"NMi TraSys", THE ULTIMATE CARRIER & MULTIPLIER FOR THE UNIT OF VOLUME FOR HIGH-PRESSURE NATURAL GAS

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SUMMARY
The paper describes the newly developed "NMi TraSys" - NMi Traceability System. This travelling carrier & multiplier of traceability has been realized to embody a significant part of the Dutch National traceability-chain for high-pressure gas-flow measurements. The number of contributions of uncertainty as well as their values, due to 'copy-losses' and 'installation-effects' during the traditional transfer of traceability from one facility to another, are decreased.
First results are presented about observed repeatability and reproducibility, uncertainties and consistency checks. The device will include in time, reference values of three different independently realized primary standards (viz. DDD - Dynamic Displacement Device, GOPP – Gas-Oil Piston-Prover and NMi TraSys itself). With internal harmonization processes at NMi VSL with 'input' reference values from the three other primary standards, viz. DDD-conventional, DDD-extended pressure level and GOPP, the aim of 0,1% uncertainty at 4.000 m^3/h and p = 60 bar is within reach. This will improve the uncertainty as well as the stability of the Dutch National reference values considerably.
NMi TraSys will be used as a set of Travelling Reference Meters, creating an efficient availability of stable and validated Harmonized Reference Values for high-pressure gas-flow.

INTRODUCTION

Since the early sixties NMi realizes traceability for high-pressure gas-flow measurements of Natural Gas [1-2]. The traceability-chain of the reference values starts in Dordrecht (NMi VSL) and runs via installations in Groningen (Gasunie) and Bergum (NMi VSL), ultimately to the facility in Westerbork (Gasunie). At each of the facilities traceability is available, not only for direct testing and calibrations of gas-meters, but also (via sets of Travelling Reference Meters) for other test-facilities at pressures ranging from atmospheric conditions till 70 bar [3].
Up till now, every three years a re-calibration cycle takes place at each of these separate test-facilities. Main disadvantage is the time-consuming process that results in an average down-time of four to five weeks per facility during the re-calibration. Moreover copy-losses at each comparison step, different compositions in Natural Gas, different temperature conditions will lead to additional sources and contributions in uncertainty and time-delays because of time of transportation and preparation.
With NMi TraSys, most of these disadvantages are overcome. Another advantage is that the re-calibration cycle is not dependent on the operational availability of each facility. The system is mobile (Transportable) and can be installed at any site "with two flanges" and with conditions for a "source" and a "sink" for Natural Gas (or other gas).
The design of the mobile set of travelling reference meters makes a free exchange of rotary piston gas-meter inserts or cartridges possible. It is anticipated that third parties may send their identical cartridges to be mounted in NMi TraSys to be directly calibrated and linked to the already available reference values of the other NMi-cartridges in the system. The cartridges are relatively light-weight that will drop cost of transport (freight) to a large extend. The first metering skid is in operation since December 2002. Presently, the heat-exchange system with pressure reduction unit is built. The second skid will be finalized in the next months. In November 2003, NMi TraSys is planned to become operational. Its performance will be compared and evaluated against the results of the conventional re-calibration cycle of the complete Dutch traceability-chain for high-pressure gas-volume.

EMBEDDING "NMi TraSys" INTO DUTCH SYSTEMS OF TRACEABILITY
From point of view of statistics, it is more favourable to increase the amount of sets of independent reference values rather then to try to get one ultimate primary standard. In the standard on uncertainty analysis [4], uncertainty sources are quantified making a difference between sources of "type A" (determined by statistical methods) and "type B" (estimated or guessed by experience and expertise). The later source of uncertainty is definitely much more difficult to determine.

Therefore, linking completely independent and uncorrelated sets of data will add redundancy and reliability. Total uncertainty level will decrease roughly with a factor $1/\sqrt{n}$, in which n = number of independent sets of reference values. If e.g. three CMC's (Calibration and Measurement Capability) of three sets would be equal, then a total uncertainty, according to this rule of $1/\sqrt{n}$*CMC = $1/\sqrt{3}$, would the result, replacing the original CMC's based on a linear averaging the sets of data.

