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THE D&H Z-METER USED AS VOLUME CORRECTING DEVICE
IN TURBINE METERING STATIONS.

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Summary

This paper describes a method to determine globally the correction factor ,using a D&H Z-meter, for the normalization of the gross volume flow rate measured by a turbine meter in a natural gas metering station.

1 INTRODUCTION

1.1 History

Since 1973, confronted with very large gas flow measurements, Distrigaz decided to develop orifice plate metering stations equipped with high precision digital instruments interfaced with a central minicomputer. The pressure and differential pressure were measured by Desgranges & Huot automatic deadweight balances (maximum error on reading values is lower than .1%). The base density and the compressibility of the gas were constant factors.

In the year 1975, the arrival of North Sea gas ,of variable composition, caused additional measurements. The objective was to measure if possible all the parameters of the ISO 5167 equation with a maximum allowable error of .1% of the measured value, together with a long term stability of several years without recalibration. At that moment the existing density meters and reference density meters had accuracies of about .2% and were dependent on the real gas composition. Moreover, there was no method accurate enough to predict the compressibility factor of natural gases from gas composition. The A.G.A. NX-19 method, depending on the gas composition, can reach a 1% error at high pressure for gases containing large amounts of higher hydrocarbons.

All these requirements and facts led Distrigaz to request the french manufacturer Desgranges & Huot to develop and build original devices independant of the gas composition: a buoyancy based density meter using a 1 liter sphere and a device measuring the compressibility factor , in fact the factor $(p.Z_n)/Z$, the "Z-meter". The density at reference conditions (p_n = 1.01325 bar, T_n = 273.15 K) is calculated from the equation : $\rho_n = \rho \cdot (p_n.T.Z)/(p.T_n.Z_n)$.

Later it appeared that the Z-meter integrated in volumetric metering

systems was the ideal corrector for variable composition gases.

At the present time, more than 25 Z-meters are in operation (six from 1976 and six from 1979 in orifice metering stations, the others later in turbine meter metering stations) and show performances exceeding the most optimistic expectations. Every check of the Z measurement on the site with pure methane and/or pure nitrogen shows a better than .1% agreement with the pure component data from the table. Due to its qualities and the ease with which it can be put into service, this instrument is also used intensively in laboratories. As several papers have already been written on it with regard to this application, it seemed useful to recall its industrial origin.

Recently,the Van der Waals Laboratory in Amsterdam sponsored by the "Groupe Européen de Recherches Gazières" (GERG) and the University of Oklahoma sponsored by the "Gas Research Institute" (GRI) have independently developed highly accurate equations to predict the compressibility factors for natural gases from knowledge of temperature, pressure and gas composition typically with an accuracy of 0.1 % for custody transfer conditions. But the uncertainties attached to the gas analyses and to the line pressure measurements have to be added to those of the equations. Another thing is that the programs using these equations take a big part of the computer memory and cannot run in our minicomputers in their actual state .

1.2 Base equation in volumetric metering systems

Turbine meters measure a gross volume flow ,i.e. the gas flow at pressure and temperature conditions of the meter. As it is customary to express gas quantities ,not in terms of mass, but in terms of volume, it is necessary to standardize the base conditions of this volume flow.

The "base" conditions referred to in this paper are the "normal" conditions, i.e. pressure p_n = 1.01325 bar and temperature T_n = 273.15K. The symbol for "normal m3" is m3(n). These conditions are

commonly used in continental western Europe.

The relation between the normalized volume Qc and the gross volume Q is defined by the following expression:

$$Qc \ (m3 \ (n)) = Q \ (m3) \ \frac{p \ T_n \ Z_n}{p_n \ T \ Z} \qquad (1)$$

where:

      p is the thermodynamic pressure of the gas expressed in bar.

      p_n is the base pressure (1.01325 bar)

      T is the thermodynamic temperature of the gas.

      T_n is the base temperature of the gas. (273.15 K)

      Z is the compressibility factor of the gas at pressure p et temperature T.

      Z_n is the compressibility factor at base conditions.

The factor $\dfrac{p \ Z_n \ T_n}{p_n \ Z \ T}$ is called "normalization (or "correction") factor"

The "Z-meter" is able to measure globally the factor:

$$\frac{p \ Z_n \ T_n}{p_n \ Z} \qquad (\text{ at the temperature of the Z-meter } T_z)$$

of gases, within a certain pressure and temperature range, with an accuracy better than .1 % . The additional measurement of the line temperature T_l is therefore sufficient to calculate the normalization factor.

2 COMPRESSIBILITY FACTOR

Conventional signs :

The symbol "T" means that the temperature is expressed in K, and "t" means that it is expressed in °C.

2.1 Definition

The equation of state of an ideal gas is written :

$$pV = nRT$$

where :

n is the number of moles contained in volume V,

R is the universal gas constant,

p is the thermodynamic pressure of the gas,

T is the thermodynamic temperature of the gas.

Real gases do not behave exactly as described by this law. To take this into account, the equation of state for real gases becomes :

$$pV = nZRT$$

Factor Z, which is a function of pressure and temperature, is called the "compressibility factor". Its value is therefore representative of the non-ideality of the gas. All gases being ideal at zero pressure, Z tends towards one when the pressure tends towards zero. This fact is essential to understand the various methods described below.

2.2 Operating principle of the Z-meter
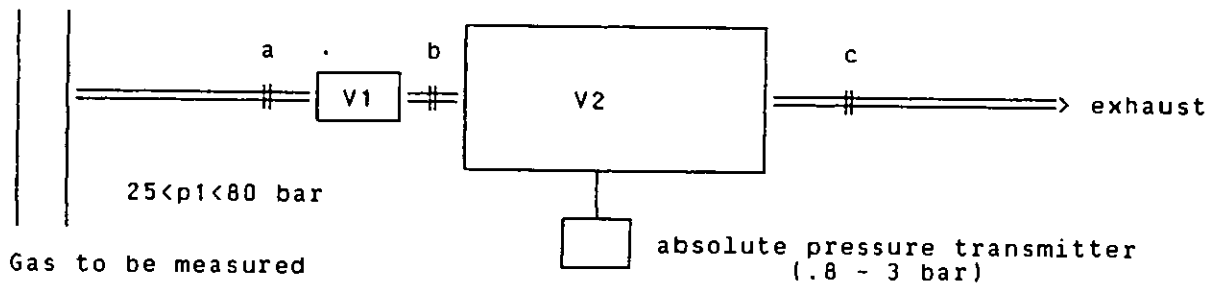
The Z-meter is composed of two volumes V_1 and V_2 of different sizes surrounded by a massiv metallic wall of great thermal inertia. The small volume V_1 (its capacity is about 20 cc) ,consisting of a 6 mm OD tube, is welded as a spiral arround the large cylindrical volume V_2 to improve thermal exchanges between them . The two volumes are isolated by three valves:

-the inlet valve a which links volume V_1 to the gas line of which
  compressibility factor has to be measured
-the by-pass valve b which separates the two volumes
-the exhaust valve c which links volume V_2 to the atmosphere

The three interdependent valves are driven by one pneumatic motor controlled by a solenoid valve.

The operation of the Z-meter is cyclic and may be divided into two phases :

- state 1 : valves a and c are open and valve b is closed.
        The law of real gases applies for the two volumes :

$$p_1 V_1 = n_1 Z_1 RT_1 \qquad (1)$$

$$p_2 V_2 = n_2 Z_2 RT_2 \qquad (2)$$

where : - n_1, n_2 are the numbers of moles of the gas

contained respectively in volumes V_1 and V_2

- p_1 is the pressure of the gas to be measured

- p_2 is the atmospheric pressure

- T is the temperature of the metal mass of the apparatus

- state 2 : valves a and c are closed and valve b is opened. The gas initially contained in volume V_1 expands to fill the total volume $V_1 + V_2$.

Once thermal equilibrium is attained, the pressure of the gas is stabilized at pressure P_3.

Temperature T is the same as before expansion, due to the large thermal buffer and the small amount of expanded gas. In this situation, the thermodynamic state is :

$$p_3 (V_1 + V_2) = (n_1 + n_2) Z_3 RT \qquad (3)$$

Combining these three equations and introducing the ratio $A = V_2 / V_1$:

$$\frac{p_1}{Z_1} = \frac{p_3 (A+1)}{Z_3} - \frac{p_2 A}{Z_2} \qquad (4)$$

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For gas metering, it is not the factor Z, i.e. the compressibility factor in p and t line conditions, which is important but the ratio between this factor and the factor Z_n , i.e. the compressibility factor in normal conditions:

Conventionally: $K = Z(p,t)/Z_n$

In the subsequent text, the "compressibility factor" or "factor Z" means the ratio K.

Multiplying the equation (4) by Z_n ,it becomes:

$$\frac{p_1}{K_1} = \frac{p_3 (A+1)}{K_3} - \frac{p_2 A}{K_2} \qquad (5)$$

2.3 Calculation methods

In equation (5), A is known by the calibration of the Z-meter (see section 2.4), P_2 and P_3 are measured by the same pressure transmitter . It then remains to determine K_2 and K_3 .

The method is based on an iterative calculation of K_2 and K_3 .

To apply this method, the line pressure P_1 must be measured with an accuracy of approximatly one percent, which is easily obtained by good industrial transmitters .

