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Spin-Offs from the development of rotary gas meters

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Abstract:

The basic principle of a rotary gas meter consists of two rotors in the form of a figure-8 that rotate inside each other with the precision of a gear wheel. The outer edges of these rotors turn in a very close fitting measurement chamber. The outer edges of the turning rotors transfer fixed quantities of gas from the inlet to the outlet like small buckets. Because the radii of the sealed streams in the middle between the two rotors always vary there is a discontinuous volume of gas passing per angle revolution of the rotors. The shape of variation is near a sinus and the frequency is four times the frequency of the rotor revolution and the amplitude is near 12% of the average flow. These variations give an irregular rotating of the rotor at low flows and pressure and flow pulsation's at higher flows. These pulsation's can lead to resonance's in the installation where they are mounted in. This can give sound problems and mis-indication of the rotary gas meter itself or to other devices in the installation.

The by Instromet developed DUO rotary principle (Dutch patent number 1004751) has two pair of rotors which are synchronized in such a way that both sine waves of the transferred volumes per angular movement are in opposite phases to each other. This results in only a small variation with double frequency. To develop a rotary meter with a large measure range it is necessary to keep all leak gaps along the rotors as small as possible. The combination of DUO Principle and narrow leak gaps has demonstrated that this type of meter is suitable as high-grade reference meter. This type of meter shows a flat calibration curve over a large measuring range. It has a high-grade reproduction and a small pressure dependency over a large pressure range.

With rotary meters of the DUO principle as reference meters, Instromet has developed a series of low-pressure test benches (ITF) measure range 0.5 to 10000 m³/h at a very compact construction. For a measure range up to 1000 m³/h only two rotary meters are being used as a reference. For a measure range up to 4000 m³/h more rotary meters are being used parallel as a reference. Above 4000 m³/h also a large turbinemeter will be used as a reference. The total uncertainty in the determination of the measurement error of the meter under test is strongly dependent of the chosen trace to the primary standards. A total uncertainty less than 0.23 % is possible. For small flows, the extent of the enclosed volumes and temperature and pressure stability in the test room also determines highly the final total uncertainty.

For high pressure test facilities the "Instromet Rotary Piston Prover" IRPP is developed. The heart of the meter is a cartridge, type DUO rotor meter provided with extra narrowed leak gaps. The cartridge is placed into a cage, which is span with a flexible rubber sleeve. The measurement module, cage and sleeve on itself are put as a assembled unit into a pressure body designed for a design pressure of 100 bar. This assembled unit can be seen as the "real meter". Now it's easy and inexpensive to transport the "real meter" without its pressure body, for calibration at specialised high pressure laboratories that may be located far away.
These IRPP's are already in use by the NMi in their new re-calibration system of high pressure test facilities "Trasys" and as a sleeping standard in facility of Trans Canada Calibration in Winnipeg, Canada.

1. Introduction

1.1 Leak theory for the rotary gas meter

The basic principle of a rotary gas meter consists of two rotors in the form of a figure-8 that rotate inside each other with the precision of a gear wheel. The outer edges of these rotors turn in a very close fitting measurement chamber (see figure 1). Outside the measurement chamber the rotors are synchronised by a pair of accurate gear wheels. During the rotation of the rotors the gaps between the rotors and between the rotors and the meter housing are kept as constant and small as possible.

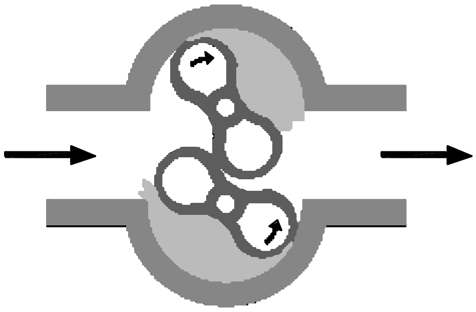


Figure 1.

The outer edges of the turning rotors transfer fixed quantities of gas from the inlet to the outlet like small buckets. Each rotation of the rotor passes four of these volumes. The quantity of gas per rotation that is taken at the inlet is equal to that which is exited, provided it is assumed that no gas is trapped in the middle, no gas returns from the outlet to the inlet and that there is no leakage through the gaps around the rotors.

The power that drives the meter is caused by the pressure drop over the rotors. By the law of conservation of energy it follows that the energy delivered by the gas is equal to the energy necessary to turn the rotors:

$$Q \cdot \Delta p = M \cdot v \qquad \text{....1}$$

The pressure difference can be written as:

$$\Delta p = M \cdot \frac{v}{Q} \qquad \text{....2}$$

Because there is a pressure drop across the meter, leakage takes place through the gaps around the rotors. Because the height of the gap is small and the length relatively long, the character of the flow will be laminar. The leak will therefore be proportional to the pressure drop.

