Proficiency Testing for Pressure Calibration at the National Voluntary Laboratory Accreditation Program (NVLAP)

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Abstract: The National Voluntary Laboratory Accreditation Program (NVLAP) has initiated a proficiency testing program for calibration laboratories accredited for pressure, designated as NVLAP code 20/T05. This program involves measurements by the laboratory on NVLAP-provided test artifacts at specific pressure points in gas, and then comparisons of the results to similar measurements by the NIST (National Institute of Standards and Technology) Thermodynamic Metrology Group. The statistical test of the value of the E_n parameter is used to determine whether or not the laboratory shows proficiency at each pressure point, and the entire set of E_n values determines whether or not the laboratory demonstrates proficiency for their declared scope in pressure. This proficiency test can evaluate both laboratories that primarily calibrate effective area of piston gauges, and laboratories that calibrate electronic pressure instruments. The test protocol, methods of data analysis, and some results to date are presented. All NVLAP calibration laboratories currently accredited for effective area of piston gauges passed the proficiency test.

1. Introduction

Proficiency testing (PT) is an important component in demonstrating the competency of a calibration laboratory to perform a measurement. As stated in *ISO/IEC 17043:2010* (E) [1], "proficiency testing …(is the) evaluation of participant performance against pre-established criteria by means of interlaboratory comparisons". Proficiency testing can identify problems so that laboratories can initiate actions for improvement, provide confidence to the laboratories customers, identify differences in laboratories providing the same service, establish the effectiveness of measurement methods, and validate claims of uncertainty. Proficiency testing is also a requirement for a calibration laboratory to receive accreditation through an accrediting body such as the National Voluntary Laboratory Accreditation Program (NVLAP) which is a part of the National Institute of Standards and Technology (NIST).

Although proficiency testing can be used in a variety of laboratory settings including testing and inspection, when used for a calibration laboratory it most often involves a participating laboratory (or participant) being provided an item (artifact) for calibration, making a measurement on that item for the parameter of interest, and comparing the result of that measurement to a known value. If the participant's result agrees with the known value to within the expanded uncertainty (the appropriate determination of the uncertainty will be discussed later), then the participant is declared to demonstrate "satisfactory" proficiency. If not, performance is “unsatisfactory” and the accrediting body decides the corrective action to be taken. The known value of the measurand on the artifact is determined by the reference laboratory, which is a laboratory that has demonstrated metrological traceability with an uncertainty small enough to discriminate the results of the participants. For PTs provided by NVLAP in the field of pressure, NIST is used as the reference laboratory as it is a signatory of the Mutual Recognition Arrangement of the CIPM (Comité International des Poids et Mesures), it has demonstrated traceability to the International System (SI) unit of pressure through numerous international comparisons, and it has a quality system based on *ISO 17025*.

At NVLAP, PT requirements for its accredited calibration laboratories are set forth in its bulletin *LB-63-2011* [2], which follows the internationally accepted policy on proficiency testing, *ILAC-P9:11/2010* [3]. The essence of this requirement is that laboratories must develop a plan for participating in PT schemes that demonstrate their scopes of accreditation. NVLAP is developing specific PT activities that laboratories can take advantage of to fulfill their PT requirements. These are not available in all parameters of accreditation, in which case laboratories must use independent PT providers or other means to fulfill this requirement.

The NIST laboratories in conjunction with NVLAP have developed a PT program for laboratories accredited for pressure, classified as NVLAP code 20/T05 in the NVLAP system. In this paper we describe this PT program and provide results showing the competency of the participating laboratories (coded to preserve confidentiality). This program will continue to be used in the coming years as more laboratories are accredited and existing laboratories come up for renewal. It is part of a suite of NVLAP-developed proficiency tests which also include standard platinum resistance thermometers, gage blocks, mass, and air kerma (X-rays or cesium 137).