On an isotherm, in the metering pressure range of 0-80 bar, the K(p,t) function may be expressed by :

$$K(p,t) = 1 + A t + B (p-1.01325) + C (p-1.01325)^2 \qquad (6)$$

where :   A = 2.8E-5
           C = 2.0E-6

The coefficients A and C are average coefficients calculated for natural gases and vary little from one gas to another. The coefficient A takes into account the temperature dependance of K at 1.01325 bar. The variability with gas composition of coefficient C is larger than that of coefficient A.

It is possible to improve the method through specific determination of coefficient C for a gas or a family of gases, possibly as a function of temperature. For example, for the mixture 50% CH4 / 50% N2 , the C factor is 3.2E-5 which causes a difference lower than 2.E-4 for the K factor at 50 bar . This correction is important especially for laboratory measurements where the degree of accuracy must be as high as possible. In that case, the determination of the compressibility factor of an unknown gas is done in two steps. The first step consists to determine the K factors at several pressures with C=0 and then to calculate the C factor of equation (6) by a "least squares method" fit. The second step consists to reenter the calculation processus using the real C value . The non-linearity error is then eliminated .

If C is fixed, the only unknown quantity in equation (6) is coefficient "B" which represents the "slope" of the function.

The first step of the calculation is to fix the initial values :
K_2 =1 and K_3 =.998   for example.

Through equation (5) and as p_1 is measured by a transmitter, K_1 can be calculated . It is then possible, through equation (6), to calculate a first approximation of B as follows:

$$B = (K_1 - (1+A\ t) - C\ (p_1 -1.01325)^2) / (p_1 -1.01325)$$

Equation (6) is then totally defined and allows the calculation of two new values K_2' and K_3' . These two values make it possible to calculate K_1' using equation (5) and so on until the difference between two successive K_1 values is lower than 1.E-4 .

In practice, three steps are sufficient.

2.4 Calibration of the Z-meter

In equation (5) of section 2.2 ,the factor A is known and the values of p_2 and p_3 are measured by the same absolute pressure transmitter.

In theory, it is very tempting to try to measure volume ratio A directly, which would make the Z-meter a fundamental apparatus. However, this is impossible with the desired degree of accuracy.

The calibration of the Z-meter consists to determine the ratio A, using pure gases from which the compressibility table is precisely known, and to calculate the transfer function of its associated pressure transmitter. Nitrogen and methane are the most frequently used gases. Helium and argon were also used in evaluating the performances of the Z-meter prototypes.

2.4.1 Absolute Pressure Transmitter

Before determining the A factor, the absolute pressure transmitter must be calibrated. This is a "Rosemount" transmitter with an analog output of 4-20 mA. The current is converted into voltage by a 50 Ohms Sfernice shunt (accuracy 5.E-5) .

The voltage measurements are provided by Hewlett-Packard 3456A multimeters of which accuracy over the 1 V range is better than .0025%. A Fluke 332D voltage standard is used for periodical checking the multimeters. The pressure standard is a Desgranges & Huot type 8000 deadweight tester (0 to 10 bar abs). Its accuracy is .01 % of the measurement.

The transmitter, of which nominal span was 0 to 7 bar abs., is adapted to .8 to 3 bar abs. In fact, p_2 ,the atmospheric pressure, is always higher than .8 bar, and p_3 ,the pressure after expansion, is always lower than 3 bar at a maximum line pressure of 80 bar and with

the A ratio that has been choosen. After setting, numerous measurements
are taken at multiple points of span. The read voltages and the
corresponding absolute pressure values are noted.

The voltage second-degree polynomial expressed in "points" (volts
multiplied by 1.E+5), is calculated as close as possible, in the "least
squares" sense, to the pressure/voltage couples:

$$p = a + bV + cV^2$$

A critical examination of polynomial quality approximation may lead
to reject the transmitter if it behaves excessively in "S". In such a
case, the second degree form is not appropriate .

```
****************************************************************
*  Transmitter:8613744                                        *
*                                                             *
*  Voltage     Stand.pressure  Calc. pressure    Absolute     *
*  Points         bar abs.        bar abs.       Deviation    *
*                                                             *
*  100140        3.0020          3.0022         -.213E-03     *
*   92845        2.8019          2.8018          .652E-04     *
*   85590        2.6017          2.6025         -.774E-03     *
*   78281        2.4016          2.4016         -.244E-04     *
*   71011        2.2015          2.2018         -.306E-03     *
*   63714        2.0013          2.0010          .283E-03     *
*   56473        1.8012          1.8018         -.618E-03     *
*   49176        1.6011          1.6010          .857E-04     *
*   41905        1.4009          1.4008          .157E-03     *
*   34644        1.2008          1.2008          .466E-04     *
*   27419        1.0007          1.0017         -.987E-03     *
*   20136         .8005           .8009         -.339E-03     *
*   20120         .8005           .8004          .107E-03     *
*   27376        1.0007          1.0005          .198E-03     *
*   34623        1.2008          1.2002          .636E-03     *
*   41885        1.4009          1.4002          .727E-03     *
*   49175        1.6011          1.6009          .124E-03     *
*   56450        1.8012          1.8012          .150E-04     *
*   63708        2.0013          2.0009          .448E-03     *
*   71000        2.2015          2.2015         -.393E-05     *
*   78295        2.4016          2.4020         -.396E-03     *
*   85563        2.6017          2.6017         -.185E-04     *
*   92858        2.8019          2.8022         -.292E-03     *
*  100100        3.0020          3.0009          .108E-02     *
*                                                             *
*   a= .24539624E+00                                          *
*   b= .27602088E-04                                          *
*   c=-.73284406E-12                                          *
*                                                             *
****************************************************************
```

2.4.2 A Ratio

Now the evaluation of the A ratio may begin . It is a question of

making the Z-meter work at different pressures between 30 and 70 bar using a gas of high purity as standard gas, for example nitrogen or methane . The pressure of the gas is measured by a Oesgranges & Huot type 5500 deadweight standard balance (.005 % accuracy) . The atmospheric pressure measured by two barometers (.01% accuracy) in the laboratory has to be added to this pressure to obtain the absolute pressure p_1 .

Pressures p_2 and p_3 are measured by the absolute pressure transmitter using the previously calculated calibration polynomial.

The temperature of the Z-meter is measured, with an accuracy better than .05°C, by a double platinium resistance of which the value at 0°C was previously determined on a .0001% accuracy measuring bridge. The standard is a "Leeds and Northrup" platinium reference thermometer supplied with coefficients corresponding to the "IPTS-68" formulae, traceable to NBS standard .

The pure gas compressibility factors being known, all the parameters of equation (5) are defined and the A ratio can be calculated.

These measurements being repeated at different pressures, a series of A values are collected and averaged . At this step, standard deviation is generally better than .01 %.

```
Z-meter ·D&H      :265
Calibration gas :CH4
Transmitter      :8613744
P=a+b*V+c*V*V  : a= .2453971E+00
               : b= .2759763E-04
               : c=-.7323275E-12
Z-meter temperature 1 :R0=100.057 Ohms
Z-meter temperature 2 :R0= 99.927 Ohms
```

P1	P2	P3	T	Z1	Z2	Z3	A
71.0483	1.01783	2.57599	19.86	.87834	.99813	.99526	49.9204
71.0483	1.01775	2.57595	19.87	.87834	.99813	.99526	49.9191
71.0481	1.01769	2.57591	19.87	.87835	.99813	.99526	49.9179
71.0479	1.01753	2.57574	19.87	.87836	.99813	.99526	49.9177
71.0479	1.01745	2.57563	19.88	.87837	.99813	.99526	49.9183
71.0479	1.01746	2.57561	19.88	.87837	.99813	.99526	49.9188
71.0479	1.01743	2.57559	19.89	.87838	.99813	.99526	49.9181
71.0479	1.01751	2.57566	19.89	.87839	.99813	.99526	49.9179
71.0479	1.01755	2.57570	19.90	.87840	.99813	.99526	49.9174
71.0479	1.01757	2.57565	19.90	.87841	.99813	.99526	49.9190

```
*   Mean A :49.9185
```

P1	P2	P3	T	Z1	Z2	Z3	A
61.0436	1.01791	2.33113	19.91	.89374	.99813	.99571	49.9185
61.0435	1.01776	2.33097	19.92	.89376	.99813	.99571	49.9182
61.0435	1.01771	2.33095	19.93	.89377	.99813	.99571	49.9165
61.0435	1.01769	2.33096	19.94	.89378	.99813	.99571	49.9151
61.0434	1.01765	2.33087	19.94	.89379	.99813	.99571	49.9163
61.0434	1.01765	2.33084	19.95	.89380	.99813	.99572	49.9168
61.0433	1.01764	2.33083	19.95	.89380	.99813	.99572	49.9166
61.0433	1.01757	2.33074	19.96	.89381	.99813	.99572	49.9170
61.0432	1.01758	2.33070	19.96	.89382	.99813	.99572	49.9184
61.0432	1.01751	2.33069	19.96	.89382	.99813	.99572	49.9160

```
*   Mean A :49.9169
```

P1	P2	P3	T	Z1	Z2	Z3	A
51.0386	1.01774	2.09311	19.97	.90994	.99813	.99615	49.9179
51.0386	1.01744	2.09288	19.97	.90995	.99813	.99615	49.9148
51.0385	1.01745	2.09285	19.98	.90995	.99813	.99615	49.9167
51.0385	1.01746	2.09281	19.98	.90996	.99813	.99615	49.9183
51.0385	1.01733	2.09278	19.98	.90996	.99813	.99615	49.9139
51.0384	1.01730	2.09271	19.98	.90996	.99813	.99615	49.9152
51.0383	1.01726	2.09267	19.99	.90997	.99813	.99615	49.9150
51.0383	1.01722	2.09261	19.99	.90997	.99813	.99615	49.9160
51.0383	1.01723	2.09262	19.99	.90997	.99813	.99615	49.9157
51.0384	1.01735	2.09274	19.99	.90997	.99813	.99615	49.9159

```
*   Mean A :49.9159
```

