FACTORS AFFECTING DIGITAL PRESSURE CALIBRATION
ASSOCIATED TECHNIQUES, USES, TRACEABILITY, AND PROBLEMS

Scott A. Crone

AMETEK Sensors, Test & Calibration

INTRODUCTION

Pressure calibration is as important today as it has been for a very long time, but the way calibration is done and the equipment used to do it has changed drastically.

Figure 1: Pneumatic Deadweight Tester

In the past it was a standard practice to use a primary standard for pressure calibration. That standard was normally a dead weight tester or a manometer. Today with more accurate secondary standards available there is a larger choice in what can be used for pressure calibration. What is used normally will depend on the requirements that have to be met and the equipment that is available.

Figure 2: Digital Pressure Reference

This paper discusses issues that should be taken into consideration when choosing a pressure calibrator from the many that are available today along with some of the challenges involved with performing a calibration or validation with a digital standard.

ACCURACY

Overall accuracy of any device is made up of several factors. Any of these can cause the device to deviate from the nominal value. Some of common factors that would normally have an effect on the accuracy of a pressure calibrator measurement are: hysteresis, repeatability (precision), linearity, temperature, stability, and gravity. A change in any of these can cause a deviation in the accuracy of the equipment used for calibration. Some types of pressure calibration equipment are affected more than others. For example, a deadweight tester would be affected by local gravity whereas a digital calibrator would not. Depending on the manufacturer, these factors may or may not be defined within the accuracy specification for an individual instrument.

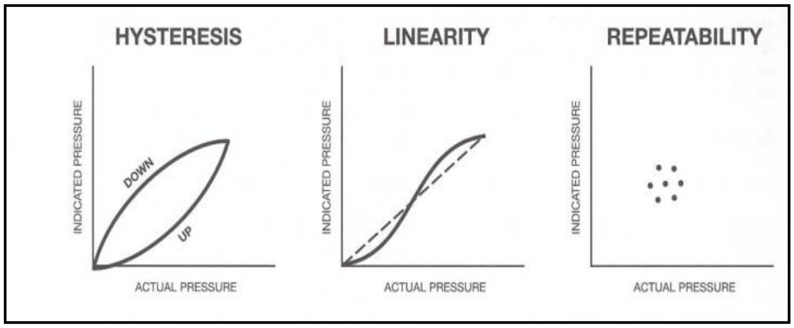

Figure 3: Factors Affecting Accuracy

There is no set standard for specifying accuracy; however, there are industry guidelines available. The NCSL International defines certain aspects of accuracy statements and manufacturers are able to use those definitions to properly specify their instruments such that an end user is able to easily compare the specifications. Refer to NCSL RP documents for more information.

In reality, accuracy is a qualitative term and not a quantitative. However, in our industry, it is widely accepted as a statement that informs the user of the quantitative agreement between the calibrator and a known standard. Some specifications base accuracy on one factor only and some use a combination of these factors. Others omit certain elements completely. It is best to be aware of what is within the specification and what is not so that a complete performance evaluation may be completed. Performing the calculations for your range of concern is the best way to understand which calibrator will meet your application needs.

A percent of full scale (%FS) and a percent of indicated reading (%READ or %IND) are the two most common ways to present accuracy: regardless of what is and what is not included. An increasingly popular way of indicating accuracy, one used by several digital calibrators, is a combination of both types of statement. It is very important to understand the differences between these for a significant error can be overlooked if these are not understood.

Accuracy based on a percent of full scale always has a fixed error value and will have the best accuracy at the upper range limit. Consequently, the nearer to zero the worse the accuracy becomes based on percent.

Accuracy expressed as a percent of indicated reading will have error values that change through the range of measurement; however, the percent of accuracy will remain constant. This means that the accuracy in percent is the same from the bottom to the top of the range of the instrument.

Accuracy expressed as a combination of percentage of full scale and percentage of reading will most often establish a percentage of accuracy that is constant down to a specific value: a percentage of reading error. At some point in the range, due to design or resolution of the instrument, the percentage of full scale component of the accuracy specification will take over. Below that point, the accuracy will worsen.

