QUARTZDYNE® A DOVER COMPANY **Quartzdyne, Inc.** 4334 W. Links Drive Salt Lake City, Utah 84120 USA Tel: 801-839-1000 www.quartzdyne.com	**Calibration Procedures & Metrology Uncertainties** January 2014

Introduction

This report summarizes the method of calibration used to characterize Quartzdyne® Pressure Transducers and provides the sources of metrology uncertainty, including the mitigating procedures to manage and control those uncertainties.

Traceability of Calibration

Calibration of Quartzdyne® Pressure Transducers is traceable to the U.S. National Pressure Standards maintained by the National Institute of Standards and Technology (NIST).

Calibration Procedure

Our pressure transducers measure absolute pressure. The pressure that the transducer senses during our calibration is the sum of the atmospheric pressure, head pressure, and the pressure generated by the pressure source, as shown in Figure 1. The unique set of coefficients for each transducer is created by "calibrating" or characterizing the device over the pressure and temperature range.

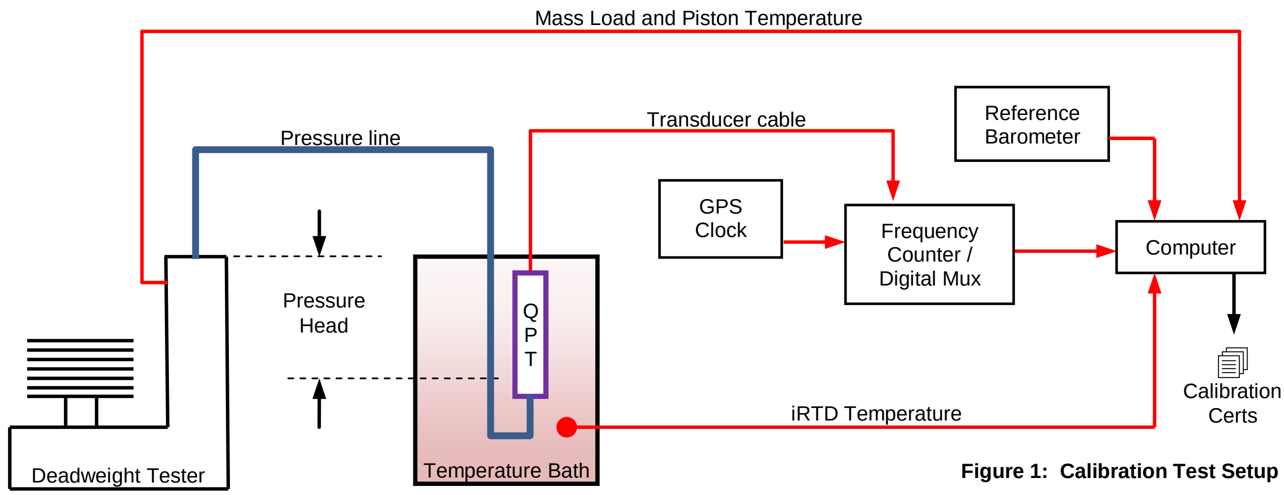

Figure 1: Calibration Test Setup

Transducers either provide frequencies (analog) or 32-bit counts (digital). Temperature-compensated pressure is computed from these outputs using a polynomial equation and the transducer's unique coefficients.

We apply 7-9 pressures at each of 5-6 temperatures. At each temperature, the pressures are typically in this sequence: ambient, 20%, 60%, 80%, 100%, 90%, 70%, 40%, 600 psia. It is not necessary to follow this exact procedure, but this sequence has several advantages:

- It provides a large enough sample of different pressures (7-9) without excessive repetition.
- It provides the same number of increasing and decreasing pressure data points to reveal the hysteresis.
- Two low pressure points show the zero return.

The pressurization process described above must be performed at several temperatures throughout the temperature range. The temperature of the pressure and temperature crystals should be uniform and stable for best performance. Since thermal gradients can cause calibration errors, we achieve < 0.02°C stability in our liquid baths.

Metrology Uncertainties

True absolute pressure is calculated for each data point using the following equation. Uncertainties in the measurement are determined by dominating variables, which are outlined in Table 1 below.

$$P_{True} = P_{atm} + (\rho_g \times h) + \frac{Mass \times g \times (1 - \frac{\rho_A}{\rho_M}) \times Units}{A_0 \times [1 + A(T_{pist} - 20)][1 + B \times P_p]}$$

Table 1: System Uncertainties (Values differ from standard due to our 4,250-foot elevation and nearby mountains.)

