A New Tool to Improve Fiscal Monitoring and Custody Transfer in The Oil and Gas Industry

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Abstract

Typically, differential pressure transmitters used for fiscal monitoring and custody transfer purposes are often calibrated with the low side open to atmosphere. If the relevant line pressure is not applied during the calibration of differential pressure transmitters, the validity of the calibration is questionable.

It is widely acknowledged that the output of differential pressure transmitters changes with line pressure due to mechanical distortion of the wetted parts. Although the distortion is thought to be extremely small, the high degree of sensitivity results in a significant change of output.

The main reason these devices are not calibrated at line pressures is the high cost and complexity of existing calibration standards, usually twin post piston gauges and pressure dividers.

This paper gives an overview of the early development of a new differential pressure standard, more stable and accurate than the classical twin post balances. This new differential pressure standard is easy to use and the time required to perform the measurements is considerably reduced compared with the more established traditional methods. The line pressure range is 0 to 30 MPa with a differential pressure range of 0.1 to 700 kPa. The piston gauge will be described in detail including its metrological characteristics and ease of operation.

1. Introduction

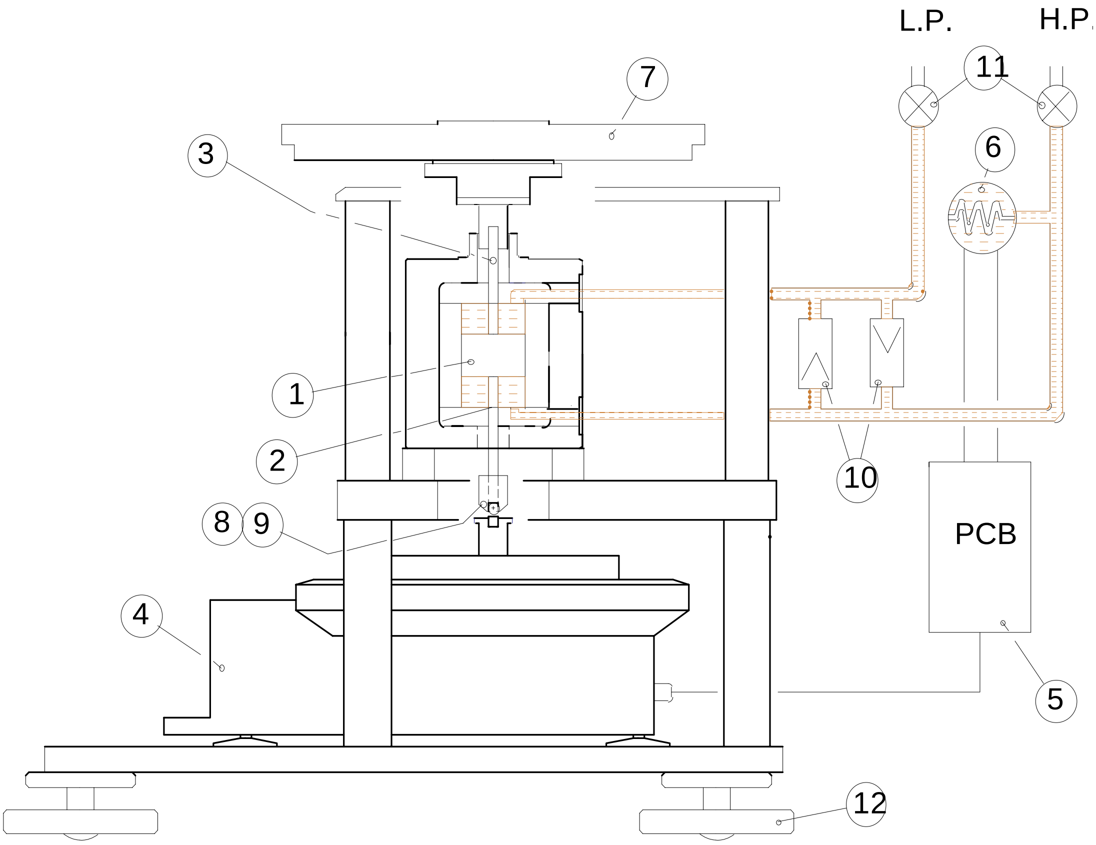
The Oil and Gas Industry is one of the main customers for differential pressure measurement and demands increasingly accurate measurement of this parameter. Traditionally, the standard used to measure differential pressure is the ‘twin-post’ pressure balance or the divider linked to a piston gauge. The basic idea of the new differential pressure standard was to use an assembly of three piston-cylinder systems: two with a small diameter (5.057 mm) and the third with a large diameter (31.749 mm) upon which the ‘high’ pressure and the ‘low pressure’ are acting. The resulting force due to the differential pressure is compensated by the weights added to the instrument carrier.