$$Q_{leak} = K_G \cdot \Delta p \qquad \text{....3}$$

$$Q_{leak} = K_G \cdot M \cdot \frac{v}{Q} \qquad \text{....4}$$

The last term can also be written as:

$$\frac{v}{Q} = \frac{da}{dt} \cdot \frac{dt}{dV} = \frac{da}{dV} \qquad \text{....5}$$

The average for a rotation is:

$$\left[\frac{v}{Q}\right]_{avg} = \frac{2p}{V_{rev}} \qquad \text{....6}$$

The average leakage along the rotors therefore becomes:

$$Q_{leak} = K_G \cdot M \cdot \frac{2p}{V_{rev}} \qquad ....7$$

Herewith we find that the leakage is proportional with the retarding torque on the rotors.
At low flow rates the braking moment M is caused almost entirely by the mechanical moment of the bearings, timing gears and the counter. These are mostly constant at low rotational speeds. Because of this the leakage along the rotors is also usually constant at the lower range. By keeping the moment and the leakage gaps (K_G) small, the leakage along the rotors can be limited. Because the leakage is the only quantity of gas that is not measured, the relative deviation in respect to the theoretical value is equal to:

$$E = -\frac{Q_{leak}}{Q} \qquad ....8$$

It follows therefore that the measurement error at low flow rates is inversely proportional to the flow. At high flow rates the mechanical friction increases somewhat but the rotors also experience a larger braking moment by the entry and exit of the gas flow and by the viscous strength of the gas in the leakage gaps caused by the relative movement between the rotors and between the rotors and the chamber.

1.2 Irregular transferred volume per angular movement of a rotary gas meter.

A better description of the momentary volume displacement by a rotary meter is obtained if one considers the instantaneous stream that is sealed between the chamber and the rotors and between the rotors themselves. Here is also the small volume which is trapped between the rotors as a tip passes through the middle not forget. In figure 2 the radii between the tip of the rotors and the chamber are indicated as R1 and R2 and the radii between the rotors themselves as r1 and r2 respectively.

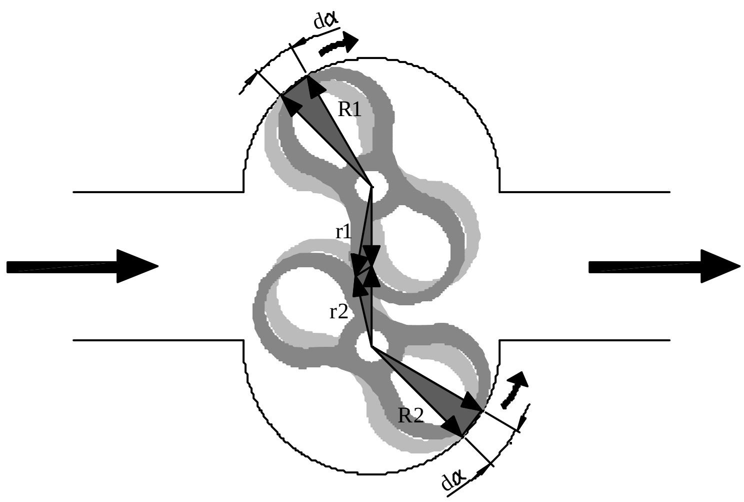


figure 2.

If one now assumes that a small rotation of the rotors is *da* and the length of the measurement chamber is equal to L, then the displaced volume can be described as:

$$dV = \left(\tfrac{1}{2}R_1^{\,2}\cdot da + \tfrac{1}{2}R_2^{\,2}\cdot da - \tfrac{1}{2}r_1^{\,2}\cdot da - \tfrac{1}{2}r_2^{\,2}\cdot da\right)\cdot L \qquad \ldots.9$$

$$dV = \tfrac{1}{2}\left(R_1^{\,2} + R_2^{\,2} - r_1^{\,2} - r_2^{\,2}\right)\cdot L\cdot da \qquad \ldots.10$$

The volume per revolution is equal to the integral of a rotation:

$$V_{rev} = \int_0^{2\pi} \tfrac{1}{2}\left(R_1^{\,2} + R_2^{\,2} - r_1^{\,2} - r_2^{\,2}\right)\cdot L\cdot da \qquad \ldots.11$$

The momentary volume change per revolution is equal to:

$$\frac{dV}{da} = \tfrac{1}{2}\left(R_1^{\,2} + R_2^{\,2} - r_1^{\,2} - r_2^{\,2}\right)\cdot L \qquad \ldots.12$$

The radii R1 and R2 remain constant during the rotation, however the sealed streams in the middle r1 and r2 always vary. Simply put, one could say that on the outside with constant radii, the gas is transported as is the metal, from the inlet to the outlet and on the inside with variable radii practically only the metal is moved from the outlet to the inlet. The difference between the two is actually the gas that is transferred from the inlet to the outlet.

