AN ANALYSIS OF THE AGREEMENT IN PRESSURE TRACEABILITY OF TWO INTERNATIONALLY RECOGNIZED COMMERCIAL LABORATORIES

Michael Bair [1], *Ken Kolb* [2]

[1] Fluke Calibration, Phoenix, Arizona, USA, mike.bair@fluke.com
[2] Fluke Calibration, Houston, Texas, Kenneth.kolb@fluke.com

Abstract: In 2010 Fluke Calibration acquired Ruska from GE Sensing, for many years a direct competitor in state of the art pressure measurements with DH Instruments (acquired by Fluke Calibration in 2007). The two laboratories maintained significantly different traceability schemes using standards of different design. Recognizing the different methods Fluke Calibration is making an effort to quantify the agreement in pressure traceability from 1.5 kPa to 400 MPa between the two laboratories through existing calibration data and current measurement comparisons. This paper looks at the different traceability schemes, reports on any measured and predicted differences throughout the overlapping pressure ranges supported, and suggests possible improvements in traceability as a unified effort in the future.

Key words: Fluid pressure, traceability, crossfloat, uncertainty, comparison.

1. INTRODUCTION

Since the early 1960's Ruska has provided state of the art traceability in pressure to their customers in the United States and internationally through a line of piston gauges. Very few commercial laboratories could offer traceability in pressure at this level, especially manufacturers of pressure standards or devices. From the early 1980s through 2007 DH Instruments distributed and developed piston gauges in competition with Ruska. Ruska and DH Instruments independently developed traceability schemes to offer traceability in pressure with uncertainties at approximately the same level. However, their traceability scheme was a significantly different, with one based on traceability through the NIST Pressure Section, and the other based on fundamental characterizations.

In 2007 Fluke Calibration acquired DH Instruments and in 2010 acquired the Ruska and Pressurements product lines from GE Sensing. Fairly soon after the acquisition of Ruska it was felt by the authors of this paper that any differences in pressure traceability needed to be discovered as soon as possible. There had been indirect information indicating that there was good agreement between the piston gauge manufacturers but never a formal direct comparison in pressure, at least not by the two companies with their lowest CMC uncertainties.

In a meeting in September of 2010 the first steps of discovering the agreement in pressure traceability were planned. First was a comparison of historical data of calibrations performed on each other's piston gauges. The second step, completed in January of 2011, was a direct comparison in gauge mode at the primary level in gas and also in oil performed by crossfloat.

Note that for simplicity in this paper Phoenix refers to Fluke Calibration in Phoenix, AZ (formerly known as DH Instruments) and Houston refers to Fluke Calibration in Houston, TX (formerly known as Ruska). And the instruments used in the comparisons are referred to by their DHI or Ruska Model Number.

2. PRESSURE TRACEABILITY

Pressure is a derived measurand in the SI system. The knowledge of pressure defined using piston gauges comes from various sources. The primary influences are the effective area of a piston-cylinder, mass and gravity. Gravity and mass can be quantified to near negligible levels of uncertainty. So, as many pressure metrologists know well, the primary challenge in establishing traceability with piston-gauges is the determination of effective area and its dependence on pressure [1]. Effective area traceability is normally achieved by an elaborate scheme that includes crossfloat comparisons and extrapolation as pressures increase.

In Phoenix effective area traceability takes the form of the Piston-Cylinder Pressure Calibration Chain [2]. In its current form the calibration chain has been in existence since 2001. Portions of the calibration chain, including low pressure oil piston-cylinders, have been in the calibration chain since 1988. The calibration chain, in its different forms has been re-determined in 1983, 1985, 1987, 1988, 1990, 1992, 1995, 1998, 2001, 2004 and most recently in 2010. The goal and success of the calibration chain has been to transfer effective area from some source of original traceability at the lowest pressure to the highest pressure with as little extrapolation and transfer uncertainty as possible. For the last 10 years the original traceability has been dimensional measurements by either NIST or PTB. Validation of the calibration chain at higher pressures has been through a formal NIST calibration or through informal comparisons with other national metrology institutes such as PTB and LNE.

