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Gauging the Pressure You're Under (or Glossary-ing over it)

Part 2B

Introduction

As noted in Part 2A, this issue started out as the side-bar from hell but has become its own entity. A proud, but bo-o-o-o-o-ring, Glossary.

And just why do we need a gauging Glossary? Well, in addition to *pressure range*, a gauge's specification occasionally includes terms like: *accuracy*, *repeatability*, *hysteresis*, *linearity*, *resolution*, *2% of reading*, *0.1% of FS*, *sensitivity*, etc. If you don't know what they mean, measuring pressure is like piloting a night-flight in your flying club's Cessna 150 thinking VORTAC is a Norse god. (Will pilots please explain that to non-pilots.)

I'll point out this Glossary is **my** interpretation of words and terms used in the pursuit of pressure measurement and may not be 'spot on' accurate. While I hope I'm close to correct, if you disagree—**complain!**

In Part 2A, and again in this issue, I throw around *indicated pressures* (what you see on the display) and *real pressures* (what the pressure actually is) so often I've contracted them to ***IP*** and ***RP***.

One final point: throughout this issue I chose ***IPs***, ***RPs***, and pressure ranges. Rather than have every other sentence contain qualifiers like, 'for example', 'let's say', 'suppose', 'such as', or 'might be', I'll boldly pick arbitrary numbers where no numbers have been picked before.

Gauge Specification Glossary

Full Scale

Full scale (abbreviated F.S.) is the entire range which a gauge can measure. The accuracy, resolution, and temperature coefficient of a gauge are typically expressed in terms of percentage of full scale (% F.S.).

For example, a gauge with a quoted accuracy of 1% F.S. and a range of 20 Torr would have an error of ± 0.2 Torr throughout the operating range.

Accuracy

A gauge's accuracy tells you how close the ***IP*** is to the ***RP***. For an ***RP*** of 3 x 10^{-5} Torr, a one-time ***IP*** measurement with an *inaccurate* gauge gives an answer anywhere between 2 x 10^{-4} Torr to 4 x 10^{-6} Torr. The one-time ***IP*** using an *accurate* gauge is between 5 x 10^{-5} Torr to 2 x 10^{-5} Torr.

Accuracy is affected by external factors such as: the gauge's proximity to strong magnetic fields; gas composition; gas temperature; UV radiation; ions from a plasma; vibration; gas conductance between gauge and chamber; contamination; and probably others.

But it can also be affected by a slew of internal factors: the gauge's mechanism; its temperature; how close the ***IP*** is to the gauge's range extremes; its mounting orientation; innate pumping speed (yes, some gauges pump gases!); and last, but far from least, ***calibration***.

Repeatability

A reasonable definition of repeatability depends on the 'system' under discussion. For a vacuum gauge, I favor this: the gauge's ability to produce the same reading every time the same pressure measurement is made. In this sense it's a measure of precision.

Change a chamber's pressure many times. Every time the ***RP*** just reaches 3 x 10^{-5} Torr note that the ***IP*** is always 2 x 10^{-4} Torr. This gauge is highly repeatable but hardly accurate. Alternatively, every time the RP just reaches 3 x 10^{-5} Torr the ***IP*** values are all over hell's half acre. However, when we average a bunch of 'em, the result is 3 x 10^{-5} Torr.

It's tempting to think the latter gauge is accurate, right? But to me, pathetic repeatability makes any claim of accuracy just plain bonkers. What if you averaged just two ***IP*** readings? Would the answer still be 3 x 10^{-5} Torr?

Repeatability depends on the stability of many internal and external parameters: temperature; gas composition; electronic voltages and currents; contamination effects; etc. And if the gauge is one of those with a ***calibration*** stability like the San Andreas fault, then add that to the list. (In the time it takes to check the gauge's repeatability its ***calibration*** may change.)

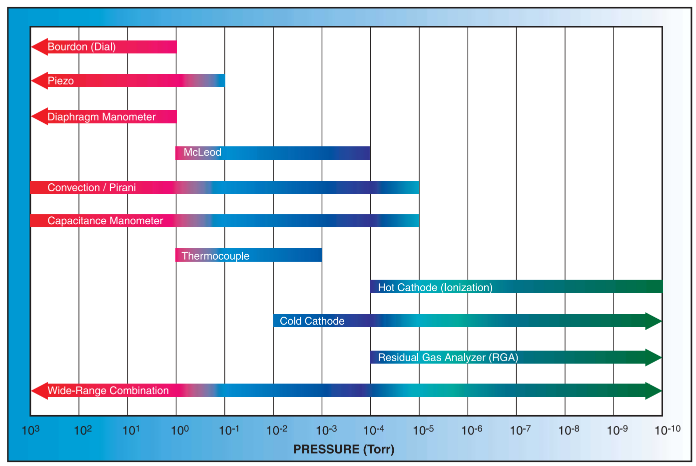
Hysteresis

This monster is associated with emotive, sci-fi or horror movie words like: backlash, elasticity, creep, 'memory', and stickiness—except here we're only dealing with the mechanics found in **force** gauges. Hysteresis differs from repeatability in recognizing that the ***IP*** depends on both the ***RP*** and the 'direction' from which the ***RP*** is reached.

