Understanding Digital Manometer Accuracy and Resolution

Digital Manometers and Their Many Uses
What is an inch of water? The correct answer to this question has taken on increased importance with the demand for better accuracy and the introduction of digital manometers. For example, let’s assume that you have just received your new digital manometer (like a Meriam M200) and you decide to verify its accuracy. The manufacturer claims 0.1% accuracy at 100 inches of water. You set up a test using a deadweight tester and a water manometer. After placing a 100 inch of water weight on the deadweight tester, you record a reading of 99.8 inches of water on the digital manometer and 100.2 inches of water on the manometer. Which is right? The answer to this question will be evident after the following discussion of manometers and dead weight testers and their relationship to digital manometers. There will also be a discussion of digital manometer accuracy and resolution.

Some Digital Manometer Applications
- Pressure transmitter calibration for process instrumentation in position.
- Industrial processes such as heat treating and quenching (cooling)
- Monitoring the flow rate of gases for flow measurement devices in industrial processes.
- Testing of pressure switches for plant processes
- Check Power plant condenser efficiency by monitoring the vacuum

Manometers - The manometer is considered a primary standard since the pressure exerted by the liquid column can be accurately determined by the measurement of basic physical properties: the height of the column and the density of the liquid. For a manometer filled with water the pressure equation is

$$p = \frac{(g_t / g_o)(\rho_w - \rho_a)h}{\rho_o}$$

$g_t$ = gravity at instrument location
$g_o$ = standard gravity (980.665 cm/sec$^2$)
$\rho_a$ = density of air at observed temperature
$\rho_w$ = density of water at observed temperature
$\rho_o$ = density of water at standard temperature
$h$ = height of water column in inches

Notice that in order to determine the pressure indicated by the height of a water column one needs to know more than the height of the column. Both the local gravity and the density of the manometer fluid and the fluid being measured, in this case water and air, need to be known. As can be seen, the pressure indicated by an inch of water varies with location and temperature. In order to make the readings comparable they must be reported at the same temperature and gravity. The three commonly used reference conditions for water columns are shown on the table below.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Temperature</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>4° C (39.2° F)</td>
<td>980.665</td>
</tr>
<tr>
<td>AGA</td>
<td>15.6° C (60° F)</td>
<td>980.665</td>
</tr>
<tr>
<td>Industrial</td>
<td>20° C (68° F)</td>
<td>980.665</td>
</tr>
</tbody>
</table>

There is only one commonly used reference condition for mercury columns: 0° C (32° F) and 980.665 cm/sec$^2$. 
The use of the wrong temperature reference for water columns can produce errors of 0.1% to 0.2%. The failure to correct a mercury column from an observed temperature of 68° F can produce an error of 0.36%. The figure below shows the errors at different latitudes caused by not correcting for gravity.

Consider the example presented earlier where the manometer indicated 100.2 inches of water and the digital manometer indicated 99.8 inches of water. In order to correct the manometer to reference conditions, some additional information is needed. The test was conducted in Corpus Christi, Texas at an ambient temperature of 27° C (80.6° F). The digital manometer displays water column referenced to 20° C.

The gravity correction factor is the gravity at 28° north latitude divided by the standard gravity (979.185/980.665 = 0.9985). The temperature correction factor is the specific gravity at the ambient temperature minus the specific gravity of air divided by the specific gravity at the reference temperature ((099654 - 0.0012)/0.9983) = 0.997). Therefore the manometer reading corrected to reference conditions is shown below.

\[(100.2)(0.9985)(0.997) = 99.85" @20° C\]

Notice the close agreement between this and the digital manometer reading.

The use of a water manometer is not practical for field calibrations since a manometer with a range of 100 inches of water would be over 8 feet tall. A solution to this problem is to substitute a heavy liquid, such as mercury, for the water and to adjust the scale to read in inches of water. This reduces the scale by a factor of 13.59, the ratio of the specific gravity of mercury to that of water. Although this reduces the scale length to less than 8 inches, it also reduces the scale resolution and therefore its accuracy. Typical accuracy for this type of manometer is 0.25 inches of water. This type of manometer can be read directly only at the conditions for which the scale was calculated. A typical scale would read inches of water referenced to 4° C when observed at 22° C at a gravity of 980.665 cm/sec^2. Corrections must be calculated if any of the conditions vary from those at which the scale was calculated. The manometer is an accurate pressure indicating device if the specific gravity of the manometer fluid is accurately known and the correction factors are properly applied.

**Dead Weight Tester** - Dead weight testers are the most accurate pressure sources available. Unlike manometers that measure pressure, dead weight testers generate accurate pressures. The pneumatic dead weight tester balances a known weight on a column of air from a nozzle of known area. Since the weight and the area can be accurately measured, the pressure generated can be determined by dividing the weight by the area. The dead weight tester is considered a primary standard since both weight and area are properties that can be easily and accurately measured. Dead weight testers with accuracies of 0.015% are readily available.

Dead weight testers also require correction factors to determine the actual pressure generated. In the evaluation example presented earlier, the digital manometer and the manometer are in agreement at 99.8 inches of water but the dead weight tester has a 100 inches of water weight. Dead weight testers are calibrated at a set of reference conditions. In this case the reference conditions are 20° C and 980.665 cm/sec^2. Because the dead weight is operating at a different gravity, the same gravity correction must be applied to the dead weight tester as to the manometer.

\[(100)(0.9985) = 99.85" @20° C\]

Notice that after applying the correction factors all three of the instruments agree within their specified accuracies. If the reference temperature were 15.6° C additional correction factors would have to be applied to the dead weight tester and the manometer. Dead weight testers can be calibrated at different temperature references and gravities. The certificate of calibration for the dead weight tester will indicate the reference conditions used for its calibration.