2. Scope of the Proficiency Test

Prior to 2011, no program existed within NVLAP for providing NIST-coordinated PTs that could test the full range of laboratory capabilities in pressure. In 2008, NVLAP conducted a one-time PT in pressure for a laboratory needing to demonstrate a level of competency with a very low uncertainty, using NIST as the reference laboratory. That PT provided a model for the program which ensued, and because of the similarity of the artifact, measurement protocol, and analysis method to those of this program its results are included in this paper. Pressure is a derived SI unit (from the meter, kilogram, and second) which is important in many aspects of modern life, such as human health, weather, air travel, transportation, and advanced manufacturing. Pressure is measured in both liquid and gas media. When the current program was devised in 2011, there were 27 NVLAP laboratories that were accredited for pressure calibration in some capacity. The range of the unit of pressure is very broad, varying from a few kilopascals (a fraction of 1 atmosphere) to tens of megapascals. NVLAP places laboratories which calibrate in the vacuum regime in a different category, which is not covered by this PT program.

The metrological device (or standard) which has the highest level of performance to realize pressure from 100 kPa to 500 MPa is a piston gauge. These are the devices which NIST uses as its primary standards for pressure in the range from 20 kPa to 280 MPa, and as its working standards to calibrate customer devices [4]. A piston gauge consists of a finely honed, round piston floating inside a round cylinder whose inner diameter is on the order of 1×10^{-6} m larger than the outer diameter of the piston. Fluid (either gas or liquid) lubricates the small gap between the piston and cylinder. The piston gauge realizes pressure by balancing the vertical force from calibrated masses in the known gravitational field, against the fluid pressure acting over a piston of known cross-sectional area. The key to using the piston gauge is to establish the effective area of the artifact, such that the pressure generated is equal to the vertical force divided by the "effective area". The term effective area is used because it is only approximately the geometrical average of the area of the piston and the cylinder in which it fits. It must be determined by careful dimensional measurement and modeling of these effects [5], or by comparison to another pressure standard such as a piston gauge or a mercury manometer.

Calibration laboratories can buy commercial piston gauges that are similar to the ones used by NIST, giving comparable performance and uncertainty to that which NIST provides. NVLAP accredited laboratories calibrate effective area and pressure, or pressure only. In designing this pressure PT program, we desired to cover both the laboratories that calibrate for effective area and those that calibrate for pressure.

In 2011 we assessed the capabilities of NVLAP laboratories for pressure and/or effective area. Our results were the following:

- Five laboratories were accredited for both effective area and pressure calibrations. Of those, all five were accredited for gas, and four of five were accredited in liquid. By the time the PT was started in 2012, there were four accredited NVLAP laboratories for effective area (two dropped, one was added). Using a gas piston gauge with a 6.9 MPa range would allow all the laboratories accredited in effective area to participate in the PT.

- Twenty two laboratories were accredited in pressure calibration only. Twenty one of the 22 laboratories perform gas calibrations, 16 of the 22 laboratories perform both gas and liquid calibrations, and one laboratory performs only liquid calibrations. There were a variety of pressure range capabilities within the 21 laboratories performing gas calibrations.

Eighteen laboratories calibrated in gas pressure to at least 3.5 MPa; two laboratories calibrated up to 1 MPa only, and on laboratory calibrated up to 137 kPa only. All 22 laboratories have the capability of calibrating an electronic pressure instrument, such as a transducer or pressure controller.

Based on the assessment, we devised two PTs, which we designated as High Level (HLPT) and Standard Level (SLPT). Specific details of each PT will be discussed in the sections which follow. The HLPT is for laboratories which calibrate effective area of gas piston gauges. The artifact to be used is a Ruska 2465 piston gauge[1] which NIST has used as a working standard for a number of years and has a substantial calibration history. It is the artifact used in 2008 for the one-time PT. The SLPT is for laboratories that calibrate pressure in gas pressure instruments up to 3.5 MPa. For this program NVLAP purchased a Fluke RPM4 reference pressure monitor as the PT artifact. This device has dual ranges (1.4 MPa, 7.0 MPa) and operates in absolute mode.

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[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

The low range will be used for the two laboratories with a 1 MPa pressure maximum, and the high range will be used for the 18 laboratories with a maximum pressure of 3.5 MPa or higher. The HLPT and SLPT taken together cover 25 of the 27 laboratories known in 2011 to provide calibrations in effective area or pressure.