- Reduce the ***RP*** from 10 to 5 Torr many times. At 5 Torr the ***IP*** always reads 5.2 Torr.
- Increase the ***RP*** from 1 to 5 Torr many times. At 5 Torr the ***IP*** always reads 4.7 Torr.

The difference between these two ***IPs*** (expressed as a percentage of the ***RP***) is the gauge's hysteresis. In this case the difference (0.5) and the ***RP*** (5) give a hysteresis of 10%, usually expressed as ±5%.

It's pretty evident, a **force** gauge's hysteresis depends on its specific design, wear, and maybe even lubrication. But let's be crystal clear about two points: it's the first characteristic we can't blame on ***calibration***; and I've no idea if 'hysteresis' starts with an aspirate 'h'.



Resolution

Here resolution has nothing to do with the promises you break every January 2nd or with formal statements made by the U.S. House or Senate. (Hmmm. . . does that sentence contain a tautology?) It is more like a microscope's resolving power. It answers the question: what is the smallest incremental pressure value that can be discriminated on the display?

Take two dial gauges with identical mechanisms and specifications—except one is 2" diameter; the other 8" diameter. The needles of both displays point towards 50 Torr but you need to estimate when the ***IP*** exceeds 51 Torr. On which dial is that easier to read (and, therefore, has the better resolution)? The 8" display, right?

For digital displays, resolution is first associated with the 'number of digits' in the display. These are often quoted as:

(a) '4-digit', which reads xxxx with any digit (0 - 9) replacing any x

(b) '3½-digit' which reads 1xxx or xxx with any digit (0 - 9) replacing any x

But add into this mix a floating decimal point and resolution gets a little oogly to explain. So, here's a table showing how I view it. Note: to find the Resolution I've assumed that the right-most "0" in the Reading has changed to the value "1". I've then subtracted the old Reading from new Reading (surprisingly, it's always 1), divided that by the old Reading and expressed the answer as a percentage.

Actual	4 Digit		3½ Digit	
Value	Reading	Resolution	Reading	Resolution
1000	1000	0.1%	1000	0.1%
2000	2000	0.05%	200	0.5%
5000	5000	0.02%	500	0.2%
1999	1999	~0.05%	1999	~0.05%
199.9	199.9	~0.05%	199.9	~0.05%
19.99	19.99	~0.05%	19.99	~0.05%
20.00	20.00	0.05%	20.0	0.5%
.5000	.5000	0.02%	.500	0.2%

Stability

Stability is the tendency for the gauge's characteristics such as: sensitivity; temperature coefficient; response to a particular gas; response to contamination; and last, but no way least, ***calibration***, to drift over some time interval. Apart from temperature coefficient, discussed below, I've never seen a stability specification.

Considering instability's insidious effects, particularly when we're talking about ***calibration***, I sure wish a gauge's various instabilities could be defined, measured, and published. But don't hold your breath. Even if possible, it would put the gauge's price in the 5th Dimension. (Anyone remember them? You do? Wow, you must be the *eminence gris* of your facility!)

Temperature Coefficient

First, before we get to gauges, let's make sure we understand one point—any temperature change will affect the ***RP***. If a vacuum chamber at 20°C (293 K) rises to 35°C (308 K) two things happen:

(a) The gas's ***RP*** rises by 308/293 (Gay-Lussac's Law linking **P** and **T**).

(b) The chamber dimensions increase from thermal expansion which increases its volume and reduces the ***RP*** (Boyle's Law linking **V** and **P**).

OK, so does the net ***RP*** increase or decrease? For a simple 10 cm radius stainless sphere: effect (a) increases the pressure ~5% while effect (b) decreases the pressure ~0.0054%. The details of effect (b) depend on the chamber's shape, dimensions, and materials, but it's take-it-to-the-bank solid—always bet on (a) to win.

Although a 15°C ambient rise affects all gauge mechanisms, most are so imprecise the change won't be noticed. However, the capacitance manometer (a **force** gauge) is so accurate (and such a good thermometer), it's worth checking how it reacts.

The literature for a popular capacitance manometer series *used* to quote two temperature coefficients for a 0.02 Torr F.S. (full scale) gauge:

(1) Zero: 0.015% F.S./°C

(2) Span: 0.04% of reading/°C

Recent literature doesn't show this any more. Perhaps the manufacturer discovered gauge users never crunched the numbers—which isn't, in my experience, exactly astonishing.

But for giggles, I'll take a 0.02 Torr F.S. gauge measuring a fixed ***RP*** of 0.01 Torr and see what happens as the gauge's temperature rises from 20°C to 35°C. (Here *fixed* ***RP*** means we're ignoring all that (a) and (b) stuff above.)

Zero: Assume at 20°C, an ***RP*** of 0.0000 Torr (that is, zero pressure) gives an ***IP*** of 0.0000 Torr. At 35°C the ***IP*** reads {0.0000 + [0.00015 x 0.02 (Torr F.S.) x 15(°C)]} or 0.000045 Torr.

