Uncertainty type u(xi) en %	Sensibility Coefficient ci	Contribution to the overall Uncertainty (in%) [ci * u(xi)]^2
A.1	Repeatability of the measurement				2,00E-01	1	4,00E-02
B.1	External calibration	3,00E-01	Normal	2	1,50E-01	1	2,25E-02
B.2	P upstream calibrated	2,00E-01	Normal	2	1,00E-01	1	1,00E-02
B.3	T upstream calibrated	2,00E-01	Normal	2	1,00E-01	-1	1,00E-02
	Combined uncertainty	$u_c = \sqrt{\sum_i C_i^2 Ui^2}$	**2,87E-01**	%			
	Expanded uncertainty	$U_E\ (K = 2)$	**5,7E-01**	%			

Table .6 Uncertainty on the flow rate Qv (n) issued by the RCT in operating conditions (upper bound on P, T and introducing a term repeatability), Normal conditions (Pn = 1.01325 bar; Tn = 273.15°K)

Ref	Uncertainty Cause	Uncertainty U(xi) en %	Distribution law Type	Divisor	Uncertainty type u(xi) en %	Sensibility Coefficient ci	Contribution to the overall Uncertainty (in%) [ci * u(xi)]^2
A.1	Repeatability of the measurement	None				1	0,00E+00
B.1	Qvn (RCT)	5,7E-01	Normal	2	2,87E-01	1	8,25E-02
B.2	Density ρn	2,40E+00	Rectangular	1,73	1,39E+00	1	1,92E+00
	Combined uncertainty	$u_c = \sqrt{\sum_i C_i^2 Ui^2}$	**1,42E+00**	%			
	Expanded uncertainty	$U_E\ (K = 2)$	**2,8E+00**	%			

Table .7   Uncertainty on the flow rate Qv (n) issued by the RCT in the test conditions with a gas of various compositions (Type NG French Network), Normal conditions (Pn = 1.01325 bar; Tn = 273.15°K)
This uncertainty takes into account the uncertainty of the density of a French natural gas networks may vary ρn =from 0.7725 to 0.8378 (Flow rate is calculated with a constant density ρn = 0.775, the uncertainty associated taking into account the extreme values of MV).

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