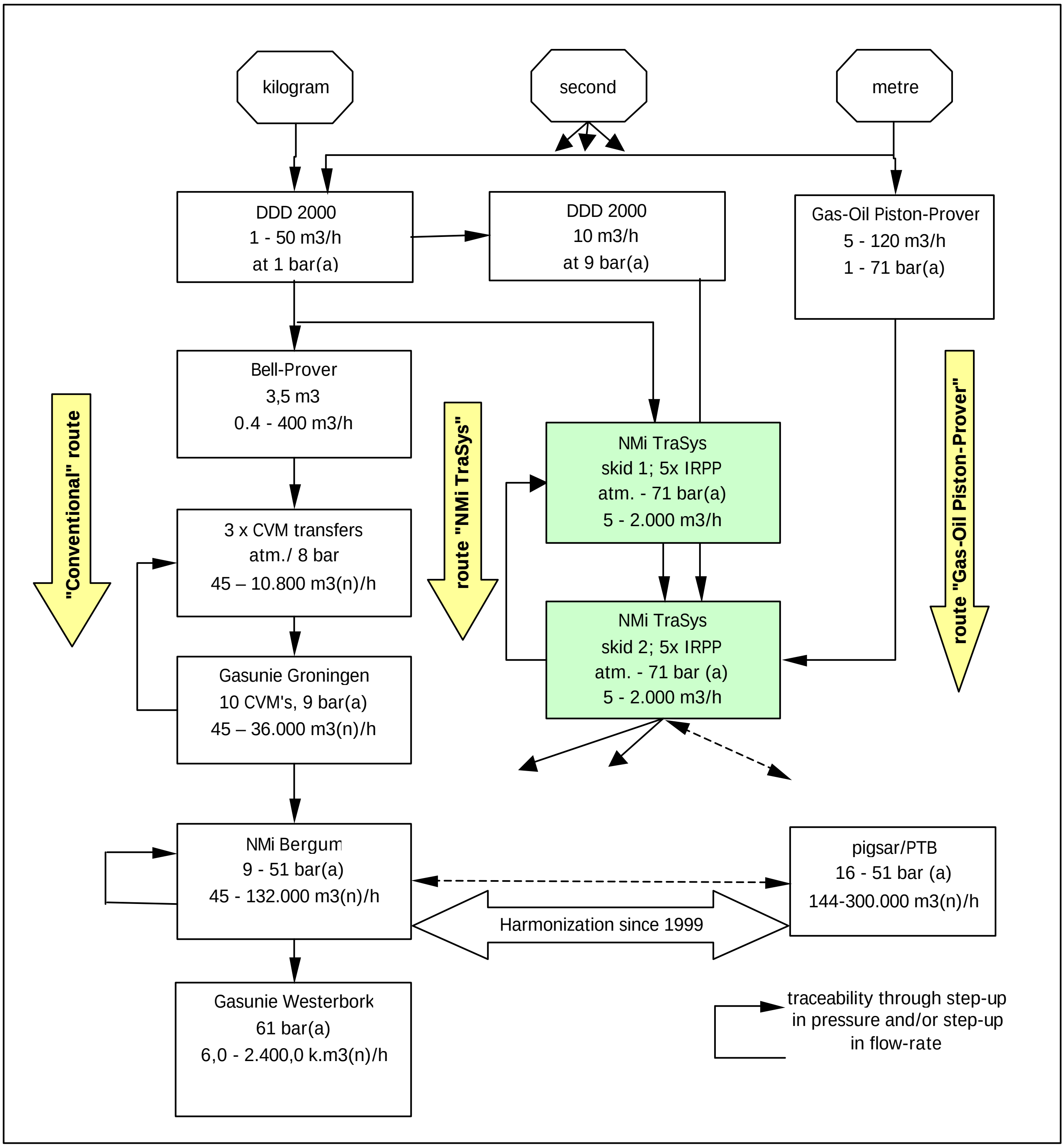


Figure 1, Three independent routes of traceability

Concluding, building three independent primary reference standards, without emphasize to improve the performances in the sense of uncertainty (CMC), a set of averaged reference values would show a considerable improvement in uncertainty. With improvements in applied technology of the individual sets the result would become even better. NMi VSL-Flow favours this principle, has called it "harmonization", and has established a procedure in which "best known reference values" are be based upon Quadratic-Weighing of the individual, original sets of reference values.
Allow a birds eye view at the position of NMi TraSys as a 'spider' in a web of three sets of Dutch Reference Values or Traceability-Chains. In the conventional Dutch Traceability-Chain [1] a CMC of 0,18% at 100 m^3/h actual and 8 bar is claimed.
A second traceability-chain is built around the Dynamic Displacement Device 2000 [5, 6]. Maximum flow-rate at 8 bar is 10m^3/h. Uncertainty after boot-strapping of volume in two steps with 5 NMi TraSys reference meters is estimated to be 0,08%.

Finally, the third Dutch traceability-chain, is built around the Gas-Oil Piston-Prover or GOPP [13]. For this system, the CMC is estimated to be 0,05% at a flow-rate of 100 m^3/h and a pressure of 8 bar. The system is stand-alone and mobile with a closed conduit, high-pressure piston-prover operating with Oil at one side and Gas at the other side.
From schematic diagrams, the calibration process of one of the ten cartridges of NMi TraSys can be deducted. Although it is possible to calibrate one of travelling rotary gas-meter (cartridges) at each pressure stage on GOPP directly, in this example one meter is calibrated at 8 bar only.

Harmonization of the three sets of reference values, organized via "Quadratic Weighing" [7, 8, 9, 15].

$$u_{harmonized} = \sqrt{\sum u_i^2 . w_i^2} \quad \text{and} \quad w_j = \frac{1/u_j^2}{\sum_{i=1}^{n} 1/u_i^2}$$

Assuming u_1 = 0,18%, u_2 = 0,08% and u_3 = 0,05% results in a crude harmonization uncertainty of $u_{harmonized}$ = 0,04%. The harmonization factors Wj when j=1, 2 and 3 are calculated to be 0,05; 0,27 and 0,68 respectively.
Obviously, the uncertainty of the conventional chain (u = 0,18%) is hardly playing a role in the harmonized reference value (impact = 5%). However for the sake of redundancy and reliability, the more than 25 year operated conventional chain will be kept 'alive' as long as is needed to prove stability of the other two recently developed Dutch Traceability-Chains.

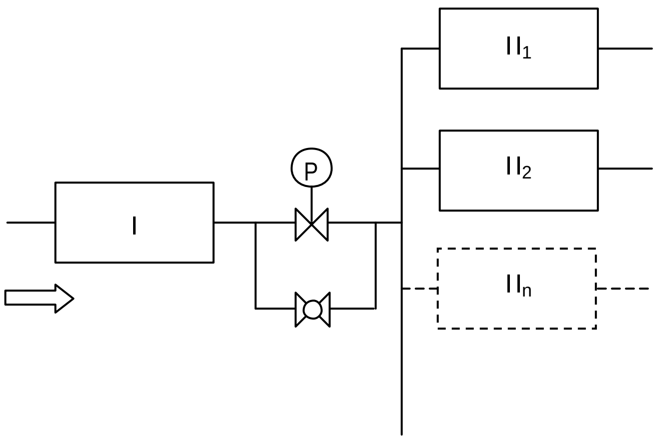


Figure 2, General circuit of boot-strapping

WORKING PRINCIPLE OF BOOT-STRAPPING, APPLIED IN "NMi TraSys"

General

The bootstrapping procedure, whether applied to create an increase in pressure, or an increase in flow-rate, relies on the comparison of one meter, in series with a set of meters in parallel (Figure 2). The meters in parallel are of the same size. In the comparison, a primary reference meter is mounted in position I, and a set of (n) identical secondary reference meters are mounted in positions I_1 to I_n. For boot-strapping of volume (Flow-rate) the regulator has no function and is by-passed.

1. Each of the (n) meters in position II is calibrated against the first reference meter in position I at the maximum flow-rate obtained at the primary reference standard (e.g. GOPP or DDD-2000). A "type A" and "type B" contribution to uncertainty results from this step.
2. Meter (I) is now calibrated at multiple flow-rates against the primary standard. Each of the (n) "II" meters can be applied and therefore fortunately, "type A" uncertainty resulting from this step is reduced by a factor √n with respect to a conventional comparison of I with a single meter II.
3. The meter at location I is calibrated at any multiple up to (n) of the original flow-rate under 1. If (n) meters are used in parallel, "type A" uncertainty of the previous step is reduced by the same factor as at 2. For multiples smaller than (n), a similar reduction can be achieved by using various permutations of meters in location II.
4. Finally the meters in location II are calibrated at these same (n) flow-rates against the meter in location I.

Steps 2 to 4 can be repeated until the maximum flow-rate of the transfer standards is reached. Of course, the process can also be executed with lower flow-rates of the primary standard.
The final flow-rate is increased by a factor (n) each time.
Boot-strapping for Pressure is discussed in the next section.