Span: The ***IP*** at 20°C is 0.01 Torr. At 35°C the IP reads {0.01 + [0.01 x 0.0004 x 15]} or 0.01006 Torr.

The combined effect of Zero and Span changes the ***IP*** from 0.01 Torr to (0.000045 + 0.01006) or 0.010105 Torr, roughly a 1% error. Since this gauge measures changes of 0.00001 Torr, this temperature effect is easily detected. That's one reason this manufacturer offers temperature control for some capacitance manometer models.

Linearity

This really means pressure linearity. If the ***RP*** changes by a factor of 100, does the ***IP*** change by the same factor? But what if the RP changes by 10,000 or 100,000? Does the ***IP*** start going kitty-wonkers at the ends of the longer range?

I don't recall seeing a gauge's linearity specs quoted. But there are all sort of charts in the gauge literature (see Part 3) clearly showing the non-linear response of many mechanisms over fairly short pressure ranges. But if the non-linearity is reproducible within the mechanism's prescribed pressure range, the manufacturer often builds in a 'linearizing' circuit into the electronics that takes the gauge's raw output and forces it into a linear response on the display.

Sensitivity

Sensitivity comes in two flavors, both referring to gauges using the ionization principle.

Relative sensitivity compares the ***IPs*** (for a given static ***RP***) when the gauge is looking at different (pure) gases. The 'standard' usually takes N_2 as 1.0 (without units since it's a ratio—see Part 4 of this series for more.)

Gauge sensitivity has odd-ball units: Torr $^{-1}$ or mbar $^{-1}$. Yeah, reciprocal pressure! This arises from the equation linking ion current (I_p), electron emission current (I_e), and pressure (P):

$I_p = S \times I_e \times P$ or $P = 1/S \times I_p / I_e$

This S is the gauge sensitivity. Actually its $3.00 name is *constant of proportionality* since it makes the pressure units balance (the current, in amps, appears in numerator and denominator and so cancels out). Typical S values range from 0.6 Torr $^{-1}$ to 20 Torr $^{-1}$. And why bother noting this? Well, if the controller doesn't operate in the gauge's sensitivity range, you can kiss reasonable pressure measurements goodbye.

Calibration

Ah yes... gauge ***calibration***. Perhaps you've wondered why it's in bold type everywhere and why I left it till last. OK, answer this quiz and I'll tell you.

- When did you last calibrate your vacuum gauge?
- Have you ever calibrated a vacuum gauge?
- Did you know vacuum gauges needed calibration?
- Have you heard some vacuum gauges lose calibration if the gas composition changes even slightly?
- Are you aware that some (all?) vacuum gauges suffer some degree of calibration drift?
- Do you believe in the Tooth Fairy?

As you can tell, when it comes to gauge calibration, I'm a tad skeptical of our collective will to do the right thing. It's more a case of: "How often do I calibrate my gauge?... surely, you've mistaken me for someone who gives a rosy rat's rear end!"

Pressure Unit Conversion Table

Pressure Units	Atmosphere	Bar	mbar	mTorr	Pa	Torr
1 atm.	1	1.01325	1013.25	7.6×10^5	1.01325×10^5	760
1 bar	0.9869	1	1000	7.5006×10^5	1×10^5	750.06
1 mbar	9.869×10^{-4}	1×10^{-3}	1	7.5006×10^2	100	0.75006
1 mTorr	1.316×10^{-6}	1.3332×10^{-6}	1.3332×10^{-3}	1	0.13332	1×10^{-3}
1 Pa	9.869×10^{-6}	1×10^{-5}	0.01	7.5006	1	7.5006×10^{-3}
1 Torr	1.316×10^{-3}	1.333×10^{-3}	1.3332	1×10^3	1.3332×10^2	1

D'you recall me writing about the grand old **gotcha** in Part 1 and how snippy I get with people who claim: "*I bought two identical gauges from you guys. I put them in the same chamber and you screwed up. They're showing different pressures!*"

Now tell me, in response to such accusations, will I say, "*Oh, we'll ship out two new gauges immediately*"? Is there a chance my first words will be "*Mea culpa*"? Am I likely to make the astonished exclamation, as does Miss Piggy, "*Moi*?" Or might I point an accusatory finger in an entirely different direction? And one final question, have I beaten this subject with enough question marks?

Find a copy of A. Berman's book "*Total Pressure Measurement in Vacuum Technology*" and you'll see he devotes **Chapter 5** (88 pages) to the subject of calibration. It ain't easy—too bad it's so necessary if you want accurate pressure readings.

That's it for this one and it's onward and upward to Part 3 with more principles and mechanisms.

Lesker On The Road

Date	Event
June 28-29	**Electronic Materials Conf.** University Park, PA Booth 101
July 11-13	**Semicon West** San Francisco, CA Booth 2108/7330
Sept 18-20	**Commercialization of Nanomaterials** Pittsburgh, PA
Nov 14-16	**American Vacuum Society** San Francisco, CA Booth 1317
Nov 28-30	**Fall MRS** Boston, MA

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