Houston traceability in effective area was established through direct NIST pressure calibrations. These include direct measurements with the NIST UIM (Ultrasonic Interferometer Manometer) for lower pneumatic pressure, and through direct crossfloat with NIST working standard piston-gauges for higher pressure hydraulic traceability. Due to the wide operating range of some of the Houston piston-gauges the Houston calibration chain uses fewer piston ranges and requires extrapolation only at hydraulic pressures greater than 280 MPa. While the Houston effective area traceability is entirely through pressure measurement, special calibrations were conducted to obtain the very lowest uncertainty available through NIST pressure measurement.

3. A FIRST LOOK

Phoenix has a 3rd party calibration service that includes the effective area determination of piston gauges. Through the years Phoenix has performed effective area determinations on many Ruska piston gauges, including models 2465, 2468, 2470, 2400 and 2450 piston gauges.

The metrology departments of Phoenix and Houston decided to assemble the results of all Ruska effective area determinations performed by Phoenix over the last 10 years and compare to the measurements from Houston. Comparisons were made both for effective area at zero pressure and at full pressure to account for the change in effective area with pressure (the b1 coefficient - lambda). The review was limited to Phoenix comparisons made within 10 years of the Houston determination. Figure 1 shows the results of the analysis. Note that all results in this paper that are given in ppm, including Figure 1, represent parts in 106.

All effective areas are shown twice in Figure 1, once at zero pressure and once at full scale pressure. Many of the lower pressure results are the same for zero pressure and full scale because the b1 coefficient was considered to be zero by both labs. All points below 10,000 kPa (1500 psi) are in gas for 2465 and 2468 piston-cylinders and above were in oil for 2400 and 2450 piston-cylinders. The dashed circles indicate an En number (the difference in the effective areas divided by the square root of the uncertainties) of greater than 1. There were four total with one for a 2465 high pressure gas piston-cylinder and three in higher pressure hydraulic ranges. It was noted that these were in the same direction.

The four instances where En was greater than 1 were evaluated. In each case it is only part of the range where the disagreement exceeds the RSS of the uncertainties. When considering that only part of the range was affected, less than 5% of the comparisons had En values greater than 1. So there was not a significant concern due to these En values.

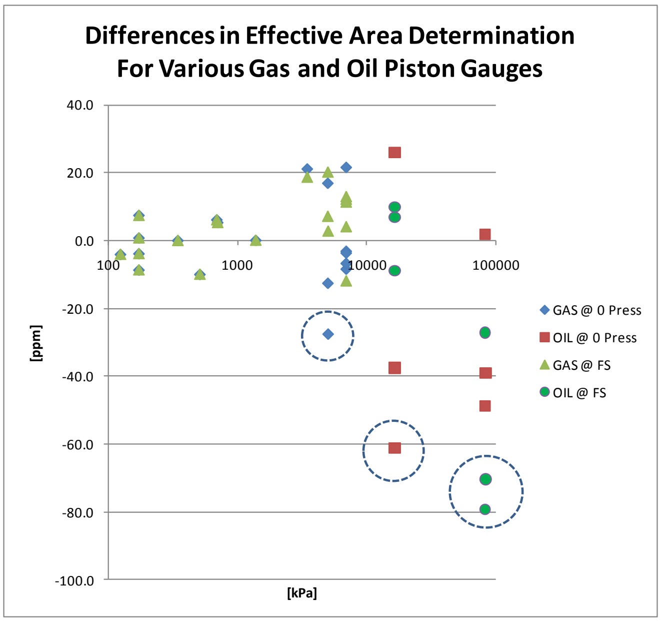

Figure 1. Results of comparing effective areas determined by Houston and Phoenix

Separating the results between gas and oil, the average agreement in gas effective area determinations was 1.6 ppm and for oil was -27.3 ppm. The results of this analysis promoted the need to perform a comparison at higher pressures in oil. In addition, if there was sufficient time, an attempt would be made to perform a crossfloat comparison using available gas piston gauges with the lowest uncertainty possible from each lab.