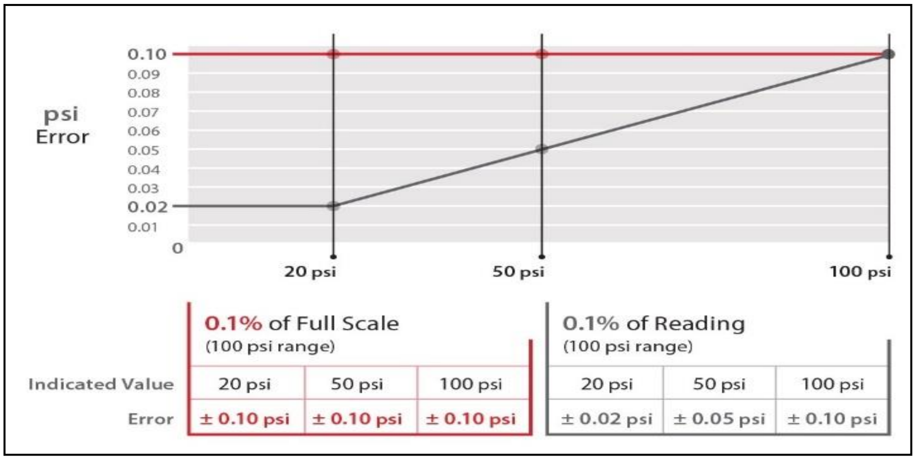

Figure 4: Graphical Representation of Accuracy Statements

Generally, a percent of indicated reading accuracy is preferred because it will indicate a better overall accuracy over the full scale of an instrument. There are however, other considerations that should be looked at when choosing a digital pressure calibrator.

<u>RESOLUTION</u>

Resolution is a function of the number of digits on a digital display and can be defined as the smallest change of the input that can be seen by the device.

The total number of digits, before or after a decimal point, is usually used to state the resolution of an instrument. Most are called out as 3.5, 4.5 or 5-digit resolution. When indicating one half of one digit this refers to the digit to the far left of the display being represented as no larger than a 1. A 3.5-digit display will indicate the highest value of 199.9 while a 4.5-digit display can indicate a value of 1999.9 and a 5-digit display will show a value of 99999.

It is important to understand that you must be able to see enough digits on a display in order to verify accuracy. A device with a 100 PSI full scale range and an accuracy of ±0.05% of full scale accuracy must be capable of indicating down to 0.05 PSI (100PSI X 0.05/100). Therefore, it would require at least a resolution of 4.5-digits to be able to see and read this accuracy. The same example with accuracy of ±0.05% of indicated reading would need an indication of 5 digits in order to prove accuracy. For example, at 9 PSI in order to prove ±0.05% indicated reading accuracy you would need to be able to see 9.0045 PSI. To do this would require a 5-digit indication.

Another issue that should be covered is a fixed point or floating point display. The number of digits to the right of the decimal point is constant on a fixed point display. With a floating point display, the number of digits to the right of the decimal point varies with the size of the reading. It can be one, two, three, four, or five depending on the number of digits on the display and the reading required. Referring to the example above based on ±0.05% of indicated reading, the accuracy would be impossible to resolve if the decimal place had been fixed at two or three digits. It has to be able to indicate the full range 100.00 PSI but also show the possible error at .0045 below 9 PSI; thus, the need for at least a 5 full digit display with a floating decimal point. There can be resolution without accuracy, but there cannot be accuracy without proper resolution.

A final note about resolution is to understand the operation of the least significant digit or the last digit to the right of the display. These digits do not always change by an increment of one. These may increment in twos, threes, or even fives depending on the design of the unit and the sensitivity of the analog to digital (A to D) converter. This is especially notable in finely decremented units such as millimeters of Mercury or kilopascals.

TRACEABILITY

Traceability is important. Without traceability there is no proof that the pressure calibration equipment is as accurate as stated.

Traceability is the ability to refer individual measurement results through an unbroken chain of calibrations to a recognized standard. The most common source used in the United States is the National Institute of Standards and Technology (NIST). However, many national labs have equivalency agreements so other national labs are certainly acceptable. The key point is the national lab traceability through to Bureau International des Poids et Mesures (BIPM) and equivalency through CIPM Mutual Recognition Agreement (MRA).

To insure an audit trail is traceable calibration results should include

- The assigned desired value
- The stated uncertainty
- Identification of the standard used in the calibration
- A statement of the environmental conditions where the calibration took place.
-

Traceability does not imply accuracy. It is a common misunderstanding that if something is traceable it is also highly accurate. Digital pressure calibrators can be traceable to a national standard and still not be accurate enough for the required calibration task.

