Blanes PRESSURE SOLUTIONS

C201 Practical Pressure Calibration:

You should have read "Calibration 101" before tackling this.

Pressure is quite easy to work with and simple to generate. Because pressure is defined as force per unit area, we can easily have a fundamental reference. When we balance the weight of reference mass-pieces applied to a reference piston with a pressure, then that pressure can be very accurately determined. This apparatus is known as a **pressure balance**, and is the fundamental mechanism used for reference pressures.

From this primary standard flows a long list of simpler devices, each designed to meet a particular need. It is important for a user to understand his requirements before purchasing a pressure calibrator.

Choosing a Pressure Calibrator

Pressure calibrators are not cheap, and there is a bewildering range of products available. Here are some suggestions to make the process less painful.

The most important factor is to determine your essential requirements, and here your quality management system will be the starting point.

Scope:
What sort of pressure instruments do you want to check? If you need to check transmitters, must the calibrator provide electrical power and measurement as well, or will you use a separate power source?

Procedures:
Do you just want to check a pressure instrument for functionality, or do you need to calibrate and certify it?

Accuracy:
What pressure ranges must be covered, and at what accuracy?

Location:
Where will the calibrator be used?

Pressure Generation?
How will the test pressures be generated.

Documentation:
What documentation will be required?

Utilisation:
How often will the instrument be used?

A review of the answers to these questions will light the way forward.

Accuracy Examined:

ISO guidelines require the reference instrument (the calibrator) to be at least 3 and preferably 10 times more accurate than the Unit under Test (UUT). We can use the acronym TUR (for Test Uncertainty Ratio) to define this.

Instrument accuracies may be expressed as a percentage of full range, or of reading, or perhaps a combination of the two. It is important to be aware of this distinction.

Example: Consider three calibrators A, B and C with a range of 1 000 kPa and accuracy of 0,05%, operated at 100 kPa.

Calibrator A's accuracy is stated as a percentage of reading: The permissible error is 0,05% of 100 kPa and is 50 Pa.

Calibrator B's accuracy is stated as a percentage of range: The permissible error is 0,05% of 1 000 kPa and is 500 Pa.

Calibrator C's accuracy is stated as 0,04% of reading plus 0,01% of range: The permissible error is 0,04% of 100 kPa, plus 0,01% of 1 000 kPa, and is 140 Pa.

All three calibrators have a permissible error of 500 Pa at 1 000 kPa!

Please don't fall into the trap of thinking that just because your calibrator is 0,05% accurate, you can use it to check any instrument that operates in the calibrator's pressure range.

Useful Range of a Calibrator:

From the example above, we can see that the error in a calibrator will often vary with the pressure.

If the calibrator accuracy is expressed as a percentage of reading, then the minimum range will be about 4 times the minimum available pressure. If the minimum useful calibrator pressure is 100 kPa, then the minimum instrument range that can be calibrated would be 400 kPa, allowing checks at 100, 200, 300 and 400 kPa.

If the calibrator range is expressed as a percentage of range, as is the case with almost all measuring instruments, then we have to look at the accuracy of the instruments to be checked. Using calibrator B above with a transmitter of accuracy 0,25% of range, and using an accuracy advantage of 3:1 between the reference and the UUT, we can determine that the maximum permissible error in the UUT is 500x3 or 1 500 Pa, and the range of the transmitter which is permitted this error will be 1 500 Pa /0,0025 or 600 kPa. Wait a minute, can this be right? My beautiful 0,05% 1 000 kPa calibrator can only be used on transmitters from 600 to 1 000kPa? Surely something is wrong?

Check it out, my mate! Do the arithmetic! Scary isn't it?

We all instinctively realise that the reference must be more accurate than the unit to be checked. Is a TUR of 3 times a bit much? This is based on using the "Root Sum Square method of combining errors. The total uncertainty in the UUT is made up of the observed error and the uncertainty of the reference standard used. If we take these uncertainties as 1 for the UUT and 0,33 for the standard, the combined error under the RSS method is $\sqrt{(1^2 + 0{,}33^2)} = 1{,}05$ which is not significantly different from the nominal 1 we allowed for the UUT. However, if we go to a TUR of 1, the answer becomes 1,41. Check your QMS as to whether you require the full potential accuracy of the UUT.

If you use a lower TUR, you can do the arithmetic to determine what the allowable uncertainty is, and thus reverse calculate the maximum indication error allowed. This does mean that a complete uncertainty budget has to be prepared, since those uncertainties which can be ignored with a decent TUR, have now to be taken into account.

Types and Characteristics of Pressure Calibrators:

Pressure Calibrators can be split into primary and secondary standards. Primary standards are based on fundamental physical properties, which do not change much. Secondary standards are adjusted to agree with a primary standard, and this adjustment function is never guaranteed stable.

P.O.Box 3357, Benoni 1500. 169, Elston Ave, Benoni, 1501, Gauteng, South Africa
Phone 422-1749/1840 Fax 421-5379 Dial code international +2711 local 011
E-mail: rod@pressuresolutions.co.za Web: www.pressuresolutions.co.za

Primary Standards:
The commonest primary standard is the deadweight tester or pressure balance. Pressure is defined as force per unit area. The pressure balance uses a fixed mass as a force generator, and a precision cylinder as a reference area. When the mass floats on top of the pressure in the cylinder, we have a precisely known pressure. A deadweight tester is a pressure balance built in to a test rig providing instrument mounting and pressure generating functions.

