Pressure Calibration Using Electronic Sensors

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Abstract

Everyday in the world of pressure measurement many gauges and transducers are calibrated using varying specification levels of Piston Gauges / Deadweight Testers as standards. These standard devices need a skilled operator and can be cumbersome to use. Many of the gauges being calibrated do not warrant the accuracy of these calibration devices and could easily be calibrated using a simpler device such as a transfer standard, likewise there are low grade Deadweight Testers that can easily be replaced with transfer standards to increase efficiency.

1. Introduction

1.1 This paper discusses one technology of transducers/sensors used in modern pressure controllers/calibrators as well as their advantages and disadvantages. The selection process to grade their accuracy and provide infinite ranging capabilities as well as the long term stability of these devices in the field is also discussed.

1.2 In the highly technical world that we live in it is common place to enter a pressure calibration laboratory and find gauges, transducers and transmitters being calibrated using a deadweight tester. Technically there is nothing wrong with this, deadweight testers derive their pressure from first principles, Pressure = Force/Area, and have been used for more than 100 years, however, they are cumbersome to use, especially to a new operator, inefficient and require many components to be recalibrated. They need to be level and as Force equates to Mass x Gravity in our pressure formula we need to know the value for gravity where we are using the device, something often overlooked. Quite often the measurement uncertainty they provide can be provided by instruments that are simpler and easier to use.

1.3 Despite these many drawbacks and others discussed in [1], the industrial deadweight tester remains popular probably due to it having a single component for generation, control and measurement of pressure. Of course at the top end of the traceability chain we need these types of devices. For high level measurements we call these more precise and more complex instruments Piston Gauges and they can provide us with 20 ppm or less measurement uncertainty. These devices are used when we require the smallest uncertainties, but these measurements are in the minority, it is the majority workload that I will concentrate on here where the industrial deadweight tester is still the primary choice of instrument for analogue gauge calibration.

Figure 1. A conventional industrial deadweight tester generates, controls and measures pressure.

2. Transfer Standards

2.1 Stability

As in all fields of measurement a transfer standard is used to disseminate measurements defined by a higher standard. A key quality of a transfer standard is that ideally it does not change due to age or use. In reality everything drifts, something that is detected between calibrations, but as long as the drift is small and predictable the transfer standard can be used with confidence and any drift can be compensated for. This drift and predictability is known as ‘Long Term Stability’ a key requirement for any device that will be used as a transfer standard.

2.2 Linearity

Another key requirement of a transfer standard is linearity over its range. We ideally need to see a straight line from 0% to 100% of range. Again we will never get a perfectly straight line but this can usually be compensated for either mechanically, electronically or within associated firmware. Some transfer standards are characterised at ‘spot points’. Only using them at the ‘spot point’ ensures traceability

2.3 Hysteresis

We need to be aware of hysteresis. This is a lag or delay within the device and is easily seen when calibrating pressure gauges. e.g. a pressure gauge will read slightly different at a cardinal point when we are performing an increasing pressure cycle than when we are on a decreasing pressure cycle.

2.4 Repeatability

We also need a device that is precise or repeatable. When we repeat the same measurement in short succession we need to get the same output or result within a know tolerance. This is commonly called repeatability or precision. Precision is a key characteristic of any type of standard used for calibration purposes, without it we can never have accuracy.

3. The transducer

3.1 As we are looking for a pressure transfer standard we will focus on the transducer as this is the measuring device and the heart of any pressure transfer standard. There are various types of transducer available from capacitive types, linear variable differential transformers (LVDTs) that are inductive position sensors and strain gauge types amongst many others. All sensors are sensitive to over pressure so safe guards need to be built into any instrument that will use them. The type of sensor discussed here is the direct resonant pressure type commonly referred to as a quartz reference pressure transducer (Q-RPT). In this design a pressure is applied directly to the vibrating part of the sensor. Using resonant structures for pressure produces a very stable device.

3.2 DH Instruments use the Digiquartz® range of sensors. DH Instruments are not the only manufacturer to use these sensors but what makes these sensors unique in a DH Instruments product is the proprietary characterisation process that they are put through that sorts them into various performance classes. The ‘raw’ sensor has a specification of 0.01% of Full Scale. DH Instruments twenty plus years of history with these sensors has shown us that some of these sensors are far better than the ‘delivered’ specification.