Boot-strapping with NMi TraSys

The boot-strapping process for NMi TraSys is organized in a slightly different way. At the position of meter "I" (see previous figure) a set of 5 meters is used, in stead of only one. The advantage is found in the fact that information is copied from one skid to the other and vice versa in roughly half the number of steps. Furthermore, the realization of two identical metering skids puts an optimum in redundancy in this system (all information is obtained "in duple"). When all 10 meters are calibrated at a certain condition, the two skids can be put in parallel to increase the capacity to a full 4.000 m^3/h at those certain conditions, finally ranging from 1 bar up to 90 bar.

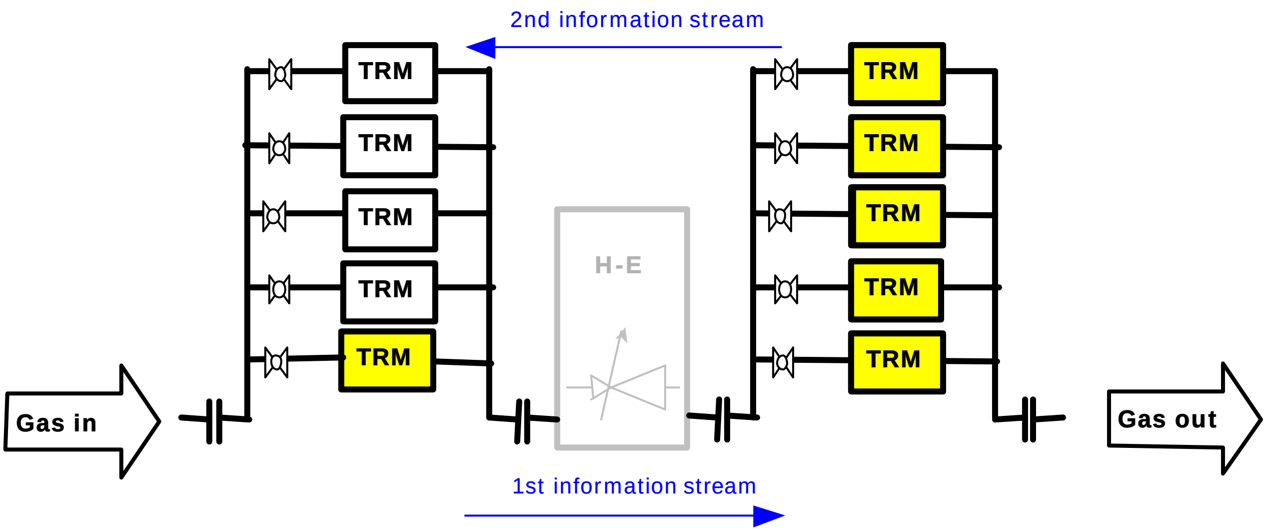


Figure 3, Boot-strapping for Volume in NMi TraSys

For bootstrapping in pressure the back-pressure regulator will be activated and set at the desired pressure. An up-stream valve controls the flow-rate. The same procedure as before is applied.

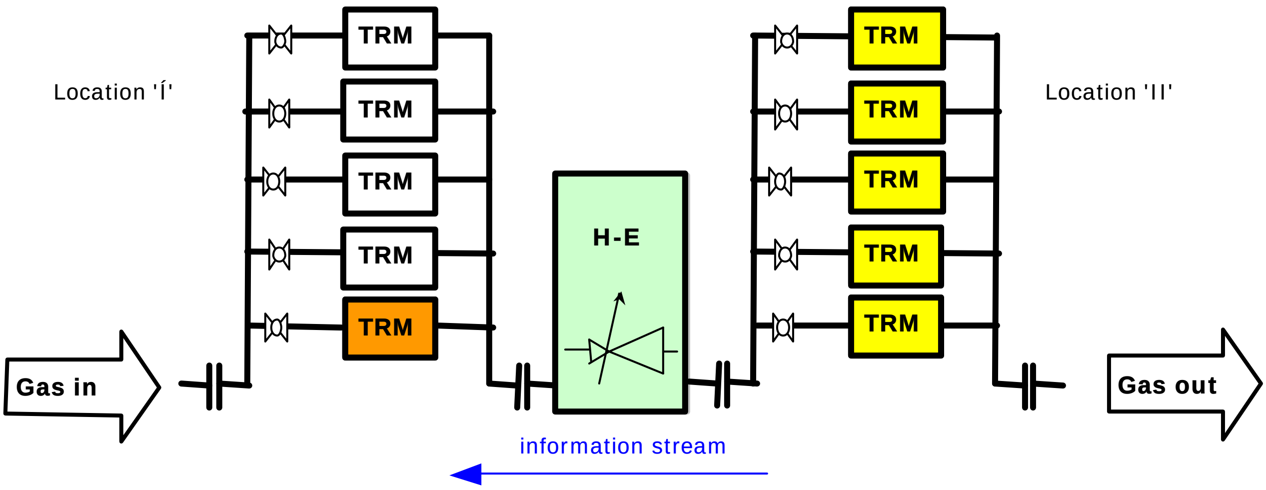


Figure 4 , Boot-strapping of Pressure in NMi TraSys

The meters at location I are calibrated at an actual flow-rate "II" which is reduced roughly by a factor P_{II} / P_I. Apart from the increase in uncertainty as explained before, an additional uncertainty results from the pressure reduction, viz. the uncertainty contribution of the difference in compressibility "Z" at the two conditions. When the "M-GERG" equation of state is used together with the gas-composition produced by a Gas-Chromatograph (GC), the uncertainty is quantified at 0,1% in absolute "Z" per pressure condition. The relatively large impact of this source motivated NMi VSL-Flow to look for a method to determine directly the Z_I/Z_{II} ratio. This will reduce this uncertainty value to about 0,03% [14].

During the boot-strapping process, changes in temperature, pressure and compressibility occur in various amplitudes. Inherently, these auxiliary parameters affect the total uncertainty. Some of these variations can be reduced by suitable measures (e.g. by installing appropriate pressure reduction and heat exchange units to control gas temperature before expansion takes place).
From the above we are able to conclude that, denoting the two pressures P_{II} and P_I respectively, the increase in flow-rate per boot-strapping pressure-stage is approximately n * P_{II} / P_I.

Following this procedure it becomes clear that it is advantageous :

- To keep the primary standard at an operating pressure or as close to that pressure as is possible. This avoids a number of uncertainty contributions, resulting from pressure reduction;
- To use transfer standards with a high rangeability (or turn-down ratio). For a boot-strap in pressure in particular, the transfer standards should be capable to measure a minimum flow-rate equalling the maximum flow-rate of the primary standard divided by the reduction in pressure;
- To use a number of identical standards. The larger the number of meters, the smaller the additional uncertainty contributed by boot-strapping in volume. Moreover, the number of repetitions of steps 2 to 4 to achieve the maximum flow-rate of the travelling reference meters is reduced.