Characteristics of the deadweight tester.
The deadweight tester does not measure pressure. It generates an accurate reference pressure which can be precisely determined. It is very stable, and has an accuracy related to "reading", actually the weights loaded. It can be very accurate, and is usually the backbone of international pressure standards. It is very simple, but mechanical. It cannot directly communicate with a computer, and requires different sets of weights to operate in other pressure units. It is almost by definition heavy and non-portable. It cannot work to zero, since the weight carrier will exert a minimum pressure. The pressure range can be quite high, but is limited in practice to about 100:1 on any given piston. Dual pistons can extend the working range. To minimise friction, seals are not used, and leakage is controlled by the use of very small clearances between the piston and cylinder. Static friction is eliminated by rotating the weights. There must be sufficient inertia in the weight carrier to spin for long enough for a stable pressure to be generated, which dictates the minimum pressure, and the maximum pressure is dictated by the physical size of the weights, and by the leakage rate, which must be low enough to allow the weights to float long enough to obtain a stable reading. Dual pistons are often used to extend the range while maintaining the weights at a size that can be readily handled.
The major influence on accuracy is the deviation of local gravity from International Standard Gravity (ISG). Many of you will believe $G = 9{,}80665\ m/s^2$. This is nominal or International Standard gravity, but the true local figure depends mainly on how far any location is from the centre of the earth. Since the earth is flattened at the poles, local gravity would vary with latitude and altitude if the earth was homogenous, which it isn't. The variations are quite significant. On the Reef, we are about 0,2% below ISG, while at the coast this drops to about 0,1% below ISG. These are very significant errors when compared to what is achievable in modern instrumentation.
The only other significant factor is temperature, which can be corrected by calculation, and many manufacturers make free software available to do this calculation.
Other factors include air density, which has a buoyancy effect on the weights; for hydraulic testers, the density of the hydraulic fluid, which buoys up the piston; and the orientation of the piston, which should be perfectly vertical. Some manufacturers build compensation into their weights, other don't. Check with your supplier.

Hydraulic deadweight testers are the norm, as the required clearances and thus precision in piston manufacture are less, but viscosity and head errors put a 100 kPa practical limit on the minimum pressure. Air operated testers are more expensive, as the clearances have to be very small indeed, and they are accordingly sensitive to contamination, but they do give excellent accuracy at lower pressures.

Other well-known primary standards are liquid columns, where a column of liquid of known density and length indicates the magnitude of the balancing pressure. Liquid columns are used for lower pressures, but the accuracy factors are not as well controlled for general use as those of deadweight testers, and thus they require careful attention for accurate work. As with deadweight testers, gravity is the single largest factor, but temperature plays a larger part, as does the true density of the measuring fluid. Columns are more amenable to multiple units, as measuring scales can be interchanged.

Secondary Standards:
Standard Test Gauges:

In the past, the commonest secondary pressure standard was the mechanical test gauge, and this is still extensively used. The normal accuracy of a standard test gauge is 0,25% of scale, which means that for calibrating industrial pressure gauges of 1%, a test gauge is required for every range, ie to calibrate a 4 000 kPa pressure gauge, use a 4 000 kPa test gauge, not a
6 000 kPa test gauge.
The single most important accuracy factor is temperature, which causes both zero and span errors. Resolution problems can also lead to errors.
Mechanical test gauges are susceptible to shock, which can shift zero or span, and accordingly have a low reliability rate. The frequency of checking depends on the amount of handling.

Digital Pressure Gauges:
Digital pressure indicators are coming more popular. In their crudest form, they provide immunity from shock damage, have better resolution, and are often simpler to adjust. One problem that all digital indicators have is that the user cannot immediately see if he is close to over-ranging the system.

Digital pressure indicators with analogue processing suffer from the same temperature limitations as mechanical gauges, but digital processing has brought major advantages.

All-Digital Pressure Calibrators:
The latest digital pressure calibrators are complementary to deadweight testers, since they are strong where deadweight testers are limited, but weak where deadweight testers are strong.

Digital mapping of the pressure transducer, combined with temperature monitoring, allows both linearisation and temperature compensation, thus vastly increasing the useful accuracy of the device. In addition, since all data is in digital form, simple data exchange with a host computer is possible. Another advantage is to allow the user his choice of pressure units for display purposes.

Digital pressure calibrators are now being packaged with power supplies allowing the powering of electronic devices such as transmitters and transducers. They can be highly portable, even intrinsically safe, and can be taken wherever needed. Bench mount and hand held versions are also available.

In this category we can also include high accuracy pressure controllers, which generate a very accurate pressure for calibration purposes, but these are normally limited to test bench applications. The biggest limitation is that the system accuracy is usually related to calibrator range, thus limiting the utility of the device, especially with high accuracy instruments like Smart pressure transmitters. The other limitation is stability. These drift with time, and require recalibration typically every 3 to 12 months. A slightly hidden problem with some of the most advanced, offering accuracies better than 0,01%, is that few pressure laboratories have the required uncertainty to maintain then to original accuracy, and there may be delays in maintaining accuracy and certification.

Summary:
Going back to our introduction, determination of needs will point us in the right direction.

If we just need a rough functional check rather than a full recertification, then accuracy is not so important, and convenience becomes the deciding factor.

For pressure gauges, much depends on how many ranges are in use. If recalibration of test gauges is a problem, or if a lot are required, a deadweight tester may be the solution.

For pressure switches, the simple semi-automated tests offered by many digital calibrators make these most attractive.

For pressure transmitters, the digital calibrator offers many advantages, falling down only on usable accuracy. If a wide number of pressure ranges are involved, the only way to obtain sufficient accuracy may be a deadweight tester (or two) coupled with an external electrical calibrator.

Finally, a word on costs. Once you have ascertained your essential requirements, these needs have to be satisfied. If you cannot afford the proper calibrator, outsource. Remember that buying a calibrator that does not meet your essential requirements is literally money down the drain.