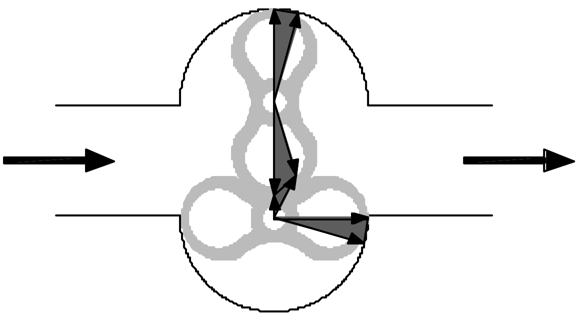


figure 3. Position of minimum $\frac{dV}{da}$

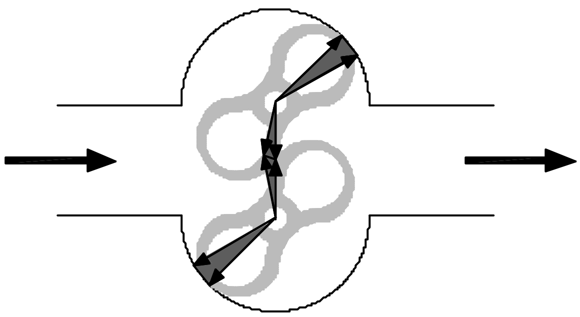


figure 4. Position of maximum $\frac{dV}{da}$

If the rotor edges are at right angles to each other, for example in figure 3, then r2 is the largest and practically the same as R2 and r1 is the smallest. Assume the rotors are 45º further such as in figure 4, then r1 and r2 are equal and on average, the same length. By the quadratic terms for the streams in the formula the volume change per revolution in the figure 3 situation is minimal and in figure 4, maximum. This variation repeats itself four times per entire revolution of a rotor. If one expands this displaced volume in regard to the angle then one gets a path for the customary rotary meter as shown in figure 4. From here it appears that for all intents and purposes a sine forming path occurs with an amplitude of about 12 %.

1.3. What are the consequences of this on a rotary meter in practice?

The transferred volume per angular movement can also be seen as the relationship between the flow and the angular velocity of the rotors.

$$\frac{dV}{da}=\frac{dV}{dt}\cdot\frac{dt}{da}=\frac{Q}{v} \qquad \ldots.13$$

With a constant flow the rotors will turn unevenly. However, force is required for the acceleration and deceleration of the rotors. These forces can only be created by an extra pressure difference over the rotors. This originates again because the gas flow is either accelerated or retarded. This results in flow variations. The pressure changes again have an influence on the volume of gas and on the pressure difference over the rotors and thus on the leakage through the gaps. There is a constant interaction between pressure, flow, rotational speed and leakage through the rotors. These show a strong interactive and dynamic behaviour.

At low flow rates the force necessary for the acceleration and deceleration and thus the pressure variations, are small. The rotors will turn unevenly and this will absorb almost all of the variations in the transferred volume per angular movement. At high flow rates the required acceleration and deceleration is high and thus the required forces are also high. Because of this practically all the variations will result in pressure/flow variations and changing leakage along the rotors. The angular velocity of the rotors remains therefore relatively constant. The pressure pulsations can be heard by the rumbling noise of the rotors at high flow rates. Between the low and high flow rates the speed of the rotors will be uneven, as well as the pressure and flow rate pulsations.

Pressure pulsations move with the speed of sound from the inlet pipe of the meter as well as from the outlet pipe. In practice it seems that a pulsation-causing resonance can be generated if the frequency and its wavelength coincides with the length of a section of pipe so that a standing wave can form (organ pipe). The result is that higher pressure pulsations and flow pulsations are generated that work against the rotary gas meter. This has again the effect that the meter produces more noise and that the leakage along the rotors alters, therefore the rotary meter will deviate. If rotary meters are placed in series with for example a turbine meter then they can, in case of pulsations and certainly in the case of resonance, have a considerable detrimental effect on accuracy of the turbine meter.

2. Practical solutions for the pulsation and resonance phenomenon

In practice three workable solutions can be considered.
The first solution is to place dampening drums directly before and behind the rotary meter. The length of the piping to the dampening drums must be kept smaller than a quarter of the wave length of the generated frequency at Qmax. The dampening drums can be filled with an absorbent material.
This solution is commonly utilised in test installations in order to prevent mutual interference between the meter-under-test and the reference meters. See figure 5.

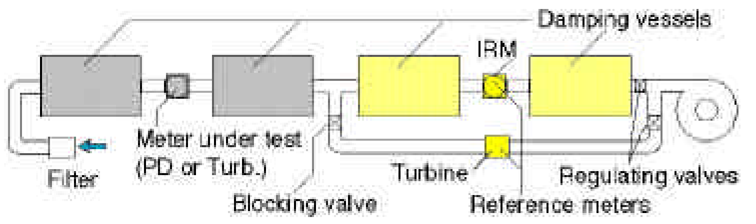
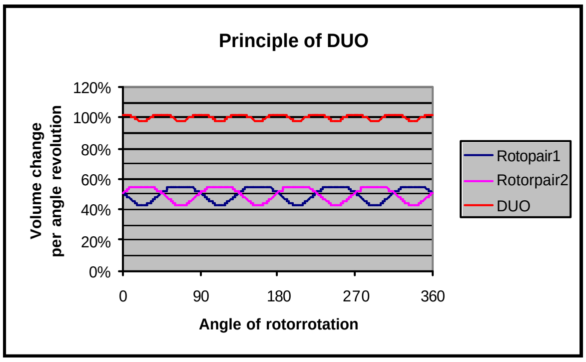


Figure 5. A test ins tallation using damping vessels.