P1	P2	P3	T	Z1	Z2	Z3	A
41.0338	1.01733	1.86245	19.99	.92675	.99813	.99658	49.9151
41.0337	1.01714	1.86229	20.00	.92675	.99813	.99658	49.9128
41.0337	1.01705	1.86219	20.00	.92675	.99813	.99658	49.9136
41.0336	1.01700	1.86213	20.00	.92676	.99813	.99658	49.9145
41.0337	1.01694	1.86210	20.00	.92676	.99813	.99658	49.9124
41.0336	1.01692	1.86208	20.00	.92676	.99813	.99658	49.9125
41.0335	1.01690	1.86208	20.00	.92676	.99813	.99658	49.9113
41.0336	1.01690	1.86207	20.01	.92676	.99813	.99658	49.9120
41.0336	1.01700	1.86210	20.01	.92676	.99813	.99658	49.9156
41.0336	1.01695	1.86210	20.01	.92676	.99813	.99658	49.9128

```
*   Mean A :49.9133
```

P1	P2	P3	T	Z1	Z2	Z3	A
31.0291	1.01687	1.63938	20.01	.94407	.99813	.99699	49.9123
31.0291	1.01678	1.63931	20.01	.94407	.99813	.99699	49.9106
31.0291	1.01677	1.63928	20.01	.94407	.99813	.99699	49.9123
31.0291	1.01677	1.63929	20.02	.94407	.99813	.99699	49.9113
31.0291	1.01682	1.63935	20.02	.94408	.99813	.99699	49.9105
31.0291	1.01682	1.63935	20.02	.94408	.99813	.99699	49.9097
31.0291	1.01680	1.63932	20.02	.94408	.99813	.99699	49.9115
31.0291	1.01673	1.63926	20.02	.94408	.99813	.99699	49.9099
31.0291	1.01682	1.63937	20.02	.94408	.99813	.99699	49.9081
31.0291	1.01683	1.63936	20.02	.94408	.99813	.99699	49.9104

```
*   Mean A :49.9107
```

```
    Mean A :49.9151    Standard deviation =.00304/49.9151=.006%
```

It would be possible to stop at this point and consider the Z-meter calibrated. However, another calculation is done to eliminate the small remainaing pressure effects .

2.4.3 New pressure transmitter coefficients

In fact, if we look at the results, we can see a small variation of ratio A with the pressure. This effect can be eliminated by recalculating new coefficients for the absolute transmitter using the mean A value previously determined .

A lot of compressibility values are collected, with the pure gas, all over the working pressure range. Each voltage value from the pressure transmitter in situations p_2 and p_3 , is memorized.

Pressure p_3 , expressed in bar, is calculated with the equation (5) in section 2.2 using the mean A value determined at the preceding calibration step. Pressure p_1 is always determined by the standard balance associated with high precision barometers.

The new coefficients of the second-degree polynomial fitting the pairs (voltage - pressure P_3) are calculated. This polynomial now constitutes the global "transmitter - Z-meter" conversion function.

For example, for the transmitter N° 8613744 ,the new coefficients are :

$$a= .24559733E+00$$
$$b= .27587092E-04$$
$$c=-.61207614E-12$$

2.4.4 Final A value

The last step consists to recalculate, at each pressure range, the A values using equation (5) and the new coefficients of the absolute pressure transmitter and to take the average of this values as final ratio A. The standard deviation is then always better than .005% .

```
Z-meter D&H       :265
Calibration gas :CH4
Transmitter       :8613744
P=a+b*V+c*V*V : a= .2455973E+00
              : b= .2758709E-04
              : c=-.6120761E-12
Z-meter temperature 1 :RO=100.057 Ohms
Z-meter temperature 2 :RO= 99.927 Ohms
```

P1	P2	P3	T	Z1	Z2	Z3	A
71.0483	1.01783	2.57616	19.86	.87834	.99813	.99526	49.9148
71.0483	1.01775	2.57612	19.87	.87834	.99813	.99526	49.9135
71.0481	1.01769	2.57608	19.87	.87835	.99813	.99526	49.9123
71.0479	1.01753	2.57591	19.87	.87836	.99813	.99526	49.9121
71.0479	1.01745	2.57580	19.88	.87837	.99813	.99526	49.9127
71.0479	1.01746	2.57578	19.88	.87837	.99813	.99526	49.9133
71.0479	1.01743	2.57576	19.89	.87838	.99813	.99526	49.9126
71.0479	1.01751	2.57583	19.89	.87839	.99813	.99526	49.9123
71.0479	1.01755	2.57587	19.90	.87840	.99813	.99526	49.9119
71.0479	1.01757	2.57582	19.90	.87841	.99813	.99526	49.9135

Mean A :49.9129

P1	P2	P3	T	Z1	Z2	Z3	A
61.0436	1.01791	2.33122	19.91	.89374	.99813	.99571	49.9150
61.0435	1.01775	2.33106	19.92	.89376	.99813	.99571	49.9146
61.0435	1.01771	2.33105	19.93	.89377	.99813	.99571	49.9129
61.0435	1.01769	2.33105	19.94	.89378	.99813	.99571	49.9115
61.0434	1.01765	2.33096	19.94	.89379	.99813	.99571	49.9127
61.0434	1.01765	2.33094	19.95	.89380	.99813	.99571	49.9132
61.0433	1.01764	2.33092	19.95	.89380	.99813	.99572	49.9129
61.0433	1.01757	2.33083	19.96	.89381	.99813	.99572	49.9135
61.0432	1.01758	2.33079	19.96	.89382	.99813	.99572	49.9149
61.0432	1.01751	2.33078	19.96	.89382	.99813	.99572	49.9124

Mean A :49.9134

P1	P2	P3	T	Z1	Z2	Z3	A
51.0386	1.01774	2.09315	19.97	.90994	.99813	.99615	49.9163
51.0386	1.01744	2.09292	19.97	.90995	.99813	.99615	49.9131
51.0385	1.01745	2.09288	19.98	.90995	.99813	.99615	49.9150
51.0385	1.01746	2.09285	19.98	.90996	.99813	.99615	49.9166
51.0385	1.01733	2.09281	19.98	.90996	.99813	.99615	49.9123
51.0384	1.01729	2.09274	19.98	.90996	.99813	.99615	49.9136
51.0383	1.01726	2.09271	19.99	.90997	.99813	.99615	49.9134
51.0383	1.01722	2.09265	19.99	.90997	.99813	.99615	49.9144
51.0383	1.01723	2.09266	19.99	.90997	.99813	.99615	49.9140
51.0384	1.01735	2.09277	19.99	.90997	.99813	.99615	49.9142

Mean A :49.9143

P1	P2	P3	T	Z1	Z2	Z3	A
41.0338	1.01733	1.86245	19.99	.92675	.99813	.99658	49.9153
41.0337	1.01713	1.86229	20.00	.92675	.99813	.99658	49.9130
41.0337	1.01705	1.86219	20.00	.92675	.99813	.99658	49.9138
41.0336	1.01700	1.86213	20.00	.92676	.99813	.99658	49.9147
41.0337	1.01694	1.86209	20.00	.92676	.99813	.99658	49.9127
41.0336	1.01692	1.86207	20.00	.92676	.99813	.99658	49.9127
41.0335	1.01690	1.86208	20.00	.92676	.99813	.99658	49.9115
41.0336	1.01690	1.86206	20.01	.92676	.99813	.99658	49.9122
41.0336	1.01700	1.86210	20.01	.92676	.99813	.99658	49.9158
41.0336	1.01695	1.86209	20.01	.92676	.99813	.99658	49.9130

Mean A :49.9135

P1	P2	P3	T	Z1	Z2	Z3	A
31.0291	1.01687	1.63935	20.01	.94407	.99813	.99699	49.9143
31.0291	1.01678	1.63929	20.01	.94407	.99813	.99699	49.9127
31.0291	1.01677	1.63926	20.01	.94407	.99813	.99699	49.9143
31.0291	1.01677	1.63927	20.02	.94407	.99813	.99699	49.9133
31.0291	1.01682	1.63932	20.02	.94408	.99813	.99699	49.9125
31.0291	1.01681	1.63933	20.02	.94408	.99813	.99699	49.9117
31.0291	1.01680	1.63929	20.02	.94408	.99813	.99699	49.9135
31.0291	1.01673	1.63924	20.02	.94408	.99813	.99699	49.9119
31.0291	1.01681	1.63935	20.02	.94408	.99813	.99699	49.9101
31.0291	1.01683	1.63933	20.02	.94408	.99813	.99699	49.9124

Mean A :49.9127

Mean A :49.9133   Standard deviation =.00130/49.9133=.003%

Now,the Z-meter is calibrated and characterized by 4 coefficients :
A,a,b,c.