A mass balance is used as a cross-float null indicator during the measurement. During the initial equilibrium the reactive force of the mass balance compensates the mass of the floating system, thus the differential pressure is directly proportional to the mass added to the carrier. In order to compensate for the natural fall of the piston, which will result in a change of the applied force, the instrument has a Thermal Compensation System. The calibration of the differential piston gauge standard was performed using a ‘twin post’ pressure balance.

2. The basic construction of the high line differential piston gauge

The schematic drawing of the instrument [1] shown in Figure 1 shows the main parts. The three piston-cylinder assemblies 1,2 and 3 with coaxial symmetry represent the ‘heart’ of the system.

The high pressure is applied to the downward face whilst the low pressure is applied to the upward face of the large diameter piston.
The triple piston-cylinder assembly is mechanically connected to the mass balance through a spring system and a tungsten carbide ball (9).



1,2,3 - piston assemblies
4 - mass balance
5 - printed circuit board
6 - thermal compensator
7 - weight carrier
8 - mechanical stop
9 - mechanical connection
10 - safety valves
11 - input valves
12 - adjustable feet

Figure 1. Schematic drawing of the new differential piston gauge

The weights corresponding to the required value of the differential pressure are loaded on a top plate carrier (7).

The signal provided by the mass balance (4) is processed by the printed circuit board (5) and then transmitted to a personal computer, which will operate (via the printed circuit board) the thermal compensator (6), in order to keep the pressure stable.

The piston gauge includes two safety systems: the first is a mechanical stop (8), to prevent damage to the mass balance (4), the second is composed of two safety valves (10) which open if the differential pressure exceeds 700 kPa (protecting the large piston-cylinder unit (1) and the instrument under test).

3. The use of the new differential piston gauge

After the system is initially powered up, it should be left for 10 minutes for thermal stabilization. With the equalizing valve open (Figure 2) the piston is rotated by the spin motor and the Coarse Tare button operated. The mass balance will read approximately 0 g.

Keeping the equalization valve open, the line pressure is applied to the both ports of the instrument. At this stage, the line pressure effect is nulled by activating the Fine Tare function. The computer display will show a plot similar to the one in Figure 2, which shows the moment when the instrument is ready for generating a differential pressure (the plot is tracing along the 0 g axis).
The equalizing valve is then closed and weights corresponding to the required differential pressure placed onto the carrier. The high pressure is adjusted until the reading of the mass balance is close to 0 g. The Hold function is then activated to allow the Thermal Compensator to adjust the low and the high pressure until the mass balance will read 0.000 g and the reading will be stable. This is the moment when the required differential pressure is generated.

An additional benefit of the design is that in a properly bled system, the null-point control is totally automatic following the addition of a new mass. The increased force will result in an imbalance at the weigh-scale, which causes an increase in power supplied to the Thermal Compensator to automatically recover the null-point