As of the time of writing of this article, the HLPT was completed by four laboratories. We report the results of those laboratories plus an additional laboratory that participated in 2008. The SLPT was initiated in the fall of 2012. Because we are in the middle of the SLPT, no results will be presented at this time, although we will mention relevant aspects of the PT.

3. Administration of Proficiency Test

Both NVLAP and the Thermodynamic Metrology Group (TMG) of NIST have responsibilities for the PT. NVLAP is designated as the coordinator; they were responsible for determining which laboratories were to participate in the HLPT and SLPT, the order and timing of the measurements, collecting the fees for participation, payment of shipping fees from NIST to the laboratories, delivering the final reports, and implementing any action to the scopes based on the conclusions of the results. TMG is the reference laboratory; they determined the reference value of the PT artifact including long term stability, determined the uncertainty in the reference value, analyzed the laboratory results, compared the participant results to the reference value along with the uncertainty of the comparison, and reported the comparative results to NVLAP. Technical questions concerning the measurements or the artifact were directed to the TMG. NIST started and completed the HLPT prior to starting the SLPT.

Prior to initiating the measurement sequence for either PT, a detailed protocol was written jointly by TMG and NVLAP. The HLPT and SLPT each had its own protocol. The protocol described the artifact, the circulation scheme, expected dates for starting and completing the measurements, relevant measurement procedures including the pressure points to be tested, information required from the laboratory, how the data would be evaluated, and what the criteria were used for “satisfactory” or “unsatisfactory” performance of the PT.

Good communication between NIST and the participants is key to keeping the PT on schedule and in handling problems that inevitably arise. Arrival and departure checks document the progress of the artifact. The protocol includes a spreadsheet that specifies the required data from the laboratory. Participant reports are due to TMG approximately two weeks after the artifact was shipped following completion of the measurements.

Because the reference value of the artifact is determined by NIST and is not an ensemble of the results from the participating laboratories, the analysis determining the “proficiency” of each laboratory can be performed once the laboratory has reported their results and NIST has completed the closing measurements relevant to the particular laboratory.

4. The High Level Proficiency Test

The HLPT was designed for laboratories performing effective area calibration of gas piston gauges in gauge mode from 358 kPa to 6.9 MPa. The laboratories accredited for this parameter have in general the lowest uncertainties, since they are calibrating devices (other piston gauges) that are very stable and are providing traceability to a large number of pressure instruments. Once the PT was initiated, four laboratories had the capability to take part. They were Henry

Troemner, LLC; Navy Primary Standards Laboratory (NPSL); Sandia National Laboratories (SNL); and Transcat-Houston (listed alphabetically).

The PT artifact was a Ruska Instruments Corporation (now Fluke Electronics) matching piston-cylinder unit, serial number V-1086. It fit into a Ruska 2465 piston gauge base, which is a common unit used in high level calibration laboratories. If a laboratory owns a 2465 base and masses, then it is common to send only the piston-cylinder unit for calibration. Two of the participating laboratories had the base and masses to perform the calibration and required only the piston-cylinder unit. For the other two laboratories, NIST TMG provided a base and mass set to perform the calibration. Mass and density values were provided for the piston and the mass set (if needed).

The nominal effective area of V-1086 is 8.39 mm^2. Both the piston and cylinder are made of tungsten carbide. The piston-cylinder unit is shown in Fig. 1. The base unit and masses that NIST provided to two of the laboratories are shown in Figs. 2 and 3. NIST provided data on the thermal expansion coefficients and their uncertainty. The participants were required to measure the piston-cylinder temperature with their own thermometers to correct for changes in effective area due to thermal expansion. Effective areas were reported at 23 °C.

Figure 1. Piston-cylinder unit used in HLPT. S/N V-1086, 8.39 mm^2 nominal effective area.

Figure 2. Ruska 2465 piston gauge base unit used in the HLPT for laboratories that do not own their own piston gauge base.

Figure 3. Masses used in HLPT for laboratories not owning a mass set.