SPECIFICATIONS OF THE SYSTEM

In the design of NMi TraSys, experience gathered in the past 25 years has been included. The concept of the, now conventional system was, and still is, fit for its purpose. It will continued to be used to produce reference values and to check the new systems until enough experience is gathered and data has been collected and verified. Sure enough, existing drawbacks and disadvantages are cleared in the new design.

As improvements (i.e. reduction) of the uncertainty in each of the steps of the traceability-chain for high-pressure gas-flow measurements can only be achieved by paying attention to every single detail, the design of the Rotary-piston gas-meter, the pipe-line configuration, the heat-exchange / pressure regulation units and the efficiency of the calibration procedures (methodology) have been scrutinized.

Disadvantages of the conventional system in order of importance

- Long traceability-chain. At the end of the chain in "Bergum", an uncertainty of 0,25% is obtained;
- Re-calibration cycle is running through three different facilities, causing considerable down-time;
- Gas-meters, used in the re-calibration cycle are 'ancient' Constant Volume Meters (CVM's). These positive displacement meters with a low degree of pulsations are not manufactured anymore;
- Handling a vast amount of different Travelling Reference Meters is time consuming (logistics, risks of accidents);
- Lots of steps leading to lots of labour and lots of data-handling;
- Complicated method, many possibilities to go wrong.

Planning and scheduling to perform the re-calibration tasks is dependent on availability of each facility and personnel, and time lags during the projected cycle is at times difficult to avoid.

Specifications of NMi TraSys

Functional requirements for NMi TraSys are presented here :

1. Minimum to maximum flow-rate at actual conditions : 4 m^3/h to 2.000 m^3/h in each skid;
2. Operating conditions : Natural Gas at 1 to 90 bar, gas temperature 0 to 40 ^0C;
3. Turn-down ratio of 1 to 100 for each individual Travelling Reference Meter of the two skids;
4. Easy exchange of Travelling Reference Meters (use of cartridges);
5. Two stand-alone metering skids and one Heat Exchange / Pressure Reduction skid;
6. Hydraulic lifts for easy positioning/adaptation at pipeline configurations in different facilities;
7. Stand-alone data-acquisition system with possibilities for data-transfer via a network, connecting all skids and up to three other Meters under Test;
8. Easy transportation and positioning of the skids;
9. Dimensions as small as possible (compact design).

Furthermore special requirements were put onto the Rotary gas-meters :

- No significant pneumatic interaction of the meters;
- Shape of the deviation curve :
  - i Difference in deviation of the meter between 10 and Q_{max} m^3/h must not exceed 0,3%
  - ii Difference in deviation of the meter between 40 and Q_{max} m^3/h must not exceed 0,15%
- Pressure dependency :
  - i Shift of the deviation curve between 8 bar and 50 bar must not exceed 0,2%
  - ii Shift of the deviation curve between 1 bar and 50 bar must not exceed 0,3%
- Differences between all Rotary gas-meters referring to deviation curves (homogeneity and consistency) :
  - i Deviation of each individual meter must not differ more than 0,1% with the mean deviation curve of all meters together between 10 and Q_{max} m^3/h.

Deviation = (indication of the meter - reference value) / reference value *100%

GENERAL USE AND DESCRIPTION OF "NMi TraSys"

Initial sets of reference values for the unit of volume of Natural Gas are realized and validated in a System for Basic Verification at atmospheric conditions. In boot-strap processes higher flow-rates are realized. Expansion-steps give flows at higher pressures. NMi TraSys is one of the current developments at NMi to reduce the uncertainty of its traceability-chain [5, 6].

NMi TraSys will represent the complete Dutch traceability-chain for high-pressure gas-flow. Obtained actual flows range from 5 to 2.000 m^3/h at pressures from 1 bar up till 90 bar. The device will include reference values of three different independently realized primary standards in The Netherlands, viz. two DDD - Dynamic Displacement Devices and GOPP – Gas-Oil Piston-Prover. NMi TraSys is intended to become part of the Harmonization [5, 6, 7, 8, 13].

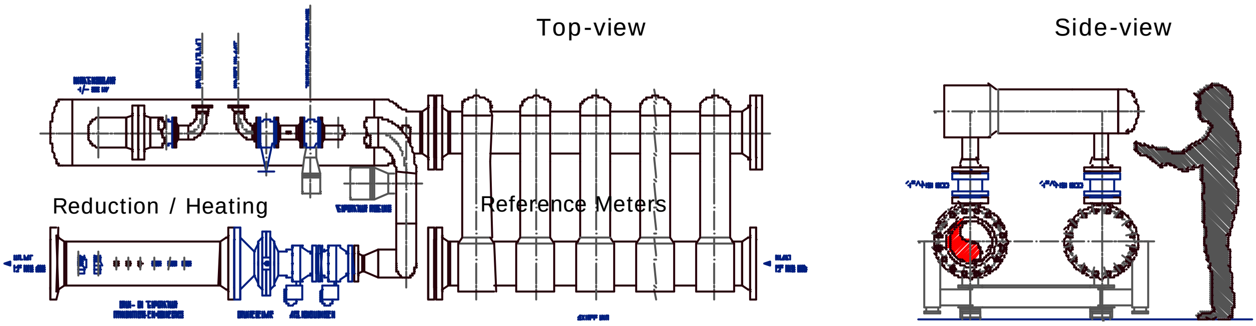


Figure 5 , "NMi TraSys"

The complete system consists of two metering skids, each with five reference meters, together with a skid containing a heat-exchange / pressure-reduction unit. The sketch indicates one skid with reference meters and part of the temperature-pressure control unit.
The five gas-meters (G250) of a metering skid can be put in parallel facultative. When the pressure-reduction valve is opened completely, gas-meters of skid 1 are compared with those of skid 2 at the same operating conditions. In this way reference values at higher gas flow-rates (boot-strapping to higher flow-rates) are realized. If however the reduction mode is applied, boot-strapping (under expansion) to higher pressures is realized.

PROCESS AND INSTRUMENTATION DIAGRAM AND FEATURES OF THE DATA-ACQUISITION SYSTEM
The simplified Process and Instrumentation Diagram is shown in figure 6.

Description

TRM Travelling Reference Meter, here a G250, 4" duo Rotary principle with pulsation dampening membrane (Instromet Rotary Piston meter, second generation);

Heat Exchange / Pressure Reduction Skid

Z/Z meter An on-line compressibility-ratio meter, measuring the ratio of compressibility of gas at the two different pressures (operational conditions) with a small uncertainty, new values every 20 minutes (refreshing rate);

GC Gas Chromatograph. An on-line analyzer for the actual composition of Natural Gas, refreshing rate 5 minutes. The actual composition is used to calculate the theoretical compressibility factor at the different operating conditions (for check measurements);

DAS Data Acquisition System. A cabinet with stand-alone computer for continuous data-sampling and data-storage. The stand-alone computer communicates with a master-computer, communicating with DAS over a network cable.