A second solution is the principle of the DUO rotary meter. Here two pairs of rotors are placed in one housing with a common inlet and outlet. The rotors are synchronised in such a way that both sine waves of the transferred volumes per angular movement are in opposite phases to each other (See figure 6).



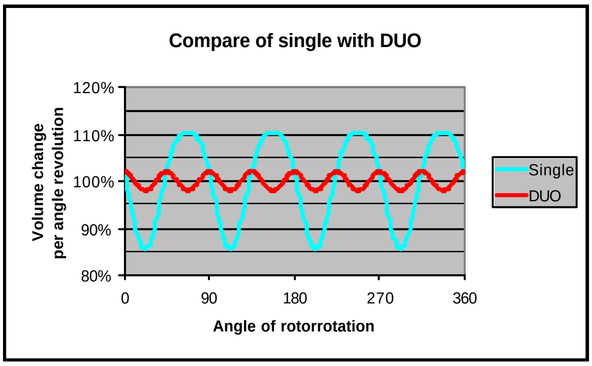


figure 6. Principle of DUO

figure 7. Compare of single with DUO

Unfortunately the shapes of the sine waves are not exact. Because of this a residual varia tion is left over with a double frequency and an amplitude of something less than 2% (see figure 7). In practise such a variation does not seem to have a mutual influence with meters that are placed in series. In any case the deviation remains within the uncertainties of test installations.

A third solution is placing a flexible wall between the inlet and outlet of the meter. The pulsations between the inlet and outlet are by definition in opposite phases to each other and what goes in at the inlet is s imultaneously coming out the outlet. Thus each variation in transferred volume per angular movement shall, if the wall is flexible enough, be dampened out. With this solution an IRM-A-G250 (see figure 8) was built with a by-pass and a 4mm thick rubber membrane fitted in the middle between two DL300 covers. Beyond the by-pass a perforated plate was fitted in the inlet and outlet in order to block the pulsations to the outside. This rotary meter produced a very good repeatable and flat curve at atmospher ic pressure and at 8 bar and 16 bar. The maximum flow was however, limited by the high resistance of the double perforated plates to 150 m3/h. NMi is still using this meter as a travelling standard.

figure 8. Reference meter NMi

figure 9. IRM-A DUO G250 reference meter

3. The development of the IRMA DUO1 reference meter

Through the combination of the DUO principle with the idea of small leakage gaps and buffer volumes in front of and behind the meter, and by using existing parts we come to the following construction. Two measurement modules with the small rotor profile of the IRMA type are coupled together and placed in the housing with a large rotor profile. By connecting the outlet of a measurement module with internal movement to the outlet of the housing, one can ensure there is no connection between the inlet and the outlet. At the inlet a rather open space is created and at the outlet, a narrower. The gas can flow in and out over the whole width of the module. By manufacturing the rotors and the module housing with extra accuracy the gaps were narrowed. The result was a meter with a very large range and a very flat curve, practically the same with atmospheric air as with natural gas at 8 bar and 16 bar. The shift between the errors with the different test pressures was slight. With higher pressures the curves lie somewhat lower to about 0.15% at 16 bar. It is not entirely clear if these differences are due only to the meter because these lie within the uncertainty of the test installations.
From this meter type, three sizes are in production, a G40, G100 and G250.

4. Statistical Analysis of the test data of rotary meters that are used as travelling standards

At Instromet it is common that the test installations used for meter production are completely checked every year and additionally, are checked weekly with travelling standards. The travelling standards used are cycled such that at least every four weeks all the usual test points have been done. From these travelling standards, up to date statistics are kept. Statistic analysis of this data naturally says a lot about the stability of the installations but besides this, a lot about the travelling standards themselves and the meter types used for that purpose.
For the rotary meter production at Instromet two test installations were built during the mid-90s in which in addition to a turbine meter and wet drum meter as standard meters, a rotary meter was also utilised. The rotary meters under test were similarly placed between two dampening drums. Some rotary meters have also been picked as travelling standards. Since the development of the DUO rotary meter they have been used in an increasing number of installations as a standard and also as a travelling standard