The circulation scheme and measurement periods for each laboratory were agreed upon prior to starting the PT and were listed in the protocol. NIST first measured the effective area of V-1086 in 2007, with demonstrated relative stability of 3×10^{-6} (3 ppm, parts per million) or better. Due to the stability of the PT artifact the circulation scheme consisted of two loops, with NIST making measurements prior to the first loop, between loop 1 and 2, and at the end of the second loop. Two laboratories made measurements during loop 1 and two laboratories made measurements during loop 2. The dates of the measurements are given in Table 1.

Month of Measurement	**Laboratory**
August 2011	NIST
February 2012	Navy Primary Standards Laboratory
March 2012	Sandia National Laboratory
May 2012	NIST
July 2012	Henry Troemner LLC
August 2012	Transcat-Houston
November 2012	NIST

Table 1. Circulation and Measurement Dates of the HLPT.

Reports on the proficiency of the first two laboratories were issued following the May 2012 NIST measurements, and reports on the final two laboratories were issued following the November 2012 NIST measurements.

Laboratories were required to measure the effective area of V-1086 at the 11 gauge mode pressure points of 358 kPa, 703 kPa, 1392 kPa, 2082 kPa, 2771 kPa, 3460 kPa, 4149 kPa, 4839 kPa, 5528 kPa, 6217 kPa, and 6907 kPa. Measured values of pressure were to agree within 0.3 % of the nominal values. The laboratories were required to report standard uncertainties (k = 1) at each pressure point for Type A, Type B, and combined uncertainty.

4.1 Performance and Stability of the PT artifact

The PT artifact V-1086 was calibrated multiple times at NIST both to determine the reference value of its effective area and to assign an uncertainty due to long-term stability. Ideally, the uncertainty due to long-term stability should be small compared to the other uncertainty components determined at the time of calibration at NIST and the participant laboratory. This allows better evaluation of the proficiency of the laboratory. Piston gauge artifacts should have a relative stability of several parts in 10^6.

The four calibrations used by NIST in evaluating the artifact were conducted in 2008, 2011 (prior to loop 1), May 2012, and November 2012. Several calibrations in 2007 demonstrated agreement to the four calibrations presented here to 3 ppm or better, however they are not included since they were conducted at different pressure points or against a different NIST standard. The reference standard for the NIST calibration was piston gauge PG13, which has the same nominal effective area as V-1086 and is used extensively in the calibration service. Hence V-1086 receives its traceability through PG13; PG13 is traceable to NIST piston gauge primary standards PG38 and PG39 as described in [5]. The establishment of PG38 and PG39 as primary standards is documented in [6]. For the 2008 and both of the 2012 calibrations, two calibration points were taken at every pressure, with the difference between the points being that the sets of masses were switched between PG13 and V-1086. This procedure of "mass switching" eliminates bias errors in the mass values. The results shown for each calibration are the average of the two readings at each pressure. The results are presented in Fig. 4 in a normalized fashion. At each pressure, the four calibrations (2008, 2011, 5/2012, and 11/2012) of effective area were averaged (A_{ave}), and the figure plots the relative deviation of each calibration from the average (A_i - A_{ave}) / A_{ave}. The maximum relative deviation was -4.3 × 10^{-6} (-4.3 ppm), with 39 of 44 deviations ≤ 2 × 10^{-6} (2 ppm). There is no systematic drift in effective area with time. The relative standard deviation of the four readings at each pressure ranges from 0.7 × 10^{-6} to 3.1 × 10^{-6} (0.7 ppm to 3.1 ppm). We therefore take as the k = 1 relative standard uncertainty due to long-term stability a value of 3 × 10^{-6} (3 ppm). Shown also on Fig. 4 is the Type B standard uncertainty, u_B, of V-1086 when calibrated against PG13, which is the same for all NIST calibrations. The deviations from the average are well within the Type B uncertainty.