3.3 From [2] it can be seen that with a population of over one hundred sensors there is no influence on stability caused by the frequency or intensity of use of a sensor, it is purely a function of time. It is seen that the stability is a combination of the offset and a change in slope over the full range of the Q-RPT and that the dominant change in stability is the offset and not the slope drift error. A single point calibration is required at zero or atmospheric pressure to recalibrate any offset. The offset drift error is proportional to the span of the Q-RPT so the lower the range, the lower the drift, in terms of pressure. Gauge Q-RPTs automatically correct for changes in offset when resting at zero, whilst absolute Q-RPTs correct at atmospheric pressure using an Auto Zero function. With the data recorded we are able to provide a 1-year stability uncertainty of 0.005% of reading if the Auto Zero function is turned off.

3.4 Each sensor goes through the proprietary characterisation process and is selected as a ‘Premium’, ‘Standard’ or ‘Full Scale Standard’ class for gas sensors 10 MPa or less. The process allows us to provide a 0.008% of reading to 30% of AutoRanged span, 0.01% of reading to 30% of sensor span and a 0.015% of AutoRanged span specification, respectively for 1-year. For sensors higher than 10 MPa, where smaller uncertainties are not generally required only ‘Standard’ class sensors are provided with 0.013% or 0.018% of reading depending on pressure range. We have also introduced a 0.02% of reading class for hydraulic pressures greater than 7 MPa for lower accuracy requirements. The same class sensor also comes with a 0.025% of reading specification for 2-years.

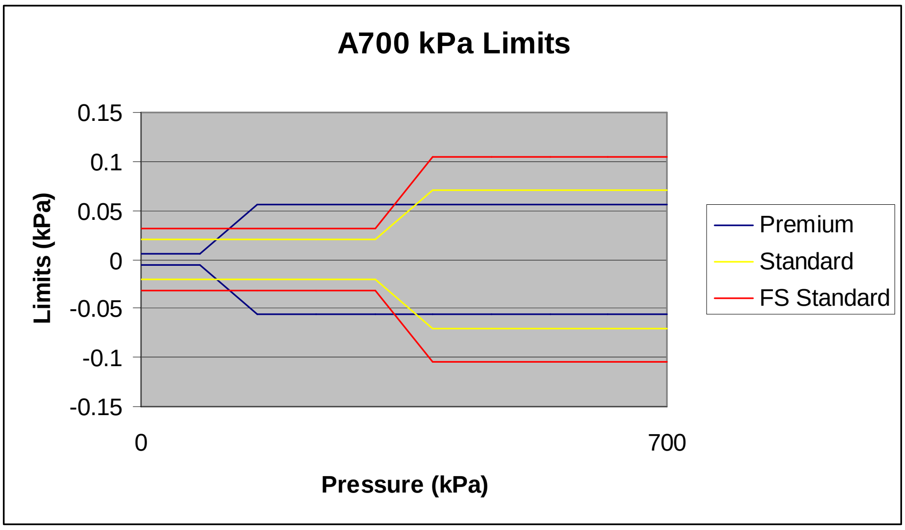

Figure 2. Characterisation limits for an Absolute 700 kPa Q-RPT

3.5 Premium and Full Scale Standard sensors provide us with a % of AutoRange specification. This means that when using one of these sensors in our controller or readout the sensor can be AutoRanged so we can optimize the sensor to the maximum pressure of the device under test while at the same time improving the specification of the measurement.

4. Incorporating a Q-RPT into an Instrument

4.1 Once the Q-RPT has been selected and characterised it is mounted into a Q-RPT module. This is a rigid standardised assembly that protects the Q-RPT from unwanted connection stresses and mechanical stresses being applied to the sensor during transportation. Over the last 20 years it has been found that mounting the Q-RPT in this module also helps reduce long term drift of the sensor. The module also conveniently houses valves to support AutoRanging, Measurement mode and switching of the active Q-RPT in dual controllers / calibrators and readouts. It is this module that is fitted into the final product.

Figure 2. DHI Q-RPT modules

5. Q-RPT based Transfer Standards

5.1. Using Q-RPTs in transfer standards provides many advantages in modern instruments. Manufactures are able to produce instruments that can provide a percentage of reading specification not just based on the full range of the Q-RPT but on the ‘autorange’ value selected by an operator.