2.4.5 Last laboratory check

An ultimate verification is made before the Z-meter leaves the
laboratory for a metering station to evaluate the accuracy of the
Z-meter in its outside working conditions. The Z-meter is equipped with
its field instruments which have been previously calibrated, i.e. the
gage line pressure transmitter for p_1 measurements and the temperature
transmitter for the Z-meter temperature measurements. Several Z-meter
expansions are carried out at different pressure levels with another
pure gas than the one used for the calibration. For example; if the
Z-meter has been calibrated with methane, the verification is done with
nitrogen. The measured Z values are compared with the compressibility
factors calculated from the table. The results showed until now always
a very good agreement between those values. The error is lower than
.01% at 50 and 60 bar ,and lower than .03% at 40 and 70 bar.


```
Comparison with Z table for N2
*********************************

Z-meter D&H       :265
Calibration gas :CH4
A factor          :49.9133
Transmitter       :8613744
P=a+b*V+c*V*V :  a= .2455973E+00
              :  b= .2758709E-04
              :  c=-.6120761E-12
Line pressure transmitter :8613720
P=a+b*V+c*V*V :  a=-.1856433E+02
              :  b= .8795945E-03
              :  c=-.1219839E-10
Z-meter temperature 1 :  R0=100.057 Ohms
Z-meter temperature 2 :  R0= 99.927 Ohms


**********************************************************
*     P          T          Z      ZTABLE    DEV.*1E-3*
**********************************************************
*   71.0806     21.43     .99640    .99614      .26    *
*   71.0810     21.44     .99639    .99615      .24    *
*   71.0813     21.45     .99637    .99615      .22    *
*   61.0595     21.47     .99517    .99518     -.01    *
*   61.0591     21.48     .99518    .99518     -.00    *
*   61.0588     21.49     .99516    .99519     -.03    *
*   51.0592     21.51     .99483    .99471      .12    *
*   51.0581     21.52     .99481    .99472      .09    *
*   51.0583     21.53     .99479    .99472      .06    *
*   41.0628     21.56     .99511    .99475      .36    *
*   41.0616     21.58     .99507    .99475      .32    *
*   41.0616     21.59     .99506    .99476      .31    *
**********************************************************
```

2.5 Method of transferring Z

This method, developed by Distrigaz, is usefull for predicting the value $K'(p',t')$ from the value $K(p,t)$, i.e. in other pressure and temperature conditions, without need for the gas composition. Its existence is fundamental in the Distrigaz metering systems.

2.5.1 Transferring in temperature (40 < p <70 bar):

$$K_f = (1 + (A+B\ K_i)(t_f - t_i))\ K_i$$

where   A = 1.8584E-2
         B = -1.8864E-2

The value of K_i must be between .80 and .94

The significance of this formula is that the local derivative of K in relation to the temperature, on an isobar, is a function of the local value of K. To get the most from this formula, it should be iterated in steps of 1 °C maximum. The smaller the step, the more symmetrical the method. This means that if we calculate K_f from K_i and then return to K_i on the basis of the K_f obtained, we end up with a K_i which is closer to the initial value.

Example : If K_i =.9, t_i =10°C and t_f =15°C

the value of K_f transferred with a 5°C step is .90723

and the return to the initial conditions gives K'_i=.90056, i.e. a difference of .06% .

The same transfer with an iteration step of 0.1°C gives K_f =.90696 and K'_i=.90001, i.e. a difference of .001% .

2.5.2 Transferring in pressure

The basic principle is that the function $K(p,t)$ can be expressed in the form (see equation (6) in section 2.3) :

$$K(p,t) = 1 + A t + B (p-1.01325) + C (p-1.01325)^2$$

where : $A = 2.8E-5$

$C = 2.0E-6$

Parameter B, the only unknown quantity in this expression, is determined through the known value $K(p,t)$.

I.e. for the transfer of $K_i(p_i,t)$ to $K_f(p_f,t)$:

$$B = (K_i - (1+A t) - C (p_i-1.01325)^2) / (p_i-1.01325)$$

It is now possible to calculate $K(p_f,t)$

This calculation method is a non-linear interpolation between the starting point and the value of K at normal pressure and at temperature t. Care must be taken for extrapolation when the initial pressure is lower than final pressure.

2.5.3 Combined transfers (pressure-temperature)

It is important to remember that the method for transfer in temperature is only valid at high pressure, ideally around 50 bar abs. Consequently, the transfer of conditions p,t to conditions p',t' is organized as follows :

    1: p,t   ---> 50,t
    2: 50,t   ---> 50,t'
    3: 50,t' ---> p',t'

A computer program for this procedure, written in "Fortran", is given in appendix A.

2.5.4 Accuracy of the transfer method

The different mean coefficients in the transfer formulae were fitted on the basis of the compressibility factor tables for some fifteen gases of extremely different compositions. The compressibility factor of these gases was measured in laboratory at various pressures and temperatures with an accuracy better than .1%.

The reason the temperature transfer has to be done at high pressure is that all the compressibility factors used to fit the equation were given for pressures between 40 and 70 bar which corresponds to .8 and .94 for the compressibility factors of those natural gases.

These gases cover a very wide range of compositions : N_2 from 0% to 15%, CO_2 from 0% to 5%, C_2H_6 from 0% to 9%, etc.

From the measured compressibility factors at 50 bar and 15°C, K factors were generated, within a pressure range of 0 to 50 bar and a temperature range of 0°C to 25°C, using the transfer method.

None of the transferred K values deviates by more than .1% from its experimental value.

Furthermore, in most cases an extrapolation to 60 or even 70 bar does not give rise to any errors greater than .1 %

The method was also tested for gases containing over 25% nitrogen or 25% CO_2. The .1% threshold is only crossed at the limits of the temperature range , i.e. towards 0 °C or 25 °C. Anyway, errors at these temperatures are lower than .2% if the pressure does not exceed 50 bar abs.

H2	CO2	CH4	C2H6	C3H8	I-C4H10	N-C4H10	NEO-C5H12	I-C5H12	N-C5H12	C-C5H10	>C5	O2	HE
13.93	.500	81.40	2.899	.396	.069	.079	.008	.020	.020	8.000	.072	0.000	.048

Pseudo-critical pressure: 44.66 Bar

Pseudo-critical temperature = -85.01 °C

Z_m = .99770 Z ref = .91305

T / P	0		5		10		15		20		25	
0	1.0023	.24E-06	1.0023	-.90E-05	1.0023	-.86E-05	1.0023	.33E-05	1.0023	.24E-04	1.0023	.54E-04
10	.9796	.15E-04	.9810	.15E-03	.9823	.26E-03	.9835	.35E-03	.9846	.44E-03	.9856	.52E-03
20	.9573	.86E-04	.9601	.20E-03	.9620	.42E-03	.9652	.54E-03	.9675	.65E-03	.9696	.75E-03
30	.9354	.21E-03	.9397	.36E-03	.9430	.46E-03	.9475	.55E-03	.9510	.64E-03	.9542	.74E-03
40	.9130	.35E-03	.9197	.40E-03	.9253	.38E-03	.9304	.37E-03	.9351	.40E-03	.9394	.48E-03
50	.8925	.63E-03	.9002	.39E-03	.9073	.17E-03	.9138	.00E+00	.9198	-.76E-04	.9252	-.39E-04
60	.8716	.93E-03	.8811	.33E-03	.8899	-.19E-03	.8979	-.59E-03	.9052	-.41E-03	.9117	-.84E-03
70	.8511	.13E-02	.8625	.23E-03	.8720	-.60E-03	.8825	-.14E-02	.8911	-.19E-02	.8989	-.19E-02

fig 1 : Relative deviation between measured K
and transferred K for a Slochteren gas.

H2	CO2	CH4	C2H6	C3H8	I-C4H10	N-C4H10	NEO-C5H12	I-C5H12	N-C5H12	C-C5H10	>C5	O2	HE
2.434	1.779	87.97	5.552	1.512	.186	.306	.083	.059	.064	.003	.091	0.000	.041

Pseudo-critical pressure: 46.27 Bar

Pseudo-critical temperature = -71.30 °C

Z_m = .99708 Z ref = .88375

T / P	0		5		10		15		20		25	
0	1.0030	.71E-04	1.0030	.62E-05	1.0030	-.45E-04	1.0030	-.82E-04	1.0030	-.11E-03	1.0030	-.12E-03
10	.9733	-.54E-03	.9751	-.39E-03	.9760	-.26E-03	.9784	-.14E-03	.9799	-.27E-04	.9813	.05E-04
20	.9437	-.94E-03	.9475	-.64E-03	.9509	-.35E-03	.9542	-.16E-03	.9573	.51E-04	.9601	.26E-03
30	.9143	-.11E-02	.9200	-.74E-03	.9254	-.43E-03	.9304	-.15E-03	.9350	.13E-03	.9392	.42E-03
40	.8851	-.10E-02	.8929	-.67E-03	.9001	-.37E-03	.9069	-.98E-04	.9131	.20E-03	.9189	.54E-03
50	.8560	-.63E-03	.8659	-.41E-03	.8752	-.21E-03	.8837	.00E+00	.8917	.27E-03	.8989	.63E-03
60	.8271	.59E-04	.8392	.53E-04	.8505	.67E-04	.8610	.14E-03	.8706	.34E-03	.8794	.65E-03
70	.7983	.11E-02	.8128	.74E-03	.8262	.47E-03	.8386	.34E-03	.8499	.41E-03	.8603	.71E-03