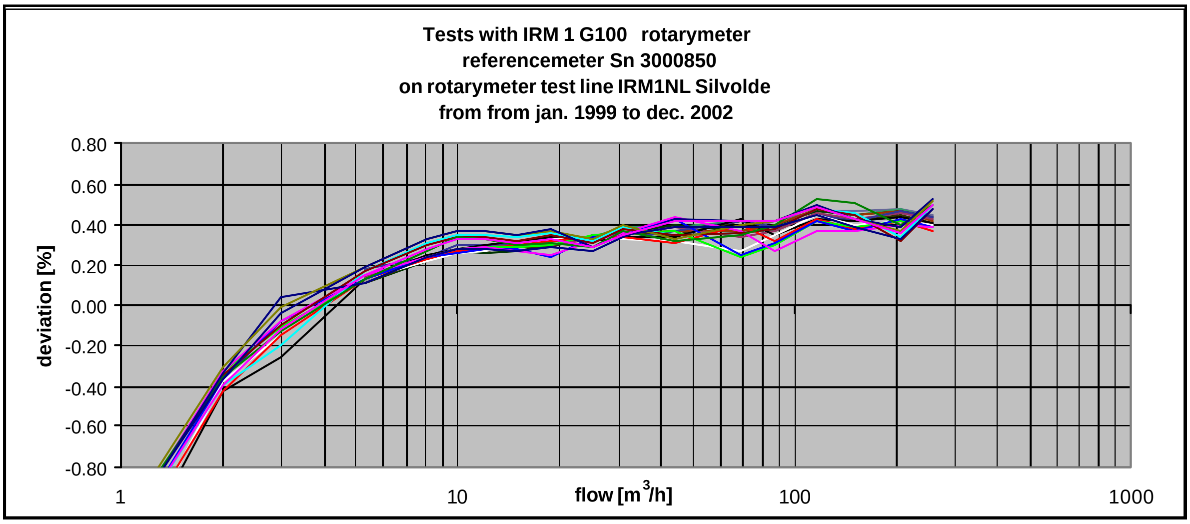


Figure 10. Statistical data of rotary reference meter over three years.

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If the results are considered over longer period then it can be seen that the results of a rotary meter against a rotary meter gives a very small variation in the measurement results than with turbine meters or a combination of rotary meter and turbine meter. The conclusion that can be drawn from this is that a rotary meter is less dependent on the installation situation and on the changing environmental conditions like for example barometric pressure, humidity and temperature. If the standard deviation (2S) of a test point of a reference turbine meter against a turbine meter is 0.1% then it can be seen that in comparison to a reference rotary meter against a rotary meter, it is about 0.05% (see figure 5 and 6).

5. Development of the Instromet Test Facility (ITF) using DUO rotary meters, rotary meter with narrowed gaps and buffer drums.

Instromet has developed a series of test installations with, as the starting point, one or more IRM3-DUO G650 and one IRMA G16 with extremely small gaps, as reference meters with respectively a turn down ratio of 1250 m³/h to 6 m³/h and 25 m³/h to 0.35 m³/h. In one reference section up to a maximum of three reference meters can be installed. See figure 7. The metering lines are placed vertically and directly above and below the reference meters dampening drums have been fitted to dampen out the pulsations.

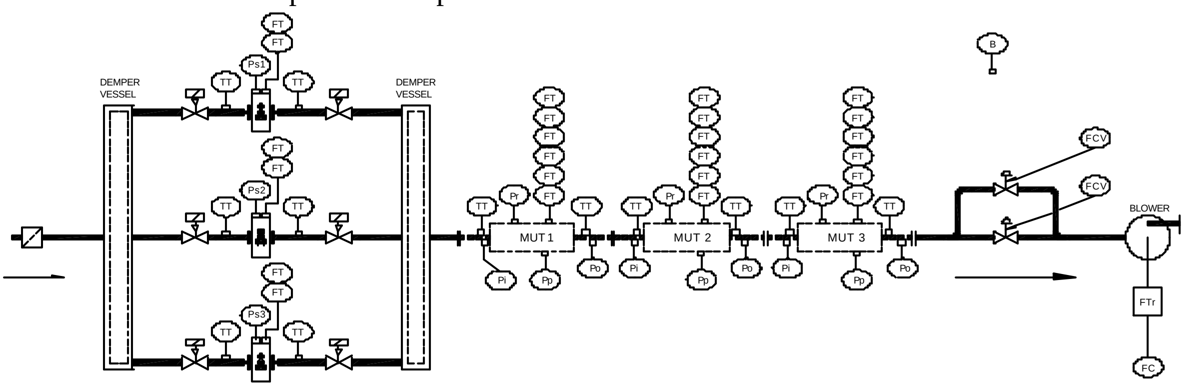

Figure 11. PI&D diagram of ITF with three meters under test.

There are three possible models.

1. IFT 1000 with a testing range of 0.5 – 1000 m³/h
   One reference section with one G16 and one G650 in parallel

2. IFT 2500 with a testing range of 0.5 – 2500 m³/h
   One reference section with one G16 and two G650 in parallel (see figure12)

3. IFT 4000 with a testing range of 0.5 - 4000 m³/h
   Two reference sections, the first with one G16 and two G650 in parallel and a second with another two G650 in parallel.