TRACEABILITY AND ACCREDITATION

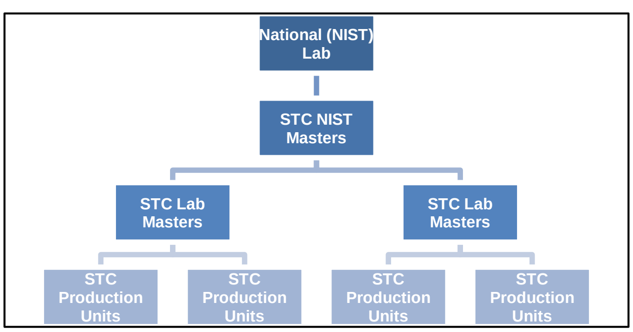

Figure 5: Sample Traceability Chain

Traceability and accreditation are two very different things. As discussed, traceability documents an unbroken chain for the measurement parameter back to a recognized standard for that parameter. Accreditation deals with the method for performing a calibration and documents a repeatable process for the same. ISO/IEC 17025 “General Requirements for the Competence of Testing and Calibration Laboratories” is one of the more recognized of the accreditations internationally. It is commonly referred to as Guide 25 and establishes stringent requirements for calibration reports, uncertainty information and calibration methods.

SITE EFFECTS

Manufacturing facilities and calibration labs have controlled environments. They typically maintain a small temperature window, are stationary, have minimal effects from the ambient weather, and have humidity control. Calibration tasks are performed in many places without such controls. Knowing how these site effects impact the pressure standard is vital in performing a successful and correct calibration.

Temperature

Temperature affects all measuring devices. This includes primary pressure standards and secondary pressure standards: including digital pressure calibrators.

Some accuracy statements will indicate the effect of temperature on the overall accuracy of the instrument. If the unit is going to be used in areas where temperature can vary it is important to include the effects of temperature in the overall measurement accuracy.

Some devices are temperature compensated over a working range. This means that the change in ambient temperature is taken into consideration during the calibration of the unit and the effects of temperature on the measured reading are either done away with or are minimal. It is very important to know the range of compensation as it may or may not include the actual site temperature where the calibration is being performed. Even with temperature compensation, if the ambient temperature is outside of the compensated range, the accuracy of the digital calibrator will be effected and a correction factor will need to be applied: just as if there were no compensation at all.

Either way it is important to understand that temperature does affect the measured reading on a digital pressure calibrator and it has to be noted and taken into consideration when looking at overall accuracy of a unit.

The below example shows a digital pressure calibrator that is temperature compensated versus one that is not. The "30

Comparing two 5000.0 psi gauges at 100°F				
Gauge	Test Point	Basic Accuracy	Temp. Effect	Total Uncertainty
30 Series	5000 psi	2.8 psi	none	2.8 psi
Brand A	5000 psi	2.0 psi	3.2 psi	5.2 psi
30 Series	3000 psi	1.8 psi	none	1.8 psi
Brand A	3000 psi	1.7 psi	1.9 psi	3.6 psi
30 Series	500 psi	0.5 psi	none	0.5 psi
Brand A	500 psi	1.3 psi	0.3	1.6 psi

Figure 6: Temperature Effects on Accuracy of a Digital Standard

Series" is fully temperature compensated, so there is no effect on accuracy at 100°F. However, the "Brand A" model has a temperature correction outside of 68°F. When calculated, this has a large effect on the measurement.

All pressure calibrators should be allowed to stabilize at the temperature they are going to be used. Even devices that are temperature compensated will have a zero shift due to changes in temperature. All digital pressure calibrators must be allowed to equalize at ambient temperature before they can be used to generate a reading within the specified accuracy.

Gravity Effect

Gravity has a major effect on primary pressure standards. Most dead weight testers are calibrated for either international standard gravity or U.S. mean gravity. The effect of gravity refers to the force that is being exerted on the masses of the deadweight testers. The measurement provided by a deadweight tester is based on force over an effective area of a piston or ball and nozzle. So, if the gravity component of the applied force is different than the gravity value to which the tester was calibrated, the output of the tester changes. Compensation for the effect of local gravity may be accomplished through calibration of the masses to that gravity or by a ratio correction. The consequence of not correcting for gravity is that the accuracy of the tester output will be diminished: this effect may be large enough to exceed the stated accuracy of the deadweight tester.

Digital pressure calibrators, because there are no weights involved, require no compensation for gravity.

Vibration

Vibration may have an effect on a measurement at low values depending on the sensor type and design. However, vibration typically does not affect higher quality digital pressure calibrators.

Vibration is a factor that has to be taken into consideration when using a primary standard. Primary standards need to be level and placed on a stable surface to function properly.

Electromagnetic Interference (EMI)

Electromagnetic interference is a potential side effect of using electronic devices in close relationships to one another. These types of devices both emit and are susceptible to EMI. If the amount of emission from one electronic device to another causes one to malfunction, this is referred to as EMI. Most EMI problems are limited to radio communications interference and are referred to as radio frequency interference (RFI).