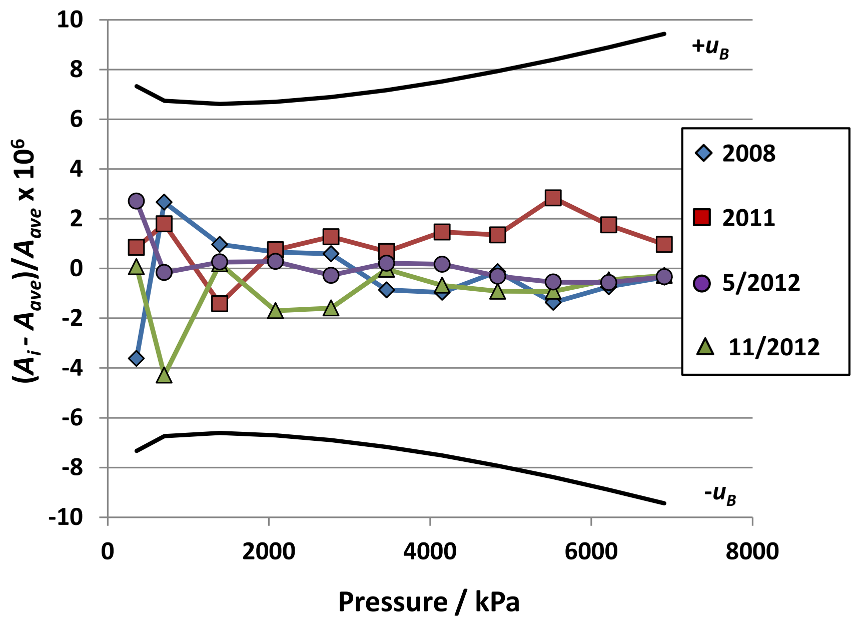

Figure 4. NIST calibration results of V-1086 against working standard PG13. Shown are deviations of effective area from average (A_i-A_{ave}) / A_{ave} of four calibrations performed in 2008, 2011, and 2012, along with the Type B standard uncertainty, u_B, in the effective area.

4.2 Method of data analysis

A PT requires simple, objective criteria to determine whether the laboratory has demonstrated its capability to make a measurement within its stated uncertainty. This is commonly done with the E_n parameter, which is a ratio of the difference in effective areas of the PT artifact between the laboratory and the reference value, divided by the expanded uncertainty (at a coverage factor of two) of that difference. In this case the reference value is the effective area measured by NIST. It is defined as:

$$E_n = \frac{d}{k \cdot u(d)} = \frac{A_L - A_{NIST}}{k\left[u^2(A_L) + u^2(A_{NIST}) + u_{LTS}^2\right]^{1/2}}, \qquad (1)$$

where:

A_L = effective area of artifact at pressure p, determined by the laboratory;
A_{NIST} = effective area of artifact at pressure p, determined by NIST;

d = difference in effective area of the artifact between the laboratory and NIST;
$u(A_L)$ = standard uncertainty in effective area, determined by the laboratory;
$u(A_{NIST})$ = standard uncertainty in effective area, determined by NIST;
u_{LTS} = standard uncertainty in artifact due to long-term stability;
$u(d)$ = standard uncertainty of the difference in effective area; and
k = coverage factor for 95 % confidence interval, $k = 2$.

The participating laboratory provides A_L and $u(A_L)$. All values of A_L and A_{NIST} are corrected to 23 °C. NIST determines the remaining parameters and calculates E_n. The E_n parameter is determined at each of the 11 pressures. For each pressure, the laboratory will satisfy the PT requirements if $|E_n| \leq 1.0$. The PT requirements are not met if $|E_n| > 1.0$.

Because the $k = 2$ coverage factor represents about a 95 % level of confidence for a single comparison, it is possible that $|E_n|$ could exceed a value of 1 at one of the 11 pressures even if the measurement processes are in statistical control and appropriate estimates of the effective areas and their uncertainties are made. Hence for the overall PT for each laboratory, the following conclusions were made:

- Not satisfy at 1 or fewer pressures: pass the proficiency test
- Not satisfy at 2 or more pressures: unsatisfactory proficiency test.