DuT Device under Test, used as watch-dog to check continuous consistency of the measurements. DuT can also be used as a Travelling Reference Meter for application of traceability in other test-facilities or metering-stations.

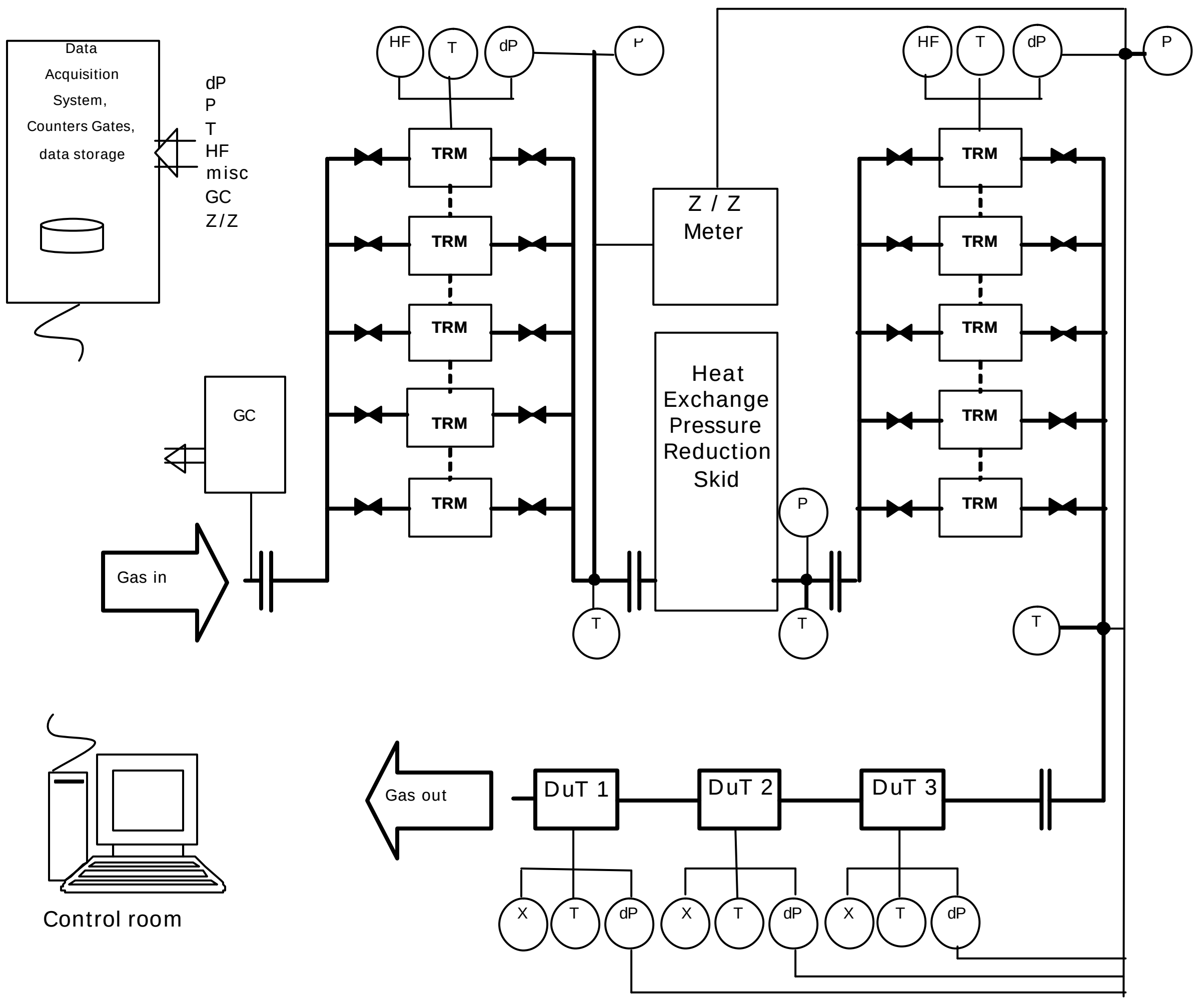


Figure 6 , P&ID of complete system

Specific features of the data-acquisition and analysis software

The on-line calculation of compressibility factor, based on the composition and following M-GERG, is corrected every 20 minutes to agree with the measurements generated by the reference Z/Z ratio-meter. This setup was selected to enhance the accuracy of compressibility factor from M-GERG (this value has a particular impact on the CMC).

The timing and pulse counting of the HF signals is carried out with a hard-ware gated counter-system to ensure proper interpolation between low and high frequent signals and to avoid timing and pulse errors. As a result of this technique, in principal, no pulse round off, or timing error is anticipated.

SPECIFIC ENGINEERING CONSIDERATIONS RELATED TO METERS AND PIPING CONFIGURATION

Design Rotary Piston Gas Meter

The applied Travelling Reference Meters are based upon the IRPP or 'Instromet Rotary Piston Prover', a high-pressure duo (pulsation compensated) rotary piston gas-meter with rubber dampening membrane. Instromet has developed a second generation IRPP for NMi TraSys. Together with NMi, improvements to earlier models have been made (Figure 7).

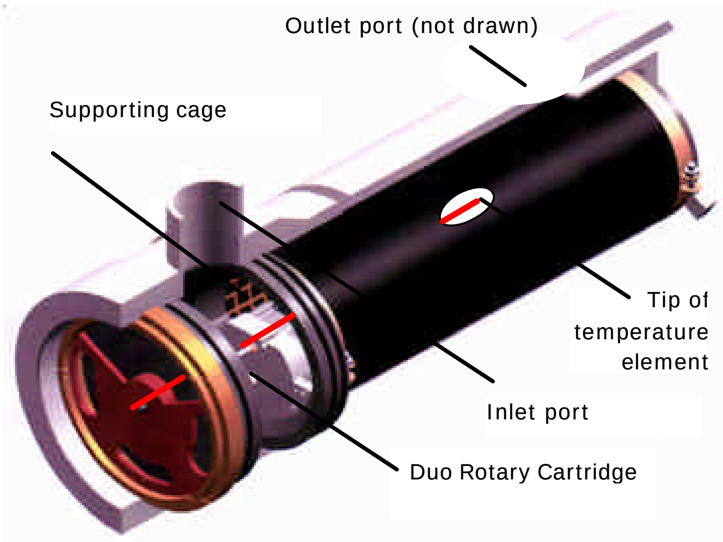


Figure 7, Exploded View of the 2nd generation Duo Rotary Piston Gas-meters with dampening membrane

- A membrane-supporting cage inside the membrane (to prevent undefined shaping of the membrane at small flow-rates);
- Improved rigidity and stiffness of the cartridge;
- Radial inlet and outlet ports (instead of radial inlet, axial outlet construction);
- Well defined sealing of the membrane to prevent all internal leakages;
- Easy removing/replacing of PT-100 internal temperature element (e.g. for calibration purposes) without de-pressurization of the system;
- Easy 'one man' exchangeability of the (aluminium) cartridge for inspection and/or transportation.