If not properly shielded, EMI and RFI can be a major problem for digital pressure calibrators. By properly shielding for EMI and RFI, this problem can be minimized or eliminated by the manufacturers of digital pressure calibrators.

This is something to be aware of as the use of devices with such technologies is increasing every day.

PERFORMANCE EFFECTS

Site effects are not the only contributing factors to errors incurred while performing a calibration or measurement task. There are certain aspects of performance including methodology, training, and equipment set up that can cause errors or contribute to an erroneous outcome.

Reproducibility

This term is often confused with repeatability, but there is a clear difference.

The ability of a device to consistently produce the same output given the same input is repeatability (precision).

Reproducibility is the ability of different operators to produce the same output with the device, given the same input. Reproducibility is influenced by the amount of “skill” involved in taking a measurement.

Errors due to reproducibility may be minimized through employee development of proper procedures and training. If technicians are using high quality instruments and trained to use a proper set up and procedure, then the potential for these errors will be minimized.

Reproducibility is generally easier in digital pressure calibrators than it is in primary pressure calibrators. However, factors such as test set-up, calibrator set-up, and ambient conditions will have an effect.

Adiabatic Effects

When using an external pressure source such as a handpump or bench pump, pressure is added to a system rather quickly. In a fluid system, this causes an effect where the temperature of the fluid rises without any external heat addition. The technician will note that pressure rises and then falls back. This is caused by the fluid cooling back to an ambient temperature and it will stabilize. Technicians should be trained to recognize this effect and to compensate for it with proper methods of controlled pressure increase.

Pressure Head Effects

When a calibrator and a device under test are at a different height level, there is another type of error introduced. This is a pressure head error and it is based on the pressure applied by the fluid to the device at a lower height. This is a very minor effect if the pressure source is pneumatic; however, in hydraulic systems, it may cause a large error.

If the device under test is higher than the reference instrument, the device under test will read lower than the reference instrument. Conversely, if the reference instrument is higher, the fluid exerts a pressure on the device under test making it read higher.

This effect is corrected by using the test level correction where the density of the fluid is multiplied by the difference in height and applied to the pressure on the reference device.

$P_L = P_R + (H_R - H_{UUT}) \times \rho_f$ (Equation 1)

P_{UUT} = pressure at the test level of the UUT

P_R = pressure on the reference instrument

H_R = height of the reference instrument

H_{UUT} = height of the UUT

ρ_f = density of the fluid

Ambient Temperature Fluctuations

Earlier in this paper, accuracy issues due to site temperatures was discussed in detail. Site temperatures also exert an influence on the performance of a calibration: specifically, to the stability of the measurement. When performing a calibration in the field, the system is subject to the weather. A change in the weather can quickly have an effect on a measurement or calibration. Take for example, a thin, black hose that is pressurized by a pneumatic handpump and it is stable in the shade of a cloud. If the cloud passes and the hose is exposed to direct sunlight, the Ideal Gas Law takes over and the gas expands; which, in turn raises pressure. The opposite would occur if the hose had been in direct sunlight and was shaded.

The technicians should be trained to identify such issues with their set up and performance. Field calibrations are not ever done in ideal conditions; however, if a technician is aware of potential issues and the associated effect on a calibration, they can recognize when an issue may occur or has occurred and be prepared.

Systematic Issues

Finger tight fittings, quick connects, high resolution displays, and other advancements have all been introduced to make things easier for the technician. However, without proper training, these improvements can instigate or mask potential sources of error.

Proper zeroing of the reference instrument is critical in obtaining a reliable measurement. The reference should only be zeroed when it is fully vented otherwise the zero may not be a true zero to atmosphere. Self-sealing fittings, if installed, can create an offset in the system and the zero will not be accurate: leading to inaccurate measurements. The user should also be aware that once a vent is closed, there may be some pressure in the system leading to a change from zero. If this is the case, then do not adjust the zero as this is an indication that there is pressure within the system.

System leaks present a problem to any technician. Even if convenient quick connects or finger tight fittings are used, there may be a system leak outside of those fittings. Technicians must be trained to identify the signs of a leak in their system. They should know the indications of a leak and how to search for the leak. They should also know the way to determine the difference between a leak and a transient condition. There are instruments available that will identify and measure a leak condition and show real time information on the screen.

Another issue that technicians face is entrapped air in a fluid system. If the system being tested is not properly vented, then the readings will be affected by the Ideal Gas Law as entrapped gasses expand and contract with temperature changes. During pressurization, the gases will heat up to a temperature higher than ambient causing a pressure increase, as the temperature equalizes pressure will decrease. This may appear to be a leak in the system. Entrapped gas must be removed prior to performing any test.