4. HIGH PRESSURE COMPARISON

The high pressure crossfloat comparison was performed in Phoenix from approximately16 to 277 MPa (2300 to 40000 psi) during the week of January 17, 2011. The comparison was performed with a Ruska 2450 piston gauge with the same range as the comparison. Three piston-cylinders from the Phoenix Piston-Cylinder Pressure Calibration Chain [3] were used to achieve the CMC uncertainties installed in the PG7302. Since separate fluids were used, sebacate for the DHI PG7302 and ST55 for the Ruska 2450, a Ruska high pressure DP cell was used to balance the pressures between the two references. Figure 2 shows the basic configuration of the crossfloat comparison.

Table 1 gives the results of the crossfloat comparison. The table includes the pressures achieved and the uncertainty in pressure for both Houston and Phoenix, the difference between the two standards in pressure and relative agreement, and the En number based on the agreement and the uncertainties. It should be noted that the uncertainties for Houston pressure are lower than what is described in Houston’s CMC in their scope of accreditation. This is due to the fact that the piston gauge used is primary and would not be used for day to day calibrations in Houston. Also presented is Figure 3, a chart of the results shown for clarity of the agreement achieved and consistency of the three references used in the PG7302.

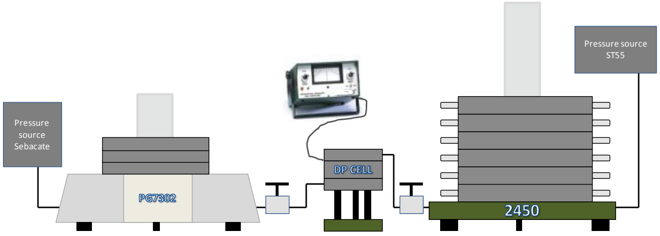

Figure 2. Configuration of the high pressure oil crossfloat comparison.

17 points were taken throughout the range of the 2450 with piston-cylinder SN J493. In the PG7302 the calibration chain 1 MPa/kg piston-cylinder SN 25D was used from 16 to 100 MPa (2300 to 15000 psi), 2 MPa/kg SN 742 from 100 to 200 MPa (15000 to 30000) and 5 MPa/kg SN 468 from 200 to 280 MPa (30000 to 40000 psi).

Table 1. Results of high pressure oil comparison.

Houston Pressure [MPa]	Houston Unc [ppm]	Phoenix Pressure [MPa]	Phoenix Unc [ppm]	Diff [ppm]	En [---]
16.42405	35	16.42395	19	6	0.15
32.68177	35	32.68144	19	10	0.26
48.93902	35	48.93834	19	14	0.35
65.19563	35	65.19483	19	12	0.31
81.45179	35	81.45082	19	12	0.30
97.70755	35	97.70673	19	8	0.21
113.9627	35	113.9622	28	5	0.11
130.2175	35	130.2168	28	5	0.12
146.4716	36	146.4712	28	3	0.06
162.7251	38	162.7251	28	0	0.00
178.9776	39	178.9780	28	-2	-0.04
195.2299	41	195.2309	28	-5	-0.10
211.4818	43	211.4825	49	-4	-0.06
227.7330	45	227.7343	49	-6	-0.09
243.9839	47	243.9866	49	-11	-0.17
260.2340	48	260.2385	49	-17	-0.25
276.4837	50	276.4901	49	-23	-0.33

It would have been advantageous to perform this crossfloat more than one time. But the schedule only permitted one run. However, a sensitivity check, to ensure that the balance was within ±1 ppm, was performed at each of the 17 points taken. To quantify the affects of temperature changes, air drafts and general repeatability of the test, a standard error of the fit was calculated to be 2.5 ppm for k=1. It was determined that in this type of test, with two different oil media, the null indicator was essential to be able to resolve these levels of agreement and test uncertainty.