5.2. Our gas pressure calibrator has a controller that can ‘turn down’, lower its control error. There is no advantage in having a good measurement uncertainty if our control uncertainty is so large it swaps the uncertainty contribution of the Q-RPT. The controller contribution to the overall uncertainty can be significant. Up to four Q-RPTs can be combined into one system providing uncertainties down to 80 ppm of reading. When we want to generate low pressure the instruments controller is able to lower the control error to enable us to get the best specification. This provides a calibrator with a wide pressure range providing really low measurement uncertainty across 98% of the controllers’ whole range.

5.3. There are choices of accuracy class of Q-RPTs in DH Instruments products and as the modules are standard it is possible to mix the accuracy types of Q-RPTs allowing a controller or readout to cover many applications in one instrument. e.g. We could have a Low pressure 350kPa Q-RPT with 80 ppm of reading and a higher pressure 7MPa Q-RPT with a 150 ppm of ‘Autorange’ Span allowing for very flexible system configuration with the best accuracy where it is required. We have Q-RPTs that cover 15 kPa to 280 MPa in gas or liquid again allowing high flexibility.

5.4. With modern instruments we can often cover the whole range of a test instrument without changing test ports, piston cylinders and mass sets, and we are able to capture the measurement results using built-in ‘Autotest’ procedures. We can also capture this test data over the conveniently provided remote interfaces. This saves the time of writing down the data and of course allows us to semi or fully automate the calibration process using software.

5.5 Many of today’s instruments are relatively portable allowing us to easily transport them and due to their relatively small size can be used where space is limited, many can also be powered by battery enabling them to be used in locations where connection to the electrical power supply is difficult or even non-existent.

6. Advantages over traditional methods

6.1 When we compare the modern transfer standard specifically to the industrial deadweight tester there are many advantages. Firstly we can generate higher pressures in one instrument, most traditional deadweight testers have a max pressure of 100 MPa (15,000 psi), we offer up to 200 MPa. It is easy to select different pressure units so we are able to cover any calibration without having to calculate different units of pressure of change piston cylinder and mass set. High resolution of down to 1 ppm is easily achievable and fine adjustment of pressure that allows us to make ‘cardinal point calibrations’ (setting a specific pressure value so that the pointer of the gauge is pointing to a scale graticule), a real advantage when calibrating analogue gauges. We do not need to be concerned if the transfer standard is not level, Q-RPTs are not susceptible to positioning, and we do not have to worry about local gravity when we head out into the field. The displayed pressure is the correct one.

6.2 There is less to calibrate. A traditional deadweight tester requires calibration of the Piston Cylinder and the mass sets. A transducer based device can be easily verified against a high-end Piston Gauge system if the owner has one or very easily shipped back to a calibration provider at a much lower cost than having to invest in a mass calibration system or the cost of shipping heavy masses, bases and piston cylinders back a calibration provider.

6.3 Finally modern transducer based instruments weigh less making them easier to transport into the field for on-site calibrations. Many have a smaller footprint than traditional industrial deadweight testers making it easier to use them when space is at a premium. Transducer based instruments enable users to program test routines to semi automate calibration processes, something that is not possible with an industrial deadweight tester which is inherently mechanical.

7.0 Conclusion

This paper has discussed the benefits of modern transducer technology and how with careful characterisation techniques these transducers can be built into modern instrumentation that meets or exceeds the specifications of traditional industrial deadweight testers. Modern instrumentation using this technology enables us to have lighter and more efficient products. There is less expertise and skill required in operating these products and for on-site work they can be taken out of their shipping case and be performing calibrations within minutes. We can readily switch between pressure units and using software we can semi or fully automate a calibration routine recording not only the reference pressure but also, with an appropriate instrument, the pressure of a test device.

8.0 References

1. E-DWT-H Electronic Deadweight Tester – A modern replacement for the conventional deadweight tester. DH Instruments. A Fluke Company. July 2009.

2. Michael Bair, Evaluating the Contribution of Stability in the Measurement Uncertainty of Resonant Quartz Pressure Transfer Standards. NCSL International, Washington DC, USA, August, 2005.