fig 2 : Relative deviation between measured K
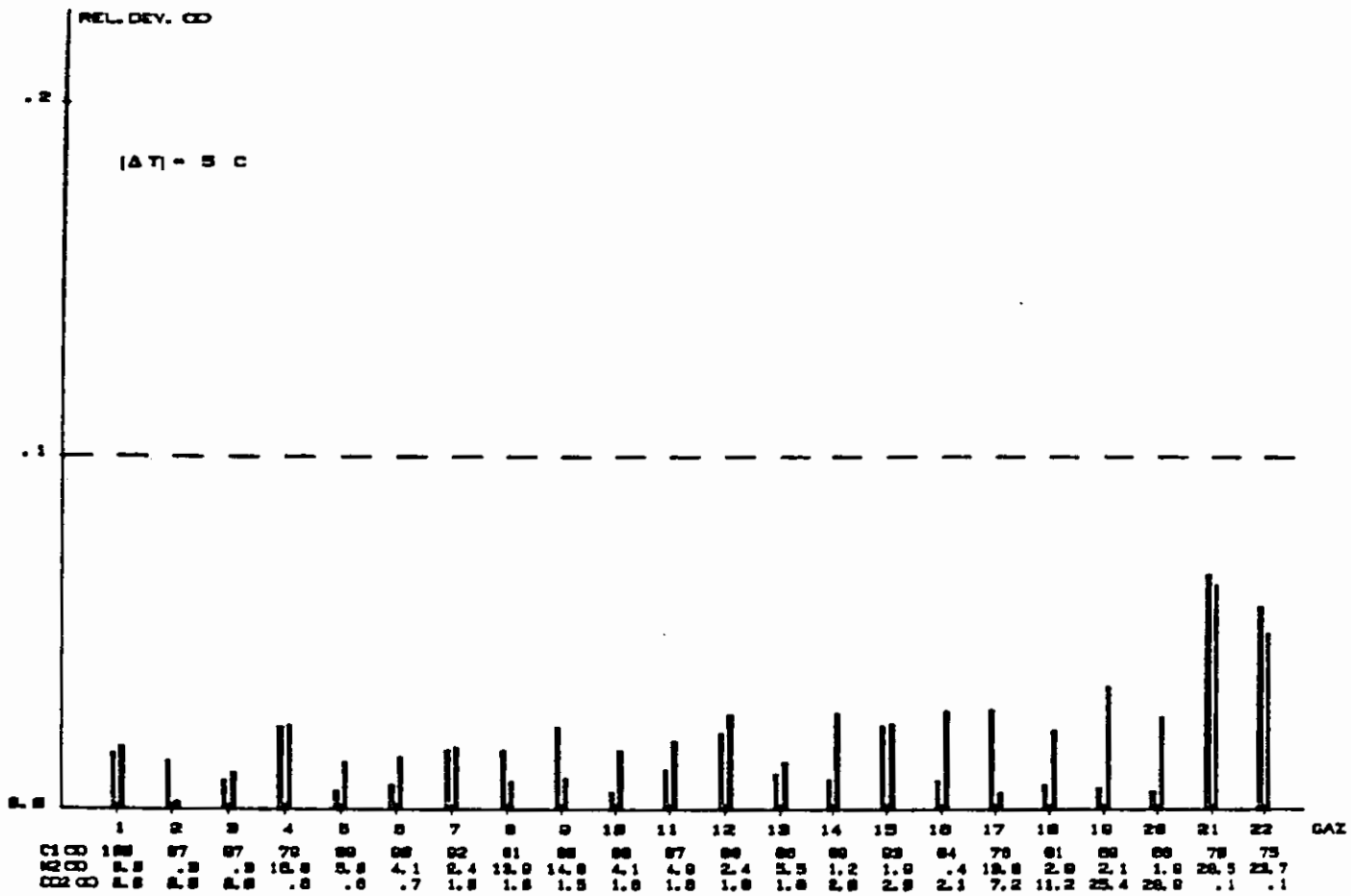and transferred K for an Ekofisk gas.
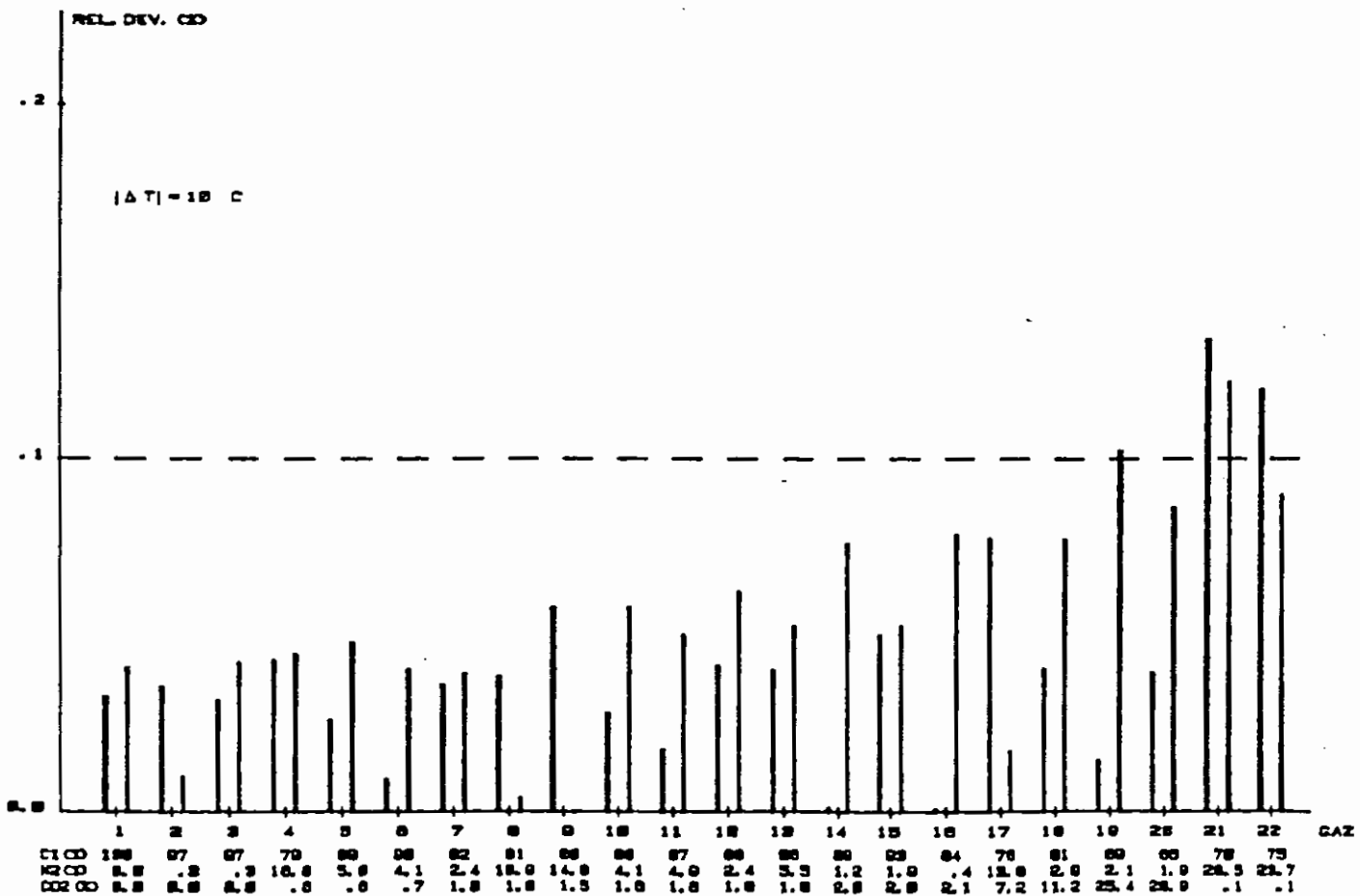
fig 3: 5 °C transfer errors at 50 bar.

fig 4: 10 °C transfer errors at 50 bar.

2.5.5 Physical interpretation of the transfer methods

The validity of the transfer methods for natural gases differing considerably in composition is so surprising that we tried to find a physical explanation.

Due to the "principle of corresponding states", we know that the function of state of all gases is identical if it is expressed in term of reduced temperature and pressure, i.e. the pressure or temperature quotient with the pseudocritical pressure and temperature of the gas. An examination of the critical pressures of the various components of natural gases shows that they are extremely similar, with the exception of CO_2.

This explains the low variation from one natural gas to another of the $2.10-6$ curvature coefficient of the K function expressed on an isotherm. This allows K to be transferred in pressure by non-linear interpolation between the two values, one of them being the K value at base pressure, which can be accurately estimated for all natural gases.

The explanation for the good performance of the transfer method for temperature is different. The critical temperatures of the natural gases components are more different than their critical pressures.

They are not, therefore, in a "quasi-corresponding" state on an isobar.

The value of the compressibility factor of these gases at 50 bar, for example, is then an indication of the non-corresponding state at this pressure. It therefore shows in which "part" of the general equation of state this gas takes place for this pressure. It is not surprising, therefore, to find a link between the local value of the K factor and the local variation of this factor with respect to the temperature. This linear relationship allows transfer in temperature.

The principle of corresponding states being only an approximation, it is logic that the transfer method performs well only within a limited pressure and temperature range.