Precautions against anticipated pneumatic interferences of meters operated in parallel.
A metering skid of NMi TraSys consists of 5 identical rotary gas-meters on a header. From experience it has become clear that in piping configurations like this, a potential risk for pneumatic (harmonic) noise exists [11]. Pulsation generators, responsible for these phenomena, are identified (Figure 8).

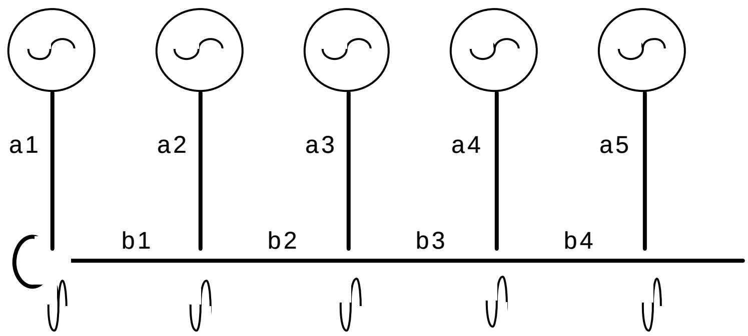


Figure 8, Schematic diagram of Noise Generation

- Gas flowing along a side-branch is able to cause an organ-pipe effect (whistling);
- Pneumatic excitation by pulsating rotary gas meters, even with the smallest amplitudes, is able to cause gas-resonances inside a tube;
- Pneumatic 'bi-poles' can arise if e.g. the sum of the pipe-lengths a1+b1 is equal to the pipe-lengths a3+b2. A symmetric standing wave with its knot at the 'T'-connection will be generated if random noise (pneumatic energy) is present in the system.

Simulation
A simulation program was developed at NMi VSL to forecast at which operating conditions suspicious situations could occur.
It was assumed that chances for resonances would increase if harmonics of the root frequency of the rotary gas-meter, organ pipe frequencies and/or bi-pole frequencies would coincide.

Main conclusions of simulation calculations
1. Compact dimensions of the skid, give smaller chances for coincidental frequencies, given the (procedural selected) flow-rates and inherent rotation frequencies of the gas-meters;
2. Equal branch pipe-lengths have to be avoided;
3. Each meter has to be isolated, not only at the inlet, but also at the outlet with shut-off valves;
4. Put flexibility in the piping configuration, e.g. to make it easy possible to mount additional spool-pieces (length) in the branches if required.

Final technical design and as-built situation of NMi TraSys
According to the requirements stated in the previous section, the design was made as shown next.

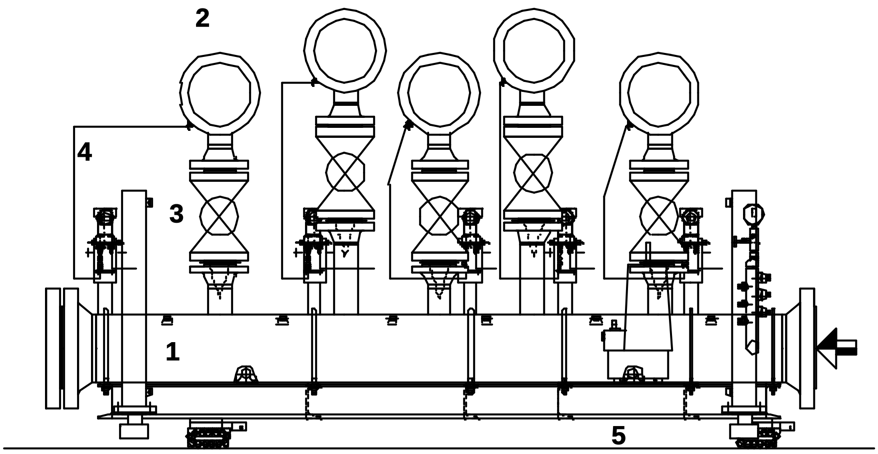


Figure 9 ,
Side View of Metering Skids 1 & 2

Legend
1. 12", ANSI 600 Header
2. 5* Duo-Rotary Gas-meters
3. Isolation with double block & bleed valve at inlet and outlet
4. Pulse lines and Reference pressure points
5. Hydraulic jack-up Skid

SPECIFIC ENGINEERING ISSUES FOR HEATE-EXCHANGE AND PRESSURE-REDUCTION SKID
A horizontal hot-water gas-heater of 850 kW serves also for better dead-weight stability. The installed flow-control valves for hot-water and cold-gas, control the temperature of the expanded gas.

The pressure-reduction skid is provided with an 850 kW heater to compensate for the temperature drop at gas expansion. The heater is somewhat over-dimensioned so that NMi TraSys can be used at various test-facilities. E.g. at the test-facility in Westerbork (Gasunie) it may be necessary to bring the gas temperature from 10 ^{0}C up to 20 ^{0}C to allow for comparisons at primary gas-conditions.
The selection of the 8" pressure regulation valve is based on the severe requirement that the down-stream gas-condition has to be absolutely free from pulsations and noise (super-sonic and sonic). Furthermore, the reproducibility and stability of the valve positioning mechanism has to be outstanding. The turn-down ratio of the valve configuration is specified at 1 to 2.000.

Conventional valves cannot cope with these requirements, therefore a "Dezurik" type *Raven Trim* was chosen. The working principle is shown in Figure 10. A large number of labyrinth disks are placed in a pile so that gas will flow through a number of corridors that connect the up-stream with the down-stream (low pressure) side of the valve.
The number of holes that are opened or semi-opened can be controlled by a moving plunger.
The cross-section area within one labyrinth channel is expanding towards the outlet openings while the gas expands to a lower pressure. So, during expansion, the velocity of the gas is kept far below sonic values, so that a smooth operation is warranted. A disadvantage may be that the controlling resolution of the valve is restricted to about half a disc height. The total stroke of the plunger is 120 mm.