If an installation is desired with an even higher testing range, then a conventional arrangement can be added with a reference turbine meter placed in a horizontal line and in parallel with an ITF 2500. With a turbine meter of DL300 an ITF6500 can be constructed and with a turbine meter of DL400, an ITF10000. In the reference sections up to three meters-under-test can be placed in series. See P&I diagram. Figure 11.

Figure 12. Reference section ITF 2500

5.1 Uncertainty analyses.

One of the most important quality aspects of a test installation is the uncertainty that can be ascertained through the error that is found at a test point. This is determined with the help of an uncertainty analysis in accordance with "The Guide to the expression of Uncertainty in Measurement" as a guide-line. The uncertainty results from the test method plus the formulae used.

The testing is the relationship of the meter-under-test with the reference meter and is based on the law of preservation of mass. Here the meters are volume meters and the mass of a gas is dependent on its state, which is determined by local pressure and temperature. The temperature and pressure must be measured at each of the separate meters. In accordance with the gas laws, described in the formulae of Boyle and Gay-Lussac, the volumetric flows can be compared with each other. In order to determine the volumetric flow the operating reference meter and the meter-under-test are fitted with impulse generators. If all the meters are synchronised as closely as possible, an accurate time measurement can be made for a pre-determined number of pulses. In order to determine the absolute pressure that will result in the smallest possible uncertainty in the final value, this absolute pressure is not measured directly. Instead of a barometer, the pressure difference between the meter-under-test and each reference meter (dp_{ref}), and the pressure difference between the meter-under-test and the environment are measured (dp measured).
The measurement error for the meter-under-test can be written in full as:

$$E_m = \frac{\left(\dfrac{n_{mut}}{tt_{mut} \cdot pulsv_{mut}}\right)}{\sum_{ref=1}^{n}\left[\left(\dfrac{n_{ref}}{tt_{ref} \cdot pulsv_{ref}}\right) \cdot \dfrac{1}{\left(1+E_{ref}\right)} \cdot \dfrac{\left(baro + dp - dp_{ref}\right)}{\left(baro + dp\right)} \cdot \dfrac{T_{mut}}{T_{ref}}\right]} - 1 \quad \ldots 14$$

A large part of the uncertainty comes from the uncertainty that comes with the error of the reference meters (E_{ref}). This uncertainty is determined through the uncertainty in the testing of the reference meter itself and the test installation used for that purpose. In this way one can go further back in the chain of traceability to the international basic unit of the kilogram and the meter in Paris. This share in the uncertainty can be kept as small as possible by testing the reference meters as far back as possible in the chain of traceability to basic units. The repeatability and stability of the reference meter itself also determine a part in the last uncertainty analysis.
The rest of the uncertainty comes from the accuracy of the pulse, time, temperature, barometer and pressure difference measurement of the performance test. This contribution in the uncertainty can be kept small by doing each measurement accurately. At Instromet we strive to limit this contribution to a maximum of 0.01% for each individual measurement. This is done by the correct choice of sensors and transmitters to obtain a good calibration. By using a high clock frequency for the pulse-time measurement, any inaccuracy here can be neglected.

However, there are a few snags.

For a temperature calibration the sensors are placed in a water bath where the temperature can be kept within a stability of 0.03ºC. During the test they are inserted in the stream and measure only the site where they are placed, whereas in another area in the profile the temperature can vary somewhat from this. Furthermore, the sensor picks up a part of the temperature by conduction and radiation. The temperature from the sensor will rest between the temperature of the gas and the pipe wall. With the sensor placed in front of or behind the meter the temperature can be different from the area in the meter where the volume is being determined. At the same time there is a delay in the sensor that causes the true temperature to lag. To keep this uncertainty low, care has to be taken that the temperature in the testing room does not alter too much or too rapidly. The test meters must also be put in the room well in advance in order to acclimatise them.

The pressure measurement causes less problems because the connections are made to the pressure measurement point of the meter and the pressure is reproduced very quickly to the pressure transmitter and thus can react rapidly to any changes. Deviations, however, can be caused by pulsations and resonances. To limit these, one must take care that there are no restrictions and/or large volumes between the connection and the transmitter.

The measurement of the pulse timing is very accurate. However, the moment when the pulse is transmitted by the meter can vary markedly by, for example, the irregular distance between the vanes, a different in distance from the pulse detector, mass inertia and/or tolerances. This can be improved by the measurement of multiples of the entire pulse transmission cycle. Longer test times can lessen the uncertainty if it concerns absolute deviations as tolerances. Additionally, if there is a badly adjusted pulse detector in combination with the amplifier or if there are loose contacts, it can happen that pulses are missed or extra pulses are generated. If one measures over a large number of pulses it will not always be directly seen as an error. These sort of errors one must always try to avoid. The deviations are normally not stable and can be observed by repeating the test. Also by taking short testing times with few pulses, it appears that a measurement error suddenly jumps during the test.