Since dead weight testers do not indicate the pressure output one must be sure that there are no leaks in the system. A leak will cause the pressure at the instrument under test to be lower than that indicated by the weights. A dead weight tester is a precision piece of equipment and should be carefully maintained and operated in a
clean environment to insure its accuracy. Because of its high accuracy, the dead weight tester is the recommended pressure source for evaluating digital manometers.

**Evaluating Digital Manometers**

The digital manometer is a recent addition to field calibration instrumentation. These instruments are light weight, approximately 1 pound, and are available with accuracies from 0.2% to 0.025%. Their accuracy places them between the manometer and the dead weight tester, while their size and weight make them more convenient for field calibration. Most available instruments have a 3 ½ or 4 ½ digit display with resolution down to 0.01 inches of water. Digital manometers are not primary standards and their accuracy should be verified periodically against a primary standard. When digital manometers are calibrated with properly corrected primary standards they require no further correction to indicate within their stated accuracy.

The evaluation of a digital manometer begins by comparing the manufacturer's published accuracy ratings. This is not as simple as it appears, since there is no standard format for accuracy statements. For example, one manufacturer may include the temperature coefficient of error in the accuracy rating by specifying the accuracy over a specific temperature range while another manufacturer may state the temperature coefficient separately. To compare these specifications, the temperature error would have to be calculated over the operating temperature range and added to the accuracy rating. Compare the following:

0.1% F.S. 0 - 40°C
0.1% F.S. + 0.01% / °C

Although both units are 0.1% F.S. the latter unit is within this limit only at its calibration temperature of 20°C. To equate the two we must multiply the temperature coefficient by the temperature difference between 20°C and 40°C ((0.01)(20) ~ 0.2%). Adding this to the 0.1% accuracy at 20°C yields an accuracy of 0.3% F.S. over the temperature range of 0°C to 40°C. Therefore, the first unit is more accurate than the second unit. Always look for a statement of temperature effect. All pressure indicators are affected by temperature and manufacturers use various methods to minimize these effects. The manufacturer that does not document temperature effect is either unaware of it or unwilling to make it known to the consumer.

The accuracy rating indicates the limit that errors will not exceed when the instrument is operated under the specified conditions. An accuracy rating normally includes linearity, hysteresis and dead band. If the specifications state the accuracy components separately, then they must be combined to determine the total accuracy rating. The method recommended by the Instrument Society of America is to take the square root of the sum of the squares of the accuracy components. Since the accuracy rating is stated at specified conditions, your evaluation tests must be conducted under the same conditions. For example, if the accuracy is specified at 70°F then the evaluation tests should be conducted at that temperature; otherwise an additional error factor may be introduced by the temperature coefficient of accuracy.

**Accuracy can be expressed in several different ways. Among them are:**

- Percent of span
- Percent of full scale
- Percent of reading

The tightest method of expressing accuracy is percent of reading while the most common is percent of full scale. An instrument with a range of 200 inches of water and an accuracy rating of 0.1% of full scale will have an error of +/-0.2 inches of water at any reading. Therefore, at 10 inches of water, the error would be 0.2 inches of water or 2% of reading. The actual error at each test point will have to be calculated before proceeding with the evaluation.

Resolution is a very important specification in digital instruments. Resolution is defined as the smallest increment that can be distinguished or displayed. The following relationship exists between accuracy and resolution: resolution can exceed accuracy but accuracy cannot exceed resolution. A 3 ½ digit instrument divides the input signal into 1999 parts. The smallest increment that can be displayed is 1 part in 1999 or 0.05% of full scale. This would limit the accuracy of this instrument to 0.05% of full scale. Although decreasing the resolution will decrease the accuracy of the instrument, increasing the resolution will not increase the accuracy. For example, a 0.05% of full scale instrument with a 4 ½ digit display has a resolution of 0.0005% of full scale, since the accuracy does not change, the additional digit provided by the increased resolution is meaningless. Do not assume that all displayed digits are significant; compare the accuracy to the resolution to determine how many digits are significant.
After determining the error limits for each test point, the instrument evaluation can proceed. An instrument or pressure source with an accuracy of between 3 and 10 times that of the instrument under evaluation should be used. A dead weight tester with an accuracy of 0.015% of reading is recommended. If the evaluation is being conducted in inches of water, then the following information must be known: the reference temperature at which the dead weight tester was calibrated; and the reference temperature at which the instrument was calibrated. This is very important since the indicated error between different reference temperatures can be as much as 0.2%. In addition, all appropriate correction factors, especially gravity, must be applied to the dead weight tester and there must be no leaks in the system.

The minimum number of recommended test points is two. These should be at 50% and 100% of each range of the instrument. A more stringent test would involve four test points, at 25%, 50%, 75% and 100% of each range. A full ten point test is usually not required to evaluate an instrument, but it does provide the most detailed information about the instrument.

The digital pressure indicator is an ideal instrument for field calibration of transmitters and recorders. It is lightweight, accurate, and easy to use. The selection of an acceptable instrument can be simplified with an understanding of accuracy specifications. The evaluation of an instrument’s accuracy requires a thorough knowledge of the primary standard used and the correction factors required.

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