Another transient condition that may be apparent is hose expansion. When a system is pressurized and a hose or tubing is used in the system, there is a certain amount of expansion that will occur. This will cause a resulting pressure drop. The hose material and diameter can minimize this effect; however, it is still likely to be observed. This should not be confused with a leaking condition.

The introduction of high resolution displays has also had an effect as technicians are now able to see more digits and quite possibly a fluctuating digit on the display of the calibrator. The technician must be trained about accuracy and resolution to be able to determine if that fluctuation is a system fluctuation or is something beyond the sensitivity of the calibrator. It may also be possible on some calibrators to change the resolution so that fluctuations beyond the sensitivity of the calibrator or the required reading resolution for the task are no longer present on the display. Such training is also important because the technician may become desensitized to the fluctuating digit and without fully understanding the indications; which, can cause an erroneous result to be recorded.

SPECIALIZED FEATURES

Intrusion Resistant Designs

There are times when measurements are required in adverse weather conditions or in atmospheres with airborne particulate such as sand or dust. The introduction of either into the inside of an instrument may render the readings inaccurate or worse yet, the instrument may become unusable. There are instruments available that carry weatherproof ratings such as an IP-67 case or a NEMA rated enclosure. These instruments may be reliably used in less than ideal conditions and still provide a reliable result.

The NEMA code is used to identify design characteristics to prevent the ingress of dirt, water, and corrosive agents. This is a numeric code with some alpha designators to identify levels of protection that span from light protection to higher degrees of intrusion by water or foreign objects. If the measurement conditions are likely, or even possibly, such that protection is required, a NEMA rated enclosure would be a desirable feature.

Ingress Protection Marking, or IP ratings, are another standard used for rating the level of protection from ingress of foreign objects or moisture into and instrument housing. This code uses a first number to identify protection from solid particle ingress, a second number for liquid ingress, and other codes to identify other protections.

These specifications may be the difference between an instrument operating or not operating in the required environment. The code definitions are readily available on the Internet and should be referenced when specifying an instrument.

Intrinsic Safety Ratings

Intrinsic safety may be a requirement when choosing a digital pressure calibrator. When using these units in today's work environment it is important to know if intrinsic safety is required and to what level.

Locations where volatile material are handled, stored, or processed are known as hazardous locations. The National Electric Code (NEC) defines hazardous locations in terms of Class, Division and Group. Ex Areas are another term for controlled areas used primarily in Europe but gaining acceptance in North America. Ex classifications are based on Zones.

The four primary agencies that test and certify equipment for use in hazardous location in North America are Underwriter's Laboratories (UL), Factory Mutual (FM), Canadian Standards Association (CSA), and Electrical Testing Laboratories (ETL) Group.

UL and CSA are further promoting the IEC Ex rating system. This is a move to bring the international standards into agreement and global understanding for all ratings.

It is important to understand the hazardous area applications and what if any certifications digital calibrators have with regards to their use in these locations. This should be a part of the selection process before being purchased or used in these locations.

Programmable Features

Manufacturers are more often including programmable features into their calibrators to address specific tasks. While this may add to the price, the long term time savings may make these calibrators financially attractive. These features may also make it easier for technicians to reproduce results and may simplify the test set up and performance.

Pressure Safety Valve testing is a common application and there are calibrators available that will automatically lock in the relief and reset pressures. Pressure Switches are regularly tested and there are calibrators with the capability to sense the change in switch state and lock in the set and reset pressures: some will also provide the hysteresis value.

Data logging may be useful in trend analysis or troubleshooting and is available on some pressure calibrators. This allows for a digital record of what the system was doing while connected.

Computer interface is a convenient feature that allows for data transfer and customization of the setup of the pressure calibrator. Some models have the capability to be configured via the computer and set up in a specific way. This may offer management a method for ensuring consistency in the way that the calibrations or measurements are performed. It may also offer convenience to the technician in that features that are not needed are disabled making the calibrator easier to use.

CONCLUSION

There are several factors to take into consideration when choosing a pressure calibrator. The topics discussed in this paper are only some that should be considered when choosing a pressure standard. It is up to the individual company, user, and the standards that have to be met as to what type of calibrator to choose and use.

It is imperative to have a working knowledge of specifications such that proper evaluations of available models are made. Additionally, when several models are available to a technician, understanding specifications and features will allow for the better selection of a calibrator to perform a specific task.

Technicians must also be aware and understanding of indications and site corrections.