3 INSTALLATION OF THE Z-METER IN TURBINE METERING STATIONS
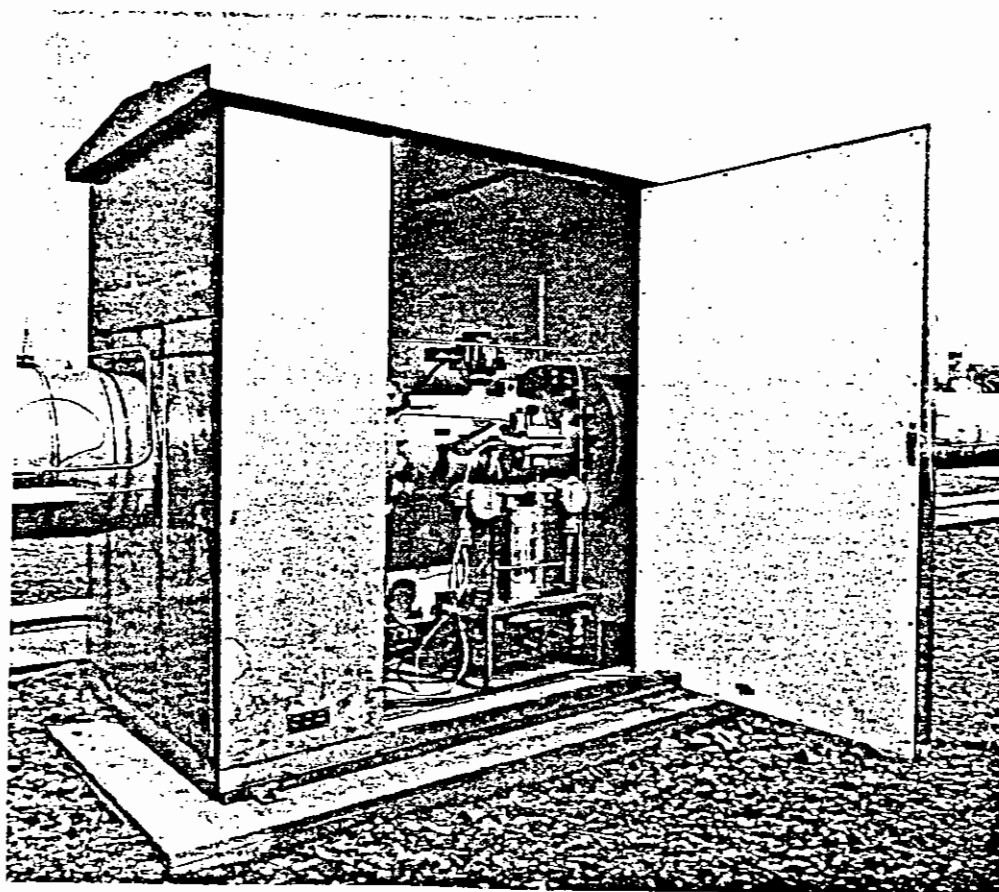
3.1 Installation Conditions

fig 5.

The Z-meter is installed close to the turbine meter, in a small aluminium cabin enclosing the meterrun. The cabin, including a wooden floor, is thermal insulated. The gas pipe acting as an exchanger, the temperature in the cabin is kept close to that of the gas. Usually, the difference is lower than 5°C. Features of this installation are the good shielding of the turbine meter mechanical index and the ease of its dismantling for meter removal.

3.2 Installation Equipments

TURBINE METER METERING SYSTEM
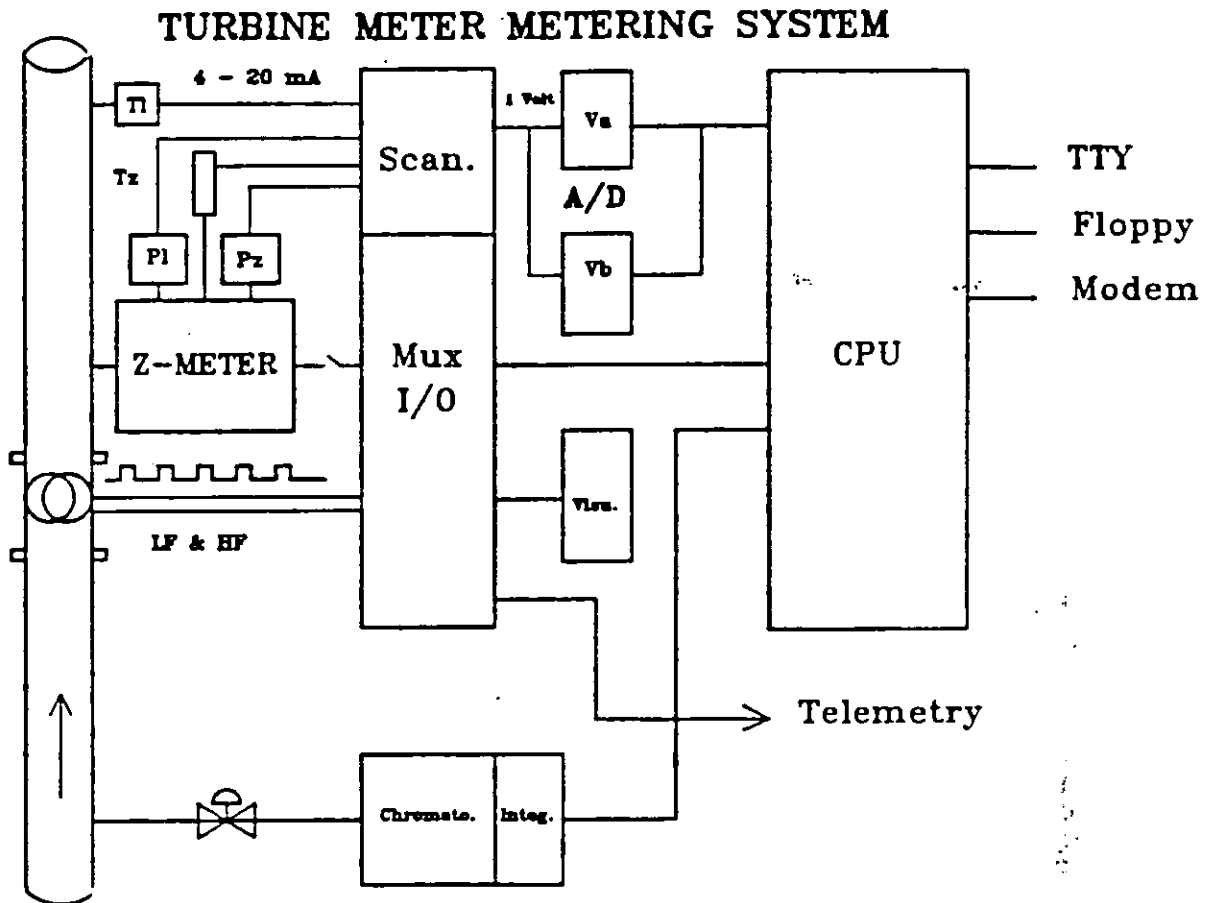
fig 6

3.2.1 Computer Equipment

The metering systems of Distrigaz are equipped with Hewlett-Packard 21 MX series minicomputers of which "RAM" memory has a capacity of 64 kbytes . All the software has been written at Distrigaz in Assembler. Mini-floppy diskettes with a capacity of 130 kbytes are used to store the "program code", the parameters qualifying the installation and the metering results. A printer-console allows man-machine commumication to

change, for example, some metering parameters and prints out all the metering results and the various events of the metering station. The Hewlett-Packard 6940B multiprogrammer has various functions, such as the turbine meter pulses counting, the pressure and temperature transmitter channels scanning, analog outputs, digital in- and outputs, etc. The voltage and resistance measurements are made by two parallel multimeters of the type HP 3455A or Fluke 8840A of which accuracy is better than .01 % .

3.2.2 <u>Pressure transmitters</u>

The pressure transmitters are manufactured by Rosemount. They produce an analog output of 4 - 20 mA. The current is converted into a voltage of .2 to 1 V by a 50 Ohms, .005% precision Sfernice shunt.

Their range is adapted to suit the metering conditions. As it is described in section 2.4.1., the Z-meter absolute transmitter, of which nominal span is 0 to 7 bar abs., is reduced to .8 to 3 bar abs. . For line pressure measurements, the most currently used transmitters have a 0 to 70 bar nominal range which can be adapted for higher pressures.

The transmitters are calibrated in the laboratory. It consists in calculating the voltage second degree polynomial expressed in "points" (volts multiplied by 1.E+5) as close as possible, in the "least squares sense", to the pressure/voltage couples:

$$p = a + b V + c V^2$$

Later on, the transmitter will never be altered again. The adjustment potentiometers are permanently sealed. If recalibration was necessary, only coefficients a, b and c will be changed. This policy allows to trace the transmitter history more efficiently.

The pressure standards are those described in section 2.4 .

The accuracy of the transmitters given by the manufacturer is +/-
0.25% of the calibrated span at the temperature of the calibration. But
the study that we have undertaken about the temperature behaviour of
some ten transmitters has revealed some significant deviation of
several "per thousand" with twenty degrees increasing or decreasing.
The results are however within the manufacturer specifications.

The deviation is mainly a zero shift, the curves beeing parallel to
themselves This fact is very important. As we shall see further on, for
the specific use of the transmitters with the D&H Z-meters, a zero
shift has no significant influence on the Z measurement. Care must be
taken for line pressure transmitters whose accuracy is directly
affected by a shift in temperature. The transmitters choosen by
Distrigaz are selected by Rosemount for their stability in temperature.
Their temperature behaviour is now systematically studied in our
laboratory and the maximum zero deviation that is tolerated on a 20°C
range is .2% .

As we shall see further on, this deviation is of little importance
for the correction factor determined by the Z-meter, but has a great
influence on the accuracy of "reference Z".

3.2.3 Temperature transmitters

The temperature transmitters are manufactured by Degussa. They
produce a signal of 4 to 20 mA for a range of -10 °C to +35 °C.