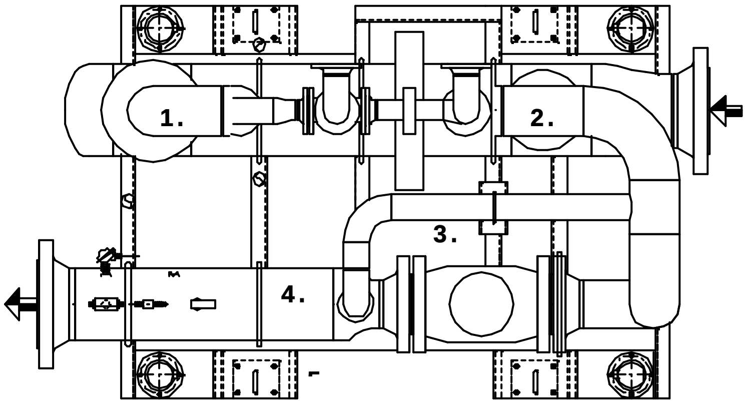
A comparable type of fine tuning valve of 1,5" is put across the 8" valve for control of the highest pressure drop (60 bar to atmospheric) at small actual flow-rates.

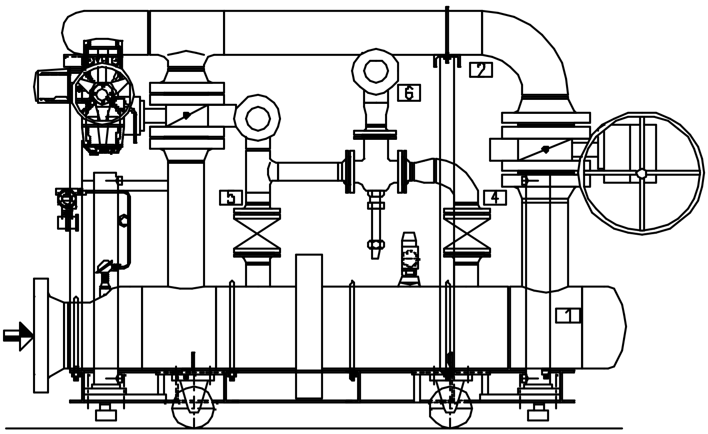
Figure 10,
Working principle of the pressure reduction trim valve "Dezurik", type *Raven Trim*.
Labyrinth disks give a smooth expansion of gas.
The expansion channels force the gas to change direction constantly during its passage. The energy of the expanding gas will be absorbed so that no sonic conditions will develop.

Construction of the Heat Exchange / Pressure Reduction Skid

<u>Figure 11</u>,
Top View of Heat Exchange / Pressure Reduction Skid

Legend
1. Heater configuration
2. 8" Heated gas line
3. 8" Pressure reduction valve and 4" fine-tune bypass-line
4. 12" ANSI #600 output line with pressure and temperature sensors and hydraulic jack-up skid





<u>Figure 12</u>,
Side View of Heat Exchange / Pressure Reduction Skid

Legend
1. 12" Heater
2. 8" heated gas output line
3. 4" Bypass with fine tune valve
4. 4" hot water return
5. 4" hot water send
6. 3 way hot water control valve

FIRST MEASURING AND EVALUATION RESULTS

Test setup

In the next picture, measuring skid-1 is shown during the tests carried out between November 2002 and February 2003. The metering skid is mounted in test-run # 1 of "Bergum". Note that the inlet and outlet connecting flanges are not in line.

Figure 13, Photograph of the setup in one of the meter runs of the "Bergum" facility

The output header of skid number-1 (photograph) can easily be mounted to the input-header of the reduction skid and the header of metering skid number-2. (not seen at the photograph)

In the period November 2002 to February 2003, metering skid-1 was extensively tested in "Bergum", the high-pressure test-facility of NMi VSL-Flow. The goal of these tests was to evaluate the handling and operating procedures, the performance of the deviation curves of the individual rotary gas-meters and the consistency when a facultative number of meters were put together in parallel operation. One 'watchdog' turbine meter was mounted in series down-stream of the skid to give an overall view of the stability of the individual performances in relation to the reference standards of 'Bergum'. Although previously extensively investigated with a Bell-Prover, the exchangeability of the cartridges was tested again to ensure the possibilities of a smooth exchange of these second generation rotary piston cartridges.

Deviation curves as a function of pressure

In figure 14, the dependency on pressure of the individual TRM's is shown. The 5 different symbols represent the 5 TRM's. Of each TRM, the average deviation curve for all tested pressures (8, 20 and 50 bar) is calculated and represented as a 'zero'-line. In this graph, the differences of the individual deviations to the own (individual) average are plotted.
The advantage of this representation is that changes in shape of the deviation curve per pressure can be evaluated. From the data in the figure one may conclude

1. consistency in the variation of the shape of the curve in relation to variation in pressure;
2. variations in deviations to pressure differences are very small for all TRM's;
3. a slight increase in spread can be observed at 400 m^3/h.

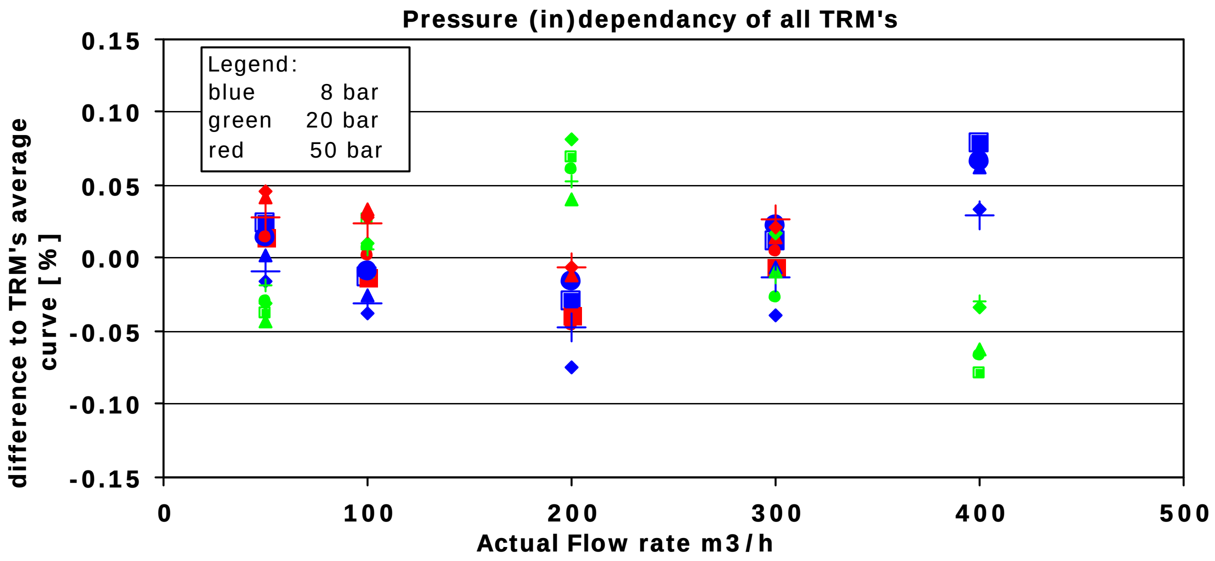


Figure 14, Dependency of TRM's on pressure

Conclusions about pressure dependency
No significant pressure dependency can be demonstrated here, assuming the natural statistical noise (background-noise) of the measurements to be ca. 0,05%.