4.3 Results of the Laboratories

The results of the laboratories are summarized in Table 2 and Figs. 5 and 6. The participating laboratories are given letter codes A, B, C, and D to maintain confidentiality (with no relation to chronological order). We further only list the difference d between the laboratory and NIST to allow concealing the reference effective area in the event of the future use of V-1086 in a proficiency test. A laboratory E is also listed; this laboratory participated in the 2008 proficiency test which used the same protocol and same PT artifact. One of the laboratories was limited in its pressure capability to 4200 kPa, so it did not achieve the four highest pressure points. The relative standard uncertainty of the NIST results ranges from 6.7×10^{-6} to 9.5×10^{-6} (6.7 ppm to 9.5 ppm).

Table 2 shows the relative difference in effective area, d/A_{NIST}, the relative expanded uncertainty of the difference at $k = 2$, $ku(d) / A_{NIST}$, and E_n for the five laboratories at the 11 test pressures. Both d and $ku(d)$ are normalized by the effective area measured by NIST; these relative values when multiplied by 10^6 yield magnitudes in “ppm”. Also shown in Table 2 is the relative expanded uncertainty of the PT artifact measured at NIST, $2u(A_{NIST})/A_{NIST}$. Figure 5 plots the relative difference for the laboratories as a function of pressure. As can be seen, the relative differences range from -0.6×10^{-6} to 49.3×10^{-6} (-0.6 to 49.3 ppm). These differences when divided by the expanded uncertainty are plotted in Fig. 6, giving the E_n parameter. Because $|E_n| < 1.0$, all laboratories passed the HLPT at all pressures.

Nominal pressure / kPa	d/A_{NIST} x 10^6					$2u(d)/A_{NIST}$ x 10^6					E_n					$2u(A_{NIST})/A_{NIST}$ x 10^6
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	
358	37.4	47.3	1.4	2.9	-0.6	39.2	63.1	22.7	31.3	30.4	0.95	0.75	0.06	0.09	-0.02	14.9
703	28.7	49.3	10.1	11.7	6.7	38.7	62.8	21.9	29.6	29.6	0.74	0.79	0.46	0.40	0.23	13.6
1392	29.2	26.4	9.5	13.8	6.0	38.6	62.7	21.7	29.0	29.5	0.76	0.42	0.44	0.47	0.20	13.3
2082	21.4	18.6	8.6	17.6	10.4	38.7	62.7	21.8	29.0	29.5	0.55	0.30	0.39	0.61	0.35	13.5
2771	23.1	19.2	9.1	15.4	11.2	38.8	62.8	22.0	29.1	29.7	0.60	0.31	0.41	0.53	0.38	13.8
3460	22.0	17.0	7.2	16.2	10.1	39.0	62.9	22.3	29.4	29.9	0.56	0.27	0.32	0.55	0.34	14.4
4149	26.2	17.2	6.3	17.1	11.0	39.3	63.1	22.8	29.7	30.3	0.67	0.27	0.28	0.58	0.36	15.1
4839	27.4		6.9	14.6	10.8	39.6		23.3	30.2	30.7	0.69		0.29	0.48	0.35	15.9
5528	28.0		6.5	15.1	9.1	40.0		24.0	30.7	31.2	0.70		0.27	0.49	0.29	16.8
6217	22.7		7.6	16.7	10.6	40.4		24.7	31.3	31.8	0.56		0.31	0.53	0.33	17.8
6907	28.2		6.6	13.9	10.1	40.9		25.5	32.0	32.5	0.69		0.26	0.43	0.31	18.9

Table 2. Results of high level proficiency test.

It is interesting to note that the laboratory differences are all positive (as are the resulting E_n) values, rather than being distributed around zero. Upon being informed of the results, one laboratory sent their working standard to NIST for recalibration; a second laboratory re-examined their traceability to NIST, changing to using the most recent NIST calibration to define their pressure scale rather than an average of previous NIST calibrations. Inclusion of these changes by the two laboratories would have reduced the positive laboratory differences for those laboratories, and for one lab some of the relative differences would be negative by up to 9×10^{-6} (9 ppm). When a laboratory shows proficiency in a PT, they are not required to take corrective action or to change their scope, even if they are systematically high or low from the reference value.