The transmitters are calibrated in the laboratory from 5 to 35°C .
The output current is converted into a voltage of .2 to 1 V by a 50
Ohms, .005 % precision Sfernice shunt. The standard is a Pt 100
resistor of which resistance at 0°C has been previously determined by
the method described in section 2.4.2 . It is used only in the
laboratory as transfer standard . Calibration consists in calculating
the voltage first degree function for the temperature, the voltage
beeing expressed in terms of "points" (volts multiplied by 1.E+5),
fitting the calibration points by the least squares method. Each
transmitter is therefore qualified by two coefficients :

$$t = a + b V$$

The accuracy on the temperature measurement is always better than .1°C .

3.2.4 Turbine flow meters

The recent introduction of several high pressure natural gas calibration rigs enables the use of turbine meters for high precision metering installations. Some of our meters have been tested on three or even four calibration facilities working at various pressures between 8 and 62 bar. More often than not, the results show accordance between the different curves within half a per cent. Modern calibration laboratories, on the other hand, claim an absolute accuracy of .3 % . We think, therefore, that using any curve established above 8 bar by one of these laboratories should guarantee an absolute accuracy of about .5%.

The accuracy on the discharge coefficient, used for orifice metering, is of the same level. At the present time, there is no clear advantage in using one method rather than the other.

However, the lower installation cost, shorter and more accurate instrument chain, the greater rangebility and the recording of gross volumes by a mechanical counter without electric power, give turbines the advantage over orifices.

In order to derive maximum benefit from the intrinsic qualities of turbine flow meters, the installation should be standardized. We are thinking here of the straight sections before and after the meter and the use of a flow straightener.

Research is underway in this field (draft ISO Standard in discussion in the TC 30 committee) .

Through the lack of any standardization, the normal installation conditions at Distrigaz are as follows :

- conical filter and "Sprenkle" type straightener, at 5
  diameters after the inlet valve
- straight section in front of the meter : 15 diameters
- straight section after the meter : 7 diameters
- heat-insulation of total meterrun.
- pressure (or the compressibility coefficient) measured
  at the "Pr" connection of the meter;
- temperature is measured downline, after the 7 diameters of
  straight section.

Recently, upon the request made by Distrigaz, the manufacturer
"Instromet" has integrated the temperature transmitter in the turbine
meter itself. Three of these meters are used now in Zeebrugge and show
very good performances (differences between the temperatures measured
on three parallel lines are always lower than .1°C) . This will perhaps
allow in the future reducing of the meterrun insulation. A study will
be carried in this respect.
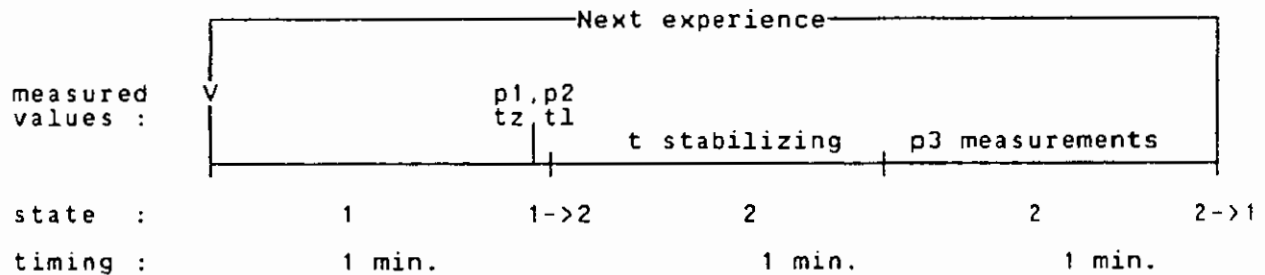
Preferably, the turbine meters generate two independent signals :
- A low frequency signal "LF" (< 1 Hz) from the meter index.
- A high-frequency signal "HF" (< 1,500 Hz) from the vanes   `
  of the turbine impeller picked off by a proximity detector.

The LF and HF pulses accumulate in electronic counters of 4 and 8
bits respectively . Preferentially, the computer uses the HF channel
for metering. This is the shortest chain as the signal is generated
directly by the vanes of the meter. In addition, the higher frequency
level gives a better resolution for calculation of the instantaneous
flow rate of the installation. If there is a problem with the HF
signal, its disappearance in particular, the computer switches to the
LF signal to continue the metering.

3.3 Z-meter measuring cycle

The Z-meter is a cyclical apparatus. The absolute pressure measured by the transmitter has not the same significance at every moment.

```
                ┌──────────────────Next experience────────────────────────┐
                │                                                          │
measured    V   │              p1,p2                                       │
values :    │   │              tz tl                                       │
            │   │                   │ t stabilizing │ p3 measurements      │
            │   │                   │               │                      │
            └───┴───────────────────┴───────────────┴──────────────────────┘

state :              1               1->2        2               2            2->1

timing :          1 min.                      1 min.          1 min.
```

When the apparatus is in state 1, the measured pressure is the barometric pressure, p_2 . This value, the line pressure p_1 , the temperature of the gas in the Z-meter t_z and in the line t_1 are memorized by the computer just before the Z-meter passes to state 2.

Passing to this state, the gas at pressure p_1 imprisoned in the small volume, is expanded and fills both volumes. The gas temperature decreases in the small volume and increases in the large one . The thermal exchange will stabilize the temperature after about one minute, as proved by a stable pressure p_3 . The gas temperature has become that of the metal mass and is practically identical to that of the gas before expansion (difference lower than .02°C) .

The computer memorizes the values of p_3 measured during the following minute and uses the average . No deviation of more than .01% between the extreme values is tolerated. Otherwise, this would indicate a leak from valve a (inlet) or valve c (exhaust), depending whether pressure p_3 is increasing or decreasing.

After this and other, mainly boundary tests, for example p_2 must be between .8 and 1.2 bar, the computer calculates the $K(p, t_z)$ factor .

The timing of one complete Z-meter cycle is 3 minutes .

3.4 Reference Z

"Reference Z" means the compressibility factor K at reference conditions : p = 50 bar and t = 15°C .

The value of 50 bar was chosen because it is close to the operation pressure of the Z-meter in the large metering stations (between 45 and 55 bar abs.) and it is mostly above the pressure normally wanted for the compressibility factor. The extrapolation will therefore never be too large .

The existence and the reliability of the transfer method described in section 2.5 has made the notion of reference Z possible .

Many reasons have led to the elaboration of this notion :

3.4.1 Asynchronism problem

The flow computer, including a quartz-crystal clock, operates in real time . The computer scans the state of the LF and HF counters of the turbine meter ten times a second . It controls the crossover of the two accumulators and conducts certain validity tests on the data . The result is a gross volume .

Every 10 seconds, the computer calculates the instantaneous volume of the station at base conditions, summing the quantities of gas passing through each meterrun and using the normalization factor in equation (1) .

The calculation is possible if the following procedure is followed. The pressure and temperature of the gas are measured several times during the cycle of ten seconds and averaged . After the 3 minutes Z-meter cycle, the computer calculates the $K(p, t_z)$ factor and determines the "reference K" . This factor is kept in memory and after each 3 minutes, the new measurement replaces the preceding value of reference K .

This factor will be used every 10 seconds to calculate the normalization factor, transferring the reference K to the line conditions .

This notion simplifies the software because only one value is stored and read in the computer memory . Moreover the accuracy on the K measurement is not altered by passing through an intermediate reference K rather than calculating directly the K factor from the initial conditions. This is due to the fact that the differences between the final and initial conditions are :

$$| t_f - t_i | < 5 \ ^\circ C$$

$$| p_f - p_i | < 5 \ bar$$

For example,

if the values measured after the 3 minutes Z-meter cycle are:

$p_1 = 61$ bar, $t_z = 9^\circ C$ and $K = .8419$

and the values measured at one computer cycle are :

$p_1 = 62$ bar, $t_1 = 4^\circ C$

the value of K directly calculated is .82721 and the value calculated passing through $K(50,15)$ is .82722 .

An important remark is that, due to the fact that the Z-meter cannot be installed inside the meterrun, a transfer of K from the Z-meter temperature to the line temperature is always obligatory even if the temperature and the pressure have not changed during the Z-meter cycle.

3.4.2 Mean K value

A possible use of reference K consists in averaging the compressibility factor measurements daily and/or hourly. This factor, pressure and temperature dependent, should first be brought to reference conditions before an average can be made.

This daily average of reference Z for each gas enables, through the transfer method, the creation of a table of K factors for every

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pressure and temperature in the normal range of metering.

In Belgium a natural gas is always qualified by its reference K.

It is important to note that in this case, the pressure p_1 measured by the transmitter must be as precise as possible .

3.4.3 Telemetry

Another possibility is that reference K could be remotely transmitted in digital or analog form to other metering stations. A central measuring station with a Z-meter could update, in this way, the compressibility function for metering stations receiving the same gas .

3.4.4 Intercomparison

If the metering station is equipped with parallel runs and several Z-meters are measuring the same gas, it is possible to compare the different "reference K" and detect a possible discrepancy. It is important to note that this comparison includes the eventual error of the associated line pressure transmitter .

3.5 Z-meter on-site verification.

As it is just hereabove mentionned, a simple check can be made if there are multiple Z-meters measuring the same gas through the comparison of the "reference Z" values .

If a problem with one of the Z-meters has been detected or if there is only one Z-meter, the following method is applied . The valve between the meterrun and the Z-meter is closed and a bottle of pure methane is connected to the entry of the Z-meter . After about five samples, a steady reading of the output is obtained. "Reference Z" of methane is printed out every 3 minutes and can be compared with the

value of the table. This is done at various pressures from 60 to 40 bar.