Consistency tests, putting TRM's in parallel operation

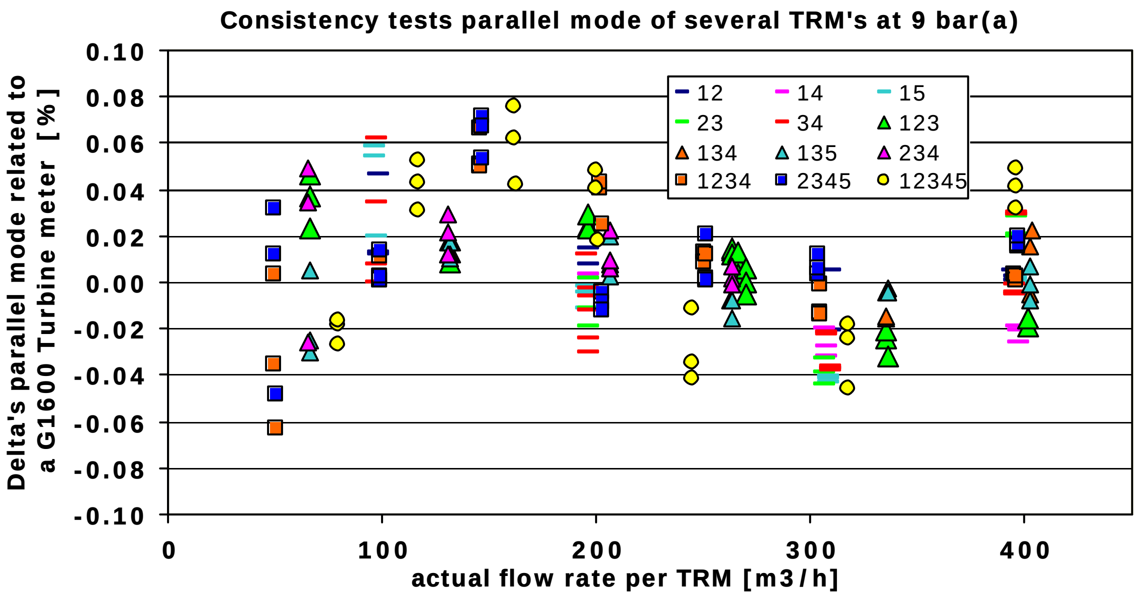


Figure 15, Consistency of parallel mode at 8 bar, the symbols refer to the combination of the TRM's numbered 1 to 5. E.g. 1-2-4 means : meter 1, 2 and 4 in parallel operation.

It is of crucial importance that the "n-1 theorem" [12] is demonstrated in a traceability chain that is dependent on parallel operation of reference meters. The boot-strapping procedure is based upon this back-bone in metrology.

The principle is not unique, a well known application of this method can be found e.g. in the field of mass determination where boot-strapping is carried out by placing a number of calibrated weights on a scale to determine the deviation of the scale at the total weight of the placed weights.
In the field of metrology of flow, the 'n-1 theorem' assumes that one can only prove consistency of a n-1 number of reference meters that are calibrated one by one and that are put into parallel operation. For example, when TRM number 1, 2, 3 and 4 are put into parallel operation, the generated reference value has to show the same value when it is determined by putting TRM 1, 2, 3 and 5 into parallel. The reason for not simply assuming that it should lead to the same results, is described in section "*Precautions against anticipated pneumatic interference of meters operated in parallel*".

The test-procedure is based upon cross-checking of a 'watchdog' G-1.600 turbine meter, which is mounted down-stream the metering skid. The deviation curve of this meter is determined via the reference meters of 'Bergum' (up to 2.000 m^3/h). The curves of the 5 individual TRM's of the metering skids are also determined via the 'Bergum' reference meters (each TRM up to 400 m^3/h). In a sequence of n!/(n-2)!/2! of possible combinations it is verified how the results of any twin operated TRM's relate to the other combinations.
The same counts for n!/(n-3)!/3! in trio combinations, n!/(n-4)!/4! for quartet combinations and finally n!/(n-5)!/5! for quintet operated TRM's. In NMi TraSys, n=5 which leads to a test sequence of

Number of combinations	*Type of combination*
10	Twins
10	Trio's
5	Quartets
1	Quintets
26	All combinations

In the previous graph, results of most of these combinations have been presented. The graph shows consistency in relation to the actual flow-rate of the TRM. One can determine the present actual flow-rate of the G-1.600 turbine meter by multiplying the actual flow-rate by the number of parallel operated TRM's

Now it will be clear that for one combination, viz. the one that puts all 'n' meters in parallel, one can not prove consistency as in the classical situation, only one combination is available. However in NMi TraSys with its second metering skid, a second 'quintet' is operational with which consistency can indeed be demonstrated.

Conclusion
From the test-results a significant correlation cannot be demonstrated to exist between the number and/or a specific combination of meters. So far, results seem to be excellent for the 8 bar condition. Similar tests at 20 and 50 bars are scheduled for the next few months.

FUTURE WORK
NMi VSL-Flow is scheduling to repeat the tests shown in the previous sections, in order to demonstrate the required long-term stability of the meters. Furthermore, a full calibration cycle needs to be carried out with metering skid-2 and the heat exchange / pressure reduction skid to copy a conventional re-calibration cycle (scheduled for November 2003). NMi VSL-Flow keeps the Flow-community informed about results and uncertainties.

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Post-Scriptum

As a National institute for Standards in Measurement, NMi VSL has a function to provide industry and society with applicable expertise and knowledge in Metrology, usually delivered as "Traceability Services". A prerequisite to this function for the Metrology of Flow is e.g., the capability to generate reliable reference values for high-pressure gas-flow measurements.
"NMi TraSys" is the creation of a mobile traceability-chain, realizing reference values covering wide ranges in pressure and flow-rates. Extending its capabilities NMi VSL keeps its dedication on track to reduce uncertainties in high-pressure gas-flow measurements. The anticipated small uncertainty of the Dutch traceability-chain will contribute to even smaller uncertainties via the Harmonization process.

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- ? Gasunie, High-Pressure Test-Facility (8-40 bar) – Groningen, The Netherlands
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