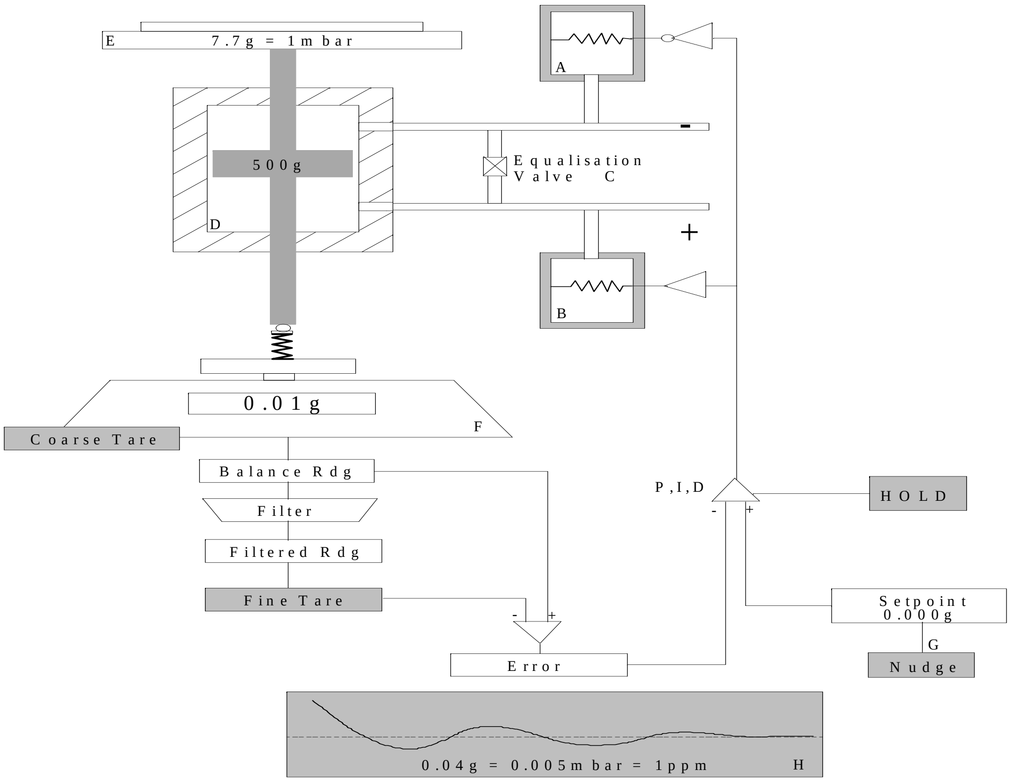


Figure 2. Functional diagram of the differential piston-gauge

In order to generate a new differential pressure the Release function is activated (deactivating the Thermal Compensators). The weights are loaded/unloaded and the high pressure re-adjusted following the same sequence detailed previously.

4. The metrological characterization of the high line differential piston gauge

4.1 Calibration Method

Several calibration methods have been developed for determining the effective area of this differential piston gauge. Initially, the calibration model of the piston-cylinder assembly considered the existence of two effective areas, one for the low-pressure side and another for the high-pressure side. The method proved to be very innovative and accurate but it was also complicated and time consuming. Therefore a second less complex method has been developed.

The calibration of the high line differential piston gauge [1,3] required the design of a special system, of which the main component is a differential pressure balance. The twin-post pressure balance is an oil-lubricated instrument and the effective area of the measuring piston-cylinder assembly and the mass of the weights are traceable to National Institute of Standards and Technology (USA). The calibration of the instrument was performed by using a “modified” differential method. In the conventional high-line differential mode the “static” piston is adjusted to generate the same pressure as the “standard” piston within the repeatability of the system. This establishes zero differential at the line pressure defined by the standard piston. Small load changes are then made to the standard piston to generate the desired differential pressures. The method used for this instrument calibration is essentially the same except for the initial zero differential step.

In normal operation the piston tare mass (the mass of the minimum operating components) and forces related to the applied line pressure are offset by the load cell. During the instrument piston calibration the load cell is not used and must be disconnected from the piston assembly. At each line pressure in the calibration the initial balance point of the dual-piston system is adjusted to compensate for the tare and line pressure effects of the minimum instrument load. This results in an initial differential pressure that takes the place of the nulling force of the load cell, and is subsequently considered as the zero differential point. Differential pressures are then applied relative to this zero point as in the conventional method. Since the zero point of the dual-piston calibration system is adjusted to compensate for the minimum instrument pressure at each line pressure, it is not necessary to determine the mass of the tare components, nor is it necessary to determine the magnitude of the line pressure effects on the tare components.