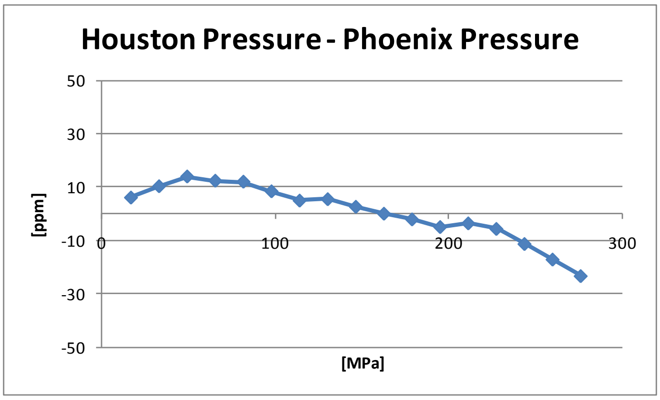

Figure 3. Agreement between Houston and Phoenix crossfloat comparison in oil.

5. LOW PRESSURE COMPARISON

In the last two days of the comparison it was decided to compare pressures at the lowest level of uncertainty possible for each lab. To achieve this a crossfloat comparison was performed between a PG9607, 50 mm piston-cylinder, 5 kPa/kg SN 1161, with a CMC pressure uncertainty of ±(5 ppm + 50 mPa), and a low range Ruska 2465 piston-cylinder with a stated uncertainty of ±7 ppm. The range of the comparison was approximately 12 to 355 kPa (1.7 to 52 psi).

The test configuration is shown in Figure 4. The crossfloat balance was determined using a Rosemount 3051c 4-20 mA low range transmitter, calibrated to ±50 Pa range. The transmitter was read using an 8846a multimeter reading voltage across a 250 ohm resistor giving ±2 volts. This provided a useful resolution of 2.5 mPa to determine equilibrium and repeatability to within 25 mPa.

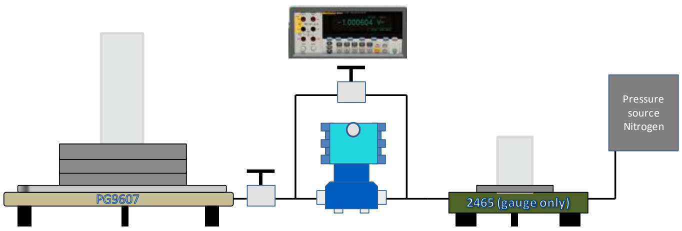

Figure 4. Configuration of the low pressure gas comparison.

Table 2 gives the results of the crossfloat comparison. This includes Houston and Phoenix pressures and uncertainties, the difference in the pressures in Pa and ppm and the En to show the level of agreement.

Considering the sensitivity of the gas piston gauges there was more concern with air drafts than with the hydraulic comparison. Measures were taken to reduce the amount of air drafts affecting the crossfloat using draft shields in key locations. One standard error of the fit of the agreement between the two references was 1.2 ppm. The 46 kPa point tended to be an outlier and was tested again with slightly more favorable results.

Table 2. Results of low pressure gas comparison.

Houston Pressure [kPa]	Houston Unc [ppm]	Phoenix Pressure [kPa]	Phoenix Unc [ppm]	Diff [ppm]	En [---]
11.87135	7.0	11.87136	9.2	-0.8	0.07
29.08174	7.0	29.08166	6.7	2.8	0.28
46.29313	7.0	46.29291	6.1	4.8	0.51
63.50436	7.0	63.50435	5.8	0.2	0.02
81.08251	7.0	81.08242	5.6	1.1	0.12
98.29284	7.0	98.29278	5.5	0.6	0.07
115.5042	7.0	115.5040	5.4	1.9	0.21
132.7155	7.0	132.7153	5.4	1.5	0.17
149.9263	7.0	149.9261	5.3	1.3	0.15
167.1367	7.0	167.1365	5.3	1.1	0.12
184.3481	7.0	184.3476	5.3	2.7	0.31
201.5593	7.0	201.5589	5.2	2.0	0.23
218.7715	7.0	218.7712	5.2	1.1	0.13
235.9819	7.0	235.9817	5.2	0.9	0.10
253.1933	7.0	253.1928	5.2	2.0	0.23
270.4045	7.0	270.4041	5.2	1.5	0.17
287.6184	7.0	287.6179	5.2	1.8	0.21
304.8289	7.0	304.8281	5.2	2.5	0.28
322.0403	7.0	322.0393	5.2	3.1	0.35
339.2515	7.0	339.2506	5.1	2.7	0.31
356.4622	7.0	356.4616	5.1	1.8	0.20
46.29298	7.0	46.29283	6.1	3.2	0.35