The tests are based on the law of conservation of mass. One starts from a stationary situation where the mass that flows through the reference meters is equal to the mass that flows through the meter-under-test. It follows that there must be no leaks and that no mass may be gained or loss between the two meters by temperature, pressure of volume changes in the enclosed spaces. One must check for leaks each time once the meter-under-test is installed and before beginning the test. However, an installation is never 100% tight and a small leak can be accepted. Especially at small flow rates, temperature differences and changes of the incoming an outgoing air during the test can have an influence on the enclosed mass. So also can a sudden change in atmospheric pressure (barometer) have a noticeable effect. A steady long lasting slow temperature change will have an influence.
The aspects above require a good uncertainty analysis to be made.

6. Development of the IRPP reference rotary meter suitable for high pressure test installations.

Arising from the trials with the IRMA DUO-I reference meters it has been proven that the changes in measurement error between atmospheric air, 8 bar and 16 bar are very slight. This led to continuing the tests at higher pressures such as 50 and 65 bar where several high pressure calibration installations carry out their calibrations. There was also the desire to revise and make the traceability from low to high pressure faster and to be able to perform this with less effort. And this with a smaller uncertainty. In order to make the IRMA DUO-I suitable a stronger meter housing was necessary. Furthermore, the remaining light resonance and pulsation phenomenon had to be established. See figure 13.

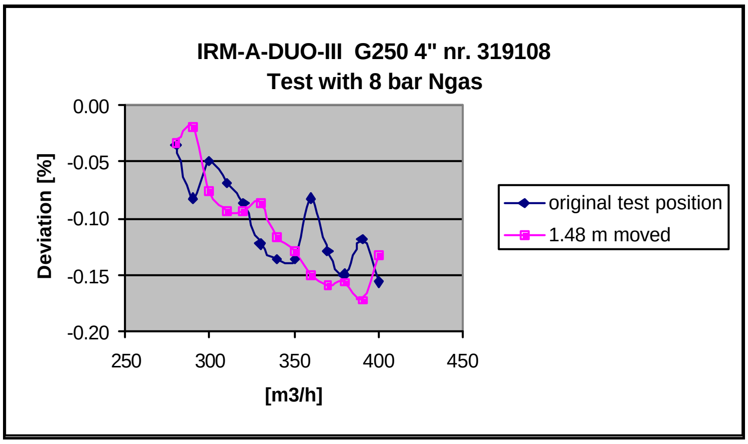

Figure 13. Example of variation in deviaton dependent on capacity and position.

By considering a construction using the measurement module of an IRMA DUO-I as a reference meter, fitting a flexible separation wall, and placing these in a housing which can withstand the pressure, a meter could be achieved that would probably fulfil all the requirements.
The measurement module is placed in a cage that is enclosed by a rubber sleeve with the outlet mouth on the outside and the inlet on the inside of the sleeve The cage has a ring on the front end that acts as a plug in the housing thus providing the separation between the inlet and the outlet.The cage and the measurement module can be slid into the housing as a unit. By integrating the pulse generator, the pressure connection and the temperature measurement into the cage and module, the result is a cartridge that can be seen as the actual meter. A housing was developed that could be quickly opened along with assistance tools for inserting and removing the cartridge easily. It is possible to test a cartridge in another housing in another part of the world without devaluing the accuracy of the meter. The advantage of this is that the housing as the pressure vessel does not need to be removed from the installation. The housing consists of a thick walled piping with a 300 diameter and with a cover on the front fitted with a connection also used for such things as filters (Quick closure). The housing is suitable for an operating pressure up to 100 bar. Two o-rings are fitted to both the cover and to the ring of the cartridge. In the wall of the pressure housing small holes have been drilled that come out between the o-rings.