4.2 Mathematical model of calibration

The effective area of the instrument piston-cylinder assembly is determined from the calibration equation:

$$\Delta p_t = \Delta p_{st} \tag{1}$$

The pressure generated by the twin-post pressure balance [2] in this “modified” differential mode is given by:

$$\begin{aligned}\Delta p_{st} = {} & \frac{\Delta m_s g b_1}{A_{H0}\left[1+\lambda_H\left(p_{H0}+\Delta p\right)\right]\left[1+\alpha_H\left(t_H-20\right)\right]} + \\ & p_{H0}\left[\frac{\left(1+\lambda_H p_{H0}\left[1+\alpha_H\left(t_{H0}-20\right)\right]\right)}{\left[1+\lambda_H\left(p_{H0}+\Delta p\right)\right]\left[1+\alpha_H\left(t_H-20\right)\right]}-1\right] \\ & - p_{L0}\left[\frac{1+\alpha_L\left(t_{L0}-20\right)}{1+\alpha_L\left(t_L-20\right)}-1\right]\end{aligned} \tag{2}$$

where:
Δm_s – mass of the weights applied to generate the differential pressure;
g – acceleration due to gravity;
b_1 – air buoyancy correction factor;
A_{H0} – effective area of the high-pressure piston-cylinder assembly;
λ_H – pressure-dependent term of the high-pressure piston-cylinder assembly;
p_{H0} – pressure generated by the high-pressure piston-cylinder assembly;

p_{L0} – pressure generated by the low-pressure piston-cylinder assembly;
Δp – nominal differential pressure;
α_H – thermal coefficient of the high-pressure piston-cylinder assembly;
t_H – temperature of the high-pressure piston-cylinder assembly during the generation of Δp_s;
α_L - thermal coefficient of the low-pressure piston-cylinder assembly;
t_L - temperature of the low-pressure piston-cylinder assembly during the generation of Δp_s
t_{H0} - temperature of the high-pressure piston-cylinder assembly during the initial cross-float;
t_{L0} - temperature of the low-pressure piston-cylinder assembly during the initial cross-float;

The pressure generated by the high-line differential piston gauge [3] can be written in a first approximation as follows:

$$\Delta p_t = \frac{\Delta m g b_2}{A_t\left[1+\alpha(t-20)\right]} - (\rho - \rho_a) g h_t \tag{3}$$

where:
Δm – mass of the weights applied to generate differential pressure;
g – acceleration due to gravity
b_2 – air buoyancy correction factor;
A_t – effective area of the high-pressure side of the piston-cylinder assembly;
α – thermal coefficient of the piston-cylinder assembly;
t – temperature of the piston-cylinder assembly during the generation of Δp_t
ρ – density of the working fluid;
ρ_a – density of the ambient air ;
h – distance between the two active faces of the large diameter piston.

The method used eliminates the influence of the fluid head [4] and the equation (2) can be re-written:

$$\Delta p_t = \frac{\Delta m g b_2}{A_t\left[1+\alpha(t-20)\right]} \tag{4}$$

which also simplifies the equation for the effective area:

$$A_t = \frac{\Delta m g b}{\left[1+\alpha(t-20)\right]} \times \frac{1}{\Delta p_{st}} \tag{5}$$

The above equation has been used for determining the effective area of the instrument piston-cylinder assembly and for the evaluation of the associated expanded uncertainty (in which case equation (5) was written explicitly).

5. Results

The calibration has been performed for the following nominal line pressures: 42 bar, 97 bar, 200 bar, 303 bar and the differential pressure points: 1.4 bar, 3.6 bar, 4.9 bar and 7.6 bar.

Table 1 presents the values of the effective area and the associated expanded uncertainty at different line and differential pressure points. The analysis of the effective area values by the line and differential pressure did not show any

Table 1

Line Pressure [bar]	Differential Pressure [bar]	Effective Area [m^2]
42.25430	1.372089	7.7040336E-04
42.25430	3.558426	7.7041683E-04
42.25429	4.892369	7.7041931E-04
42.25430	7.625145	7.7041972E-04
42.25428	3.558367	7.7042843E-04
96.60738	1.371913	7.7052191E-04
96.60734	3.558571	7.7038945E-04
96.60728	4.892288	7.7043686E-04
96.60723	6.989831	7.7042458E-04
96.60720	3.558515	7.7040028E-04
199.71166	1.372054	7.7043859E-04
199.71165	3.558497	7.7040212E-04
199.71161	4.892256	7.7043909E-04
199.71161	6.989570	7.7045033E-04
199.71161	3.558340	7.7043635E-04
302.92993	1.372176	7.7037080E-04
302.92988	3.558573	7.7038502E-04
302.92990	4.892420	7.7041419E-04
302.92996	6.989735	7.7043334E-04
302.92996	3.558271	7.7045122E-04

interdependency. Also the graph presented in Fig. 3
does not suggest the existence of any correlation between the effective area and the line pressure or the differential pressure.