The NIST uncertainty component in $u(d) / A_{NIST}$ is the same for each participant, meaning the variations in $u(d) / A_{NIST}$ between laboratories (from about 11×10^{-6} to 31×10^{-6}) are predominantly due to the variations in the laboratory component, $u(A_L)$.

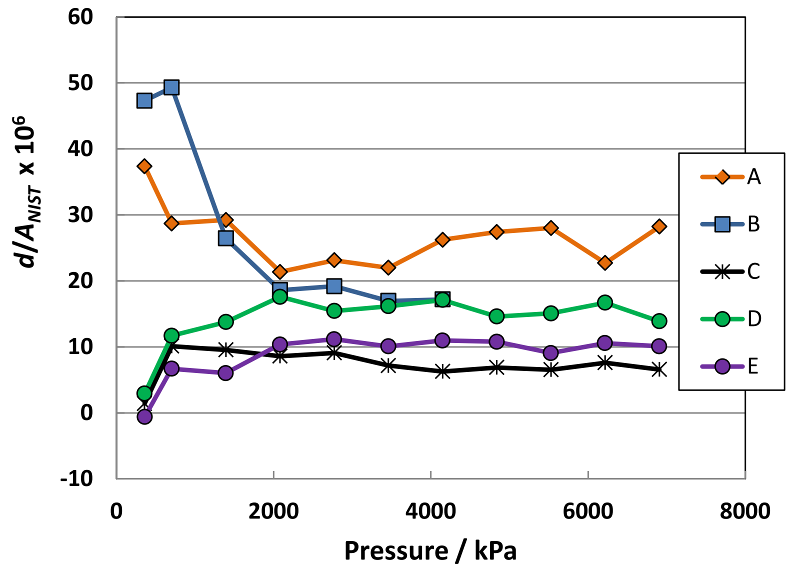

Figure 5. Relative difference, d/A_{NIST}, of the effective area of V-1086 between the laboratories and the NIST value. When multiplied by 10^6, the relative difference is in units of ppm (parts per million).

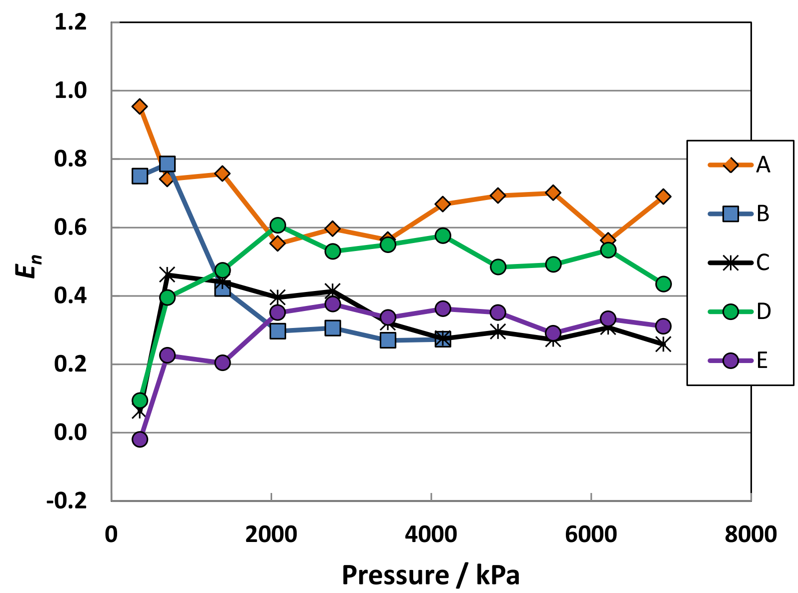

Figure 6. E_n parameter of the proficiency test for the laboratories. Because $|E_n| < 1.0$, all laboratories show proficiency at all pressures.

5. The Standard Level Proficiency Test

The SLPT was designed for laboratories performing calibrations of pressure-sensing electronic instruments such as electronic barometers or pressure transducers. The PT artifact is an RPM4 which is typical of a device the laboratories would calibrate as part of their service. Here, the absolute calibration of the PT artifact is not important, but rather how the difference between the PT artifact and the laboratory standard compares to the difference between the PT artifact and the NIST standard. We refer to this as the pressure offset.