6. ANALYSIS OF THE RESULTS

It was expected that the low pressure gas comparison should agree within the stated uncertainties. It was very encouraging that the agreement was so close. The average disagreement shown in Table 2 was +1.8 ppm and the average En was 0.2. Because of this level of agreement it was decided that there were no actions necessary in traceability for either Phoenix or Houston for low pressure gas. This is re-enforced with the historical data collected and presented in the beginning of this paper in Figure 1.

In Figure 1 the historical data shown for the effective area determinations there was an increased disagreement as pressure increased in oil determinations. The agreement is shown as Phoenix effective area determination minus Houston effective area determination. This would lead to a Houston minus Phoenix disagreement in pressure in the negative direction. This was partially experienced in the crossfloat comparison but not to the magnitude shown in Figure 1.

Even though the results of the oil crossfloat was well within uncertainties reported, it was decided to re-determine the effective area of the 2450 piston-cylinder to better align the traceability between Phoenix and Houston. There are a number of reasons for this decision. First is that the Phoenix Piston-Cylinder Pressure Calibration Chain was completed and validated very recently in 2010. Another reason is that the change in Houston traceability is far enough inside Houston uncertainty that it would not significantly affect Houston customers getting recalibrations on piston gauges. In addition to this the continuity of the three piston-cylinders used from the calibration chain was very good. Figure 2 shows this very well. Only a very slight difference, approximately 1 ppm, can be resolved in the data from when the piston-cylinders were exchanged. And finally the decision to align Houston traceability to Phoenix was influenced by the fact that Houston traceability in high pressure oil was due.

For Phoenix this comparison, especially in high pressure oil, is considered an additional official validation of the 2010 Piston-Cylinder Pressure Calibration Chain [3].

7. CONCLUSION

What should not be overlooked in the comparisons performed is that this is not just a validation of the methods for determination in effective area. Clearly on either side of the null indicators used in the crossfloat comparison were years of exclusive traceability and methods for effective area, different designs in piston gauges, different software for calculating pressure and even different methods for calculating pressure. There was not one aspect that was common or correlated between the two sides. Even considering this the measurements were in agreement at a level with which many NMIs throughout the world would be very satisfied.

For the future there are plans to fill the gaps that these comparisons left. Primarily high pressure gas up to 100 MPa (15000 psi) and also very high pressure up to 500 MPa (72000 psi) in oil where the uncertainties are significantly higher.

ACKNOWLEDGEMENTS

The authors wish to thank Erik Christopher, Engineering Technician, Phoenix, (and ex-crossfloater for Phoenix service lab) for performing set-up and data acquisition for PG7302 and PG9607 piston gauges. The results are as good as they are and plentiful because of his efforts and expertise.

REFERENCES

[1] M. Bair, *Improvements In The Determination Of Effective Area Through A Piston-Cylinder Pressure Calibration Chain*, 2002 NCSL Workshop & Symposium, San Diego, CA

[2] M. Girard, M. Bridge, P. Delajoud, *The Purpose And Implementation of a Multi-Piston Pressure Calibration Chain*, 1989 NCSL Workshop & Symposium, Denver, CO.

[3] M. Bair, *The 2010 Piston-Cylinder Pressure Calibration Chain*, May 2010, Internal Fluke Document.