When in agreement, the verification is terminated. If not, a portable D&H deadweight standard, with an accuracy of about .1%, is used to check the origin of the discrepancy .

If the transmitter is defective, it is replaced by another one which has been previously calibrated in the laboratory. If there is another problem, the Z-meter is send back to the laboratory for a more detailed examination. This will occur, for example, if there is a problem with the absolute pressure transmitter of the Z-meter.

4 ACCURACY OF THE Z-METER

4.1 Intrinsic Z measurements accuracy

The intrinsic accuracy is the basic accuracy obtained in the laboratory for Z or K measurement, taking into account that the precision for the high pressure measurement is lower than .005% if the laboratory is well equipped. Intrinsic accuracy evaluation is based on the following experimental facts : The standard deviation of the A volume ratio determination is lower than .005%. The Z-meter instrument error, within a 95 % confidence level, is then better than .01% in the temperature range for which the Z-meter was calibrated..

To this error shall be added the uncertainty of standard gas compressibility values used to calibrate the Z-meter .

Nitrogen was normally used for this purpose. Other gases such as methane, argon and helium also are utilized. It has to be noted that the compressibility of these gases sometimes differ appreciably. For instance, the helium Z value, practically linear in pressure, is above 1 within the usual pressure range. Thus, it was very interesting to confront the K measurements for helium, methane and argon by a nitrogen calibrated Z-meter with up-to-date tables.

This comparison was carried out at 50 bar and at laboratory temperature (23°C). Obtained results:

Methane : deviation < .01 % .
Helium : deviation < .02 % .
Argon   : deviation < .04 % .

The table used for methane is a fit of the Douslin measurements. Recently a new table for methane has been elaborated based on fitting 297 measurement points obtained from the compressibility factors determined by Trappeniers (1979), Douslin (1964),Schamp (1958),Roe (1972) and Vennix (1970) . These points have been used in the creation

of the GERG and GRI "Data Bank". The accuracy of this table is about
.02% at custody transfer conditions .

The close agreement between these values and those for nitrogen
allows to claim a total .035 % accuray on Z-meter calibration, i.e.
.005% due to the pressure standard, .01% due to the Z-meter itself and
.02% due to the standard Z table uncertainty.

We have no information on the real accuracy of the helium table. Its
compressibility function linearity, its originality (Z>1) and the
remarkable correspondence with the other measurements are a
supplementary proof of the Z-meter precision and its independence of
the nature of the gas.

4.2 Accuracy as a corrector

This is the fundamental topic as it concerns the use of the Z-meter
to determine the p_1/K_1 factor, i.e. the normalization factor except for
the temperature measurement.

4.2.1 Uncertainty on the line pressure transmitter

The pressure p_1 is measured at two levels of the calculation
process. The ratio p_1/K_1 being determined globally, it will be seen
that an error on the p_1 measurement will produce an attenuated error on
the ratio itself .

1) The iterative method described in section 2.3 uses successive
approximations of K_1 to calculate K_2 and K_3. K_1 is directly
affected by the error on p_1 . The final error on the p_1/K_1 ratio
will be around 25 times lower than on p_1.

If, for example, A=50, T=20°C, p_2 = 1 bar and p_3 = 2 bar the
value of K calculated by the iteration method will give K_1 = .96036
for p_1 = 50 bar and a ratio p_1/K_1 equal to 52.0638

A 1% error on the line pressure ,i.e. p_1 = 50.5 bar will give K_1 = .97036 and a ratio equal to 52.0425, i.e. a difference of .04% .

2) The other use of the separate p_1 is due to the discontinuity of the Z-meter measurements. As it has been seen in the section "Reference Z" , the p_1/K_1 factor is measured "globally" only every 3 minutes .

The pressure variation between the moment "t" when p_1/K_1 is measured and moment "t'" when normalization factor is calculated has to be taken into account. Only the pressure transmitter drift between two successive Z-meter measurements would have any significant effect on the accuracy of the p_1/K_1 factor within the normalization factor .

A numerical example will illustrate this :

Let us suppose that at moment "t" the conditions are those of the previously example : p_1 = 50 bar, the corresponding K_1 factor is .96036 and the accuracy of the Z-meter is infinite.

Supposing the pressure transmitter at that time has drifted and indicates 50.5 bar, the K_1 factor calculated from this pressure will be .97036 . Of course, it is directly affected by the pressure error.

Considering moment "t'". The exact pressure at this time is, for example, 51 bar and the K_1 factor, which is calculated from K(50,15) using the transfer formula, is .95964 . The exact p_1/K_1 ratio at this instant is then 53.1449 .

The measured pressure will be 51.50 bar . As the interval (t'-t) is small, the transmitter error shall be practically the same as at instant t.

Calculating the K_1 value at 51.5 bar from the value of this factor at 50.5 bar gives .96985 . The calculated p_1/K_1 ratio is then 53.1010 .

The difference relative to the real factor is .08 % .

In this simple example a 1 % error on the p_1 measurement has affected the p_1/K_1 ratio only by an error 12 times lower.

In addition to the function as a "Z-meter", it was demonstrated that this instrument considerably reduces the impact of the line pressure error.

4.2.2 Inaccuracy on the Z-meter pressure transmitter

As shown in equations (4) and (5) of the section 2.2, p_2 and p_3 values are very important in the determination of the Z factor by the Z-meter.

As indicated above, the basic accuracy of this apparatus is better than .1 % . Experience with about twenty such instruments used in metering stations shows that this precision is maintained for several years without absolute pressure transmitter recalibration.

All the checks carried out have proved that measuring errors were always within .1 % .

This accuracy and metrological stability seem paradoxal considering the industrial specifications of the transmitters used.

In fact, it is not a miracle at all. The results are explained by a critical examination of equations (4) and (5).

In equation (5), ratio A is about 50, K_2 is about 1 and K_3 is around .998. The second part of the equation is roughly :

$$51.10 \ p_3 - 50 \ p_2 .$$

As p_3 and p_2 are measured by the same transmitter, it is evident that any zero drift does not significantly affect the value of the

equation, i.e. K_1/p_1 . A short calculation shows the attenuation factor is at least 25.

Considering the particularly suitable conditions for the device installation, no zero deviation above 5 mbar has ever been observed. Such a deviation would only give .01 % error on p/K.

5 CONCLUSION

Our experience of several years prove that the Z-meter is a sturdy and reliable instrument . More than five hundred thousand expansions are currently carried out before a leakage problem of the valves can appear.

This apparatus is not fundamental, but calibrated with a gas which characteristics are known, it allows the measurement of the compressibility factor of any gas.

Thanks to its speed, it can be used in sequence in any process including gas flow measurements. Moreover, if the gas composition is variable, it is the ideal corrector to normalize the gas flow rate measured in turbine metering systems. Its accuracy on the P/K measurement is always better than .1% .

APPENDIX A   Z-TRANSFERRING PROGRAM:

```
                               /
          PROGRAM TRANZ,REV 27.01.84
C
C         **********************************************************
C         *                                                        *
C         * This program is used to compute  K(PF,TF)              *
C         * from K(PI,TI) .                                        *
C         *                                                        *
C         * The iteration step is about .01 °C                     *
C         *                                                        *
C         * Test values:     TI=15 PI=50 KI=.9000                  *
C         *                  TF=0  PF=25 KF=.9379                  *
C         *                                                        *
C         *                                                      *:
C         * !!!!!!!!! ONLY VALID FOR Z/Zn (K)       !!!!!!!!!    *¯
C         **********************************************************
C
C         Main Program
C         ------------
          LU=1
          WRITE(LU,1000)
          READ(1,*)TI,TF,PI,PF,ZKI
C
C         I are initial conditions
C         F are final conditions
C
C         From K(PI,TI) to K(50,TI)
C         -------------------------
          PPF=50.
          CALL TRPRES(TI,PI,PPF,ZKI,ZKF,B)
          ZKI=ZKF
          IF(TI.EQ.TF)GOTO 200
C
C         From K(50,TI) to K(50,TF)
C         -------------------------
          DELT=TF-TI
          IH=ABS(INT(DELT*100))
```

```fortran
      HH=DELT/IH
      DO 1 I=1,IH
      CALL TRTEMP(HH,ZKI,ZKPF)
    1 ZKI=ZKPF
C
  200 CONTINUE
C
C     From K(50,TF) to K(PF,TF)
C     --------------------------
      PPI=50.
      CALL TRPRES(TF,PPI,PF,ZKI,ZKF,BB)
      ZKI=ZKF
C
      WRITE(LU,1200)PF,TF,ZKI
C
 1000 FORMAT(2X,"ENTER THE FOLLOWING DATA:",/,2X,
     +"TI,TF,PI,PF,K(PI,TI)",/)
 1200 FORMAT(2X,"Value of K(p,t) for P=",F6.2,X,"bar"
     +,X,"and T=",F6.2,X,"DEG.",X,"is:",F7.4)
      END
C
      SUBROUTINE TRPRES(T,P1,P2,ZK1,ZK2,BP)
C     --------------------------------------
      DATA AP,CP,PREF/2.8E-5,2.E-6,1.01325/
      PE1=P1-PREF
      PE2=P2-PREF
      BP=(ZK1-1-AP*T-CP*PE1*PE1)/PE1
      ZK2=1+AP*T+BP*PE2+CP*PE2*PE2
      END
C
      SUBROUTINE TRTEMP(PAS,ZK1,ZK2)
C     -------------------------------
      DATA AT,BT/1.8584E-2,-1.8864E-2/
      ZK2=ZK1*(1+(AT+BT*ZK1)*PAS)
      END
```

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.