Electronic pressure instruments, such as the RPM4, are not as stable over time as a mechanical artifact such as a piston gauge. Because of this, in most cases the PT is circulated in the star pattern: NIST sends the artifact to a laboratory, and the laboratory returns it to NIST after its measurements. NIST performs the same measurements on the artifact prior to (opening) and following (closing) the laboratory measurements. The repeated measurements at NIST allow establishing the stability performance of the PT artifact. The proficiency of each laboratory participating in the PT can be determined as soon as NIST makes its measurements following the laboratory's measurements, and does not depend on the circulation pattern that follows.

The SLPT requires measurements in absolute mode. This is a more demanding test of laboratory capabilities than gauge mode, due to the requirement of establishing a zero pressure for the laboratory pressure standard. Laboratories performing pressure calibrations in absolute mode will typically use as their standard either a piston gauge which they operate in absolute mode, a piston gauge operating in gauge mode with a digital barometer, or an electronic pressure instrument. In absolute mode, establishing zero pressure requires a vacuum pump and a calibrated vacuum gauge. Electronic pressure instruments are more likely to have zero shifts than span or linearity shifts [7]. Without a good zero pressure reference or a high accuracy piston gauge operating in absolute mode, it is more difficult to establish the zero offset of the electronic gauge.

The first SLPT will be performed up to 3.5 MPa, as this is the range that covered 18 laboratories when the program was started. Once the first SLPT is completed, the same PT artifact will be used with its lower range transducer to cover the laboratories that have capability up to 1.0 MPa only. The opening NIST measurements for the first laboratory participant were made in November, 2012, and the first laboratory made its measurements in 2012. We do not report results for the laboratories participating in the SLPT as the test is ongoing. NIST uses piston gauge PG13 operated in absolute mode for the reference pressure measurements, the same standard as used in the HLPT. The 10 pressure points for the SLPT are 358 kPa, 700 kPa, 1050 kPa, 1400 kPa, 1750 kPa, 2100 kPa, 2450 kPa, 2800 kPa, 3150 kPa, and 3500 kPa.

As with the HLPT, the E_n parameter is determined at each calibration pressure. If $|E_n| \leq 1.0$, then the laboratory satisfies the PT requirements for that pressure value. In this case, E_n is the difference in pressure offset between the laboratory and NIST, divided by the expanded uncertainty of that difference. Its expression is the same as eq. (1) with the pressure offset substituted for effective area.

NIST determines the Type A uncertainty in the NIST pressure offset from 10 repeated measurements of the offset at the set pressure, and the Type B uncertainty from the uncertainty of the components contributing to the standard pressure. Typical values of the standard uncertainty of the pressure offset at NIST are 3 Pa to 28 Pa (from low to high pressure). The long term stability uncertainty is determined for each laboratory based on the opening and closing NIST measurements for that laboratory. To date, that stability uncertainty (k = 1) has ranged from 9 Pa to 19 Pa.

6. Summary and Conclusions

Proficiency testing is an important component in demonstrating the competency of a calibration laboratory to perform a measurement. The NVLAP program at NIST has developed a suite of PTs for a range of parameters to complement its assessment activities. In this paper we have described two types of PTs for pressure, classified as NVLAP code 20/T05 in the NVLAP system. One PT is used for laboratories that calibrate effective area of gas piston gauges up to 3.5 MPa, which presently covers four laboratories in NVLAP. This PT was completed in 2012 and the four laboratories so accredited all passed the PT. The second PT covers laboratories that calibrate pressure instruments only. There currently are 20 laboratories that fall in that category, a number which could change as laboratory scopes are modified or as more laboratories become accredited. In the NVLAP program there is direct comparison of the PT artifact to the NIST working pressure standards, which have direct traceability to the SI and are supported by Calibration Measurement Capabilities (CMCs) that have been vetted through the NIST quality system and numerous international Key Comparisons. We expect the NVLAP coordinated proficiency testing program to expand in the future.

7. References

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