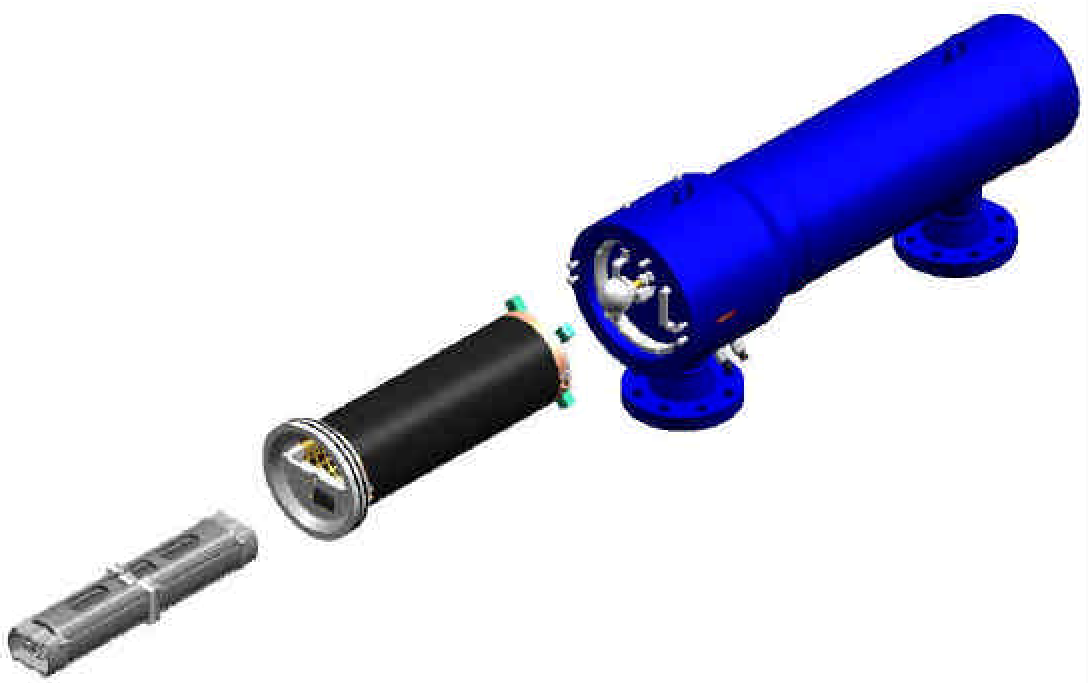

figure 14. The three main parts of IRPP construction, the measurement module, cartridge and pressure body.

With this it is possible to check from the outside whether the o-rings are leaking (Block and Bleed). Thus it can be checked and guaranteed that there is no leakage between the inlet and the outlet after the instalment of the cartridge. In and around the cartridge there is sufficient room for the flow to enter and exit the module. The sleeve has a large surface for the pressure and flow variations to pass through easily. The rubber sleeve must have sufficient strength to withstand the statistical pressure differences at the highest pressure and Qmax.

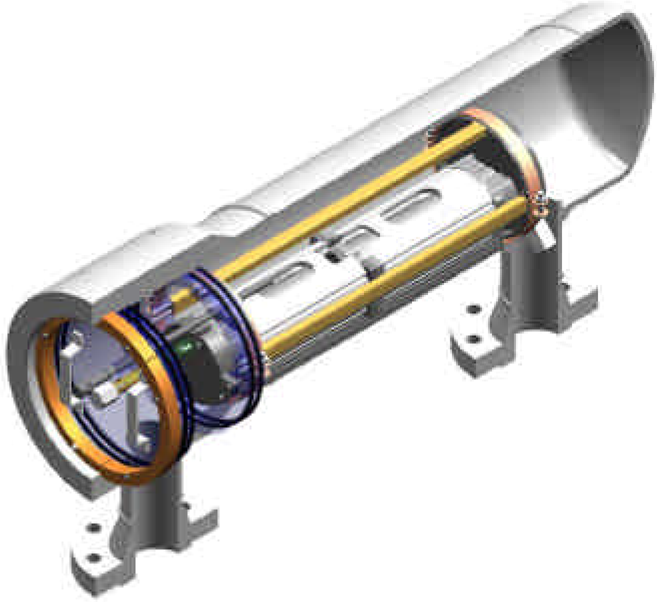

Figure 15. Cross vieuw of IRPP.

One module has a maximum capacity of 400 m³/h. By placing additional modules next to each other the capacity can be increased. At Trans Canada Calibration in Winnipeg, Canada an IRPP installation used as a sleeping standard has been installed with 10 IRPP units placed in parallel. The highest capacity of this IRPP installation total 4000 m³/h, which is equal to the maximum capacity of the operating reference, meters, namely Dl 400 turbine meters and Dl 400 ultrasonic meters.
At this moment IRPP units are being further tested by the NMi in their project Trasys and Mr. Mijndert van der Beek will be giving a presentation about this during this Flomeko.

figure 15. 10 pieces of IRPP placed in parallel used as sleeping reference at TCC-Canada.

7. References

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8. Notations

Notations

Variable	Unit	Discribtion
baro	mbar	Barometer reading
Δp	mbar	Pressure drop over the meter
E	-	Deviation in meter indication from the real volume passed
K_G	-	Constance for leakage through gabs
L	m	Length of the rotor
M	Nm	Retarding torque on the rotors
n	-	Number of pulses
dp_{mut}	mbar	Pressure drop between meter under test and environment
dp_{ref}	mbar	Pressure drop between reference meter and meter under test
Q	m^3/h	Capacity through the meter
Q_{leak}	m^3/h	Capacity of leak around the rotors
R_1	m	Tip radius rotor 1
r_1	m	radius or seal in the middle of rotor 1 against rotor 2
R_2	m	Tip radius rotor 2
r_2	m	radius or seal in the middle of rotor 2 against rotor 1
T	K	Absolute temperature at meter
tt	s	Test time
V	m^3	Volume passing meter
pulsev	Pulse/ m^3	Number of pulse per m^3 volume that passes the meter
a	rad	Turning angle of rotors
w	rad/s	Angle speed or rotors

subscripts

avg	-	Average
mut	-	Meter under test
ref	-	Reference meter
rev	-	Per complete revolution of the rotor