The relative expanded uncertainty of the individual values for the effective area varies with the line and differential pressure. The uncertainty is increasing with the increase of the line pressure, but it is decreasing with the increase of the differential pressure. Also the spread of data presented in the Fig. 3 is bigger at low differential pressure than at high differential pressure. The above observations, as well as the analysis of the uncertainty budget of effective area, have shown clearly that the main uncertainty source has been the standard twin-post pressure balance used for calibration.

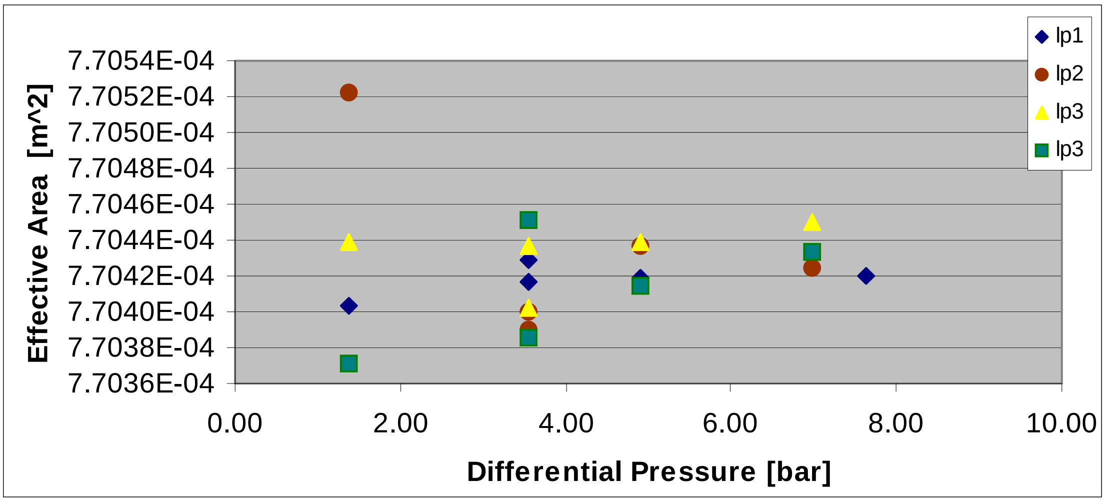


Figure 3. The effective area of the high differential piston gauge

In this case it is more appropriate to calculate the effective area by using a weighted average [5] and also to evaluate the weighted standard uncertainty corresponding to effective area.

Finally, the effective area of the high line differential piston gauge at 20 °C is:

$$A_t=(7.7042\pm0.0009)\times10^{-4}\ \mathrm{m}^2 \qquad (6)$$

where the uncertainty is the expanded uncertainty corresponding to a coverage factor of 2.

Conclusions

The theory, design and operation of a new high line differential piston gauge developed by GE Druck and GE Ruska has been presented. The development of this new differential pressure standard has been started in response to industry demand for an accurate and very easy to use standard. The instrument eliminates the initial cross-float, performed by the twin-post pressure balances and the similar cross float between a divider and a deadweight tester, by using a mass balance as a null indicator. The simple calibration method solves one of the difficult calibration problems, namely the calibration of the triple piston-cylinder assembly. The calibration method also eliminates the line pressure effects and it tares out some of the calibration corrections (increasing the accuracy of calibration). The uncertainty analysis has shown the gain in accuracy of this instrument over the classical twin-post pressure balance. As a consequence, the large diameter piston-cylinder assembly makes the instrument suitable for use as a primary standard.

Acknowledgments

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