Source of Uncertainty	Description	Mitigation
Deadweight Tester (DWT) P_{True} = ±0.01% of reading	Masses and piston wear with usage.	Pistons are cleaned monthly. On-site calibration every two years to 100 ppm
Gravity (*g*) 9.79793 m/s^2	The gravity (*g*) value scales the true pressure computation.	Interpolated from National Geodetic Survey at http://www.ngs.noaa.gov/ Lat. 40.7190736, Long -111.9949336
Piston Area (A_0) A = 9 ppm/°C B = 6 ppb/psi T_{pist} = ±0.01°C	Pressure and temperature affect the cross-sectional area of the piston.	Temperature sensor is located on piston for real-time correction, and is verified every two years.
Air Density (ρ_A) 1.018 kg/m^3	Correction is a function of room pressure, room temperature, and humidity.	Assumed constant. Seasonal 5% variation results in ±0.05 psia.
Barometric Pressure P_{atm} = 12.65 ± 0.4 psia	Barometric and HVAC system cause pressure changes in laboratory.	Barometers verified annually to ±0.1 psia.
Pressure Head (ρ_g x h) ρ_g = 0.033 psi/inch	Correction for height (*h*) between pressure standard and transducer	The height difference is measured within ±1 inch (±0.03 psia).
Frequency Counter < 1 x 10^{-12} Hz	Analog transducer frequencies need to be counted accurately.	Counters are synchronized to NIST WWVB time signal. System stops working if GPS signal is lost.
Temperature Gradients < 0.02°C	Unstable or uneven temperatures throughout bath can create temperature or pressure compensation errors.	Using stirred-liquid baths that are uniform and stable to 0.01°C.
iRTD Temperature Probe ±0.125°C	Sensing element ages or drifts over time.	Calibration probes are calibrated semi-annually to ±0.125°C (25-200°C)

Transducer Conformance

The conformance demonstrated during calibration of each transducer is shown in the certification supplied with each transducer. The chart shows the deviation of each point from the calibration equation using the coefficients calculated for the transducer. Figure 2 shows typical conformance of Quartzdyne® Pressure Transducers. The residual error at all temperatures is less than ±0.02% of full scale (FS). This includes any errors in the linearity correction, repeatability, hysteresis, and temperature errors. Note that the residual error compares the transducer to the primary pressure standard; the DWT uncertainty must be added to the residual error shown.

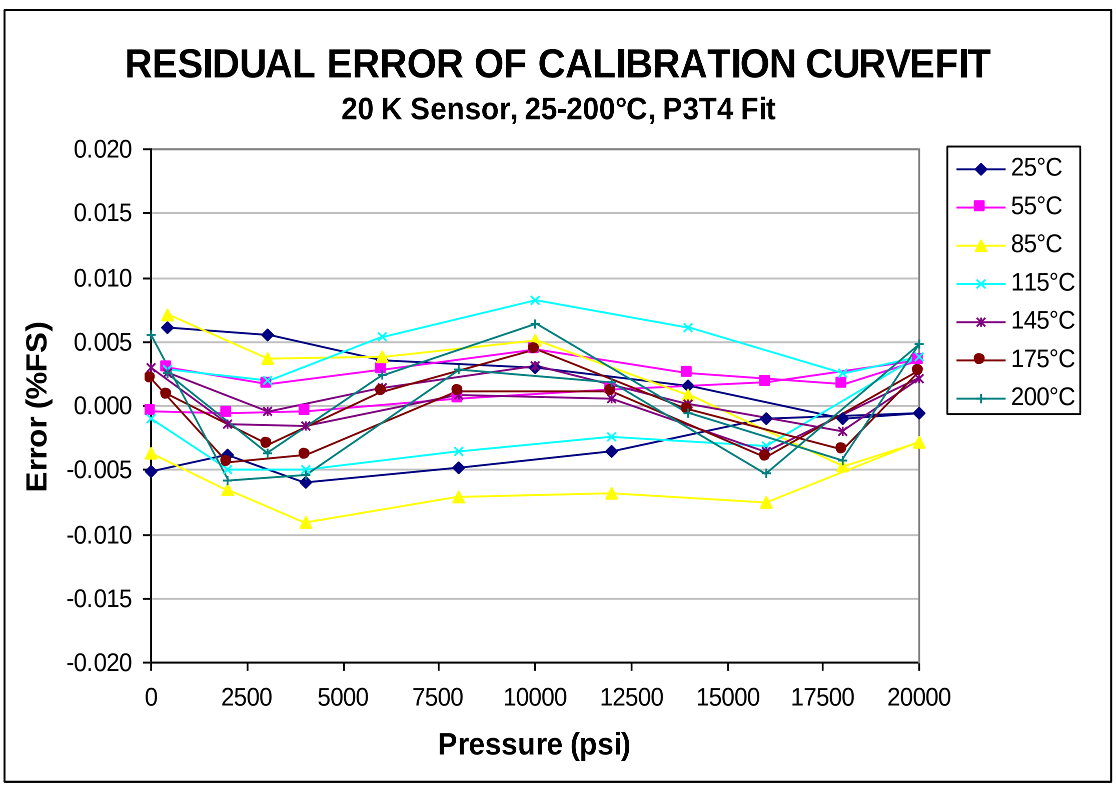

Figure 2: Calibration curve typical of a Quartzdyne® Pressure Transducer

The conformance of the transducer to the primary standards is NIST traceable. Differences between how the instrument is calibrated in the laboratory and the downhole environment may affect its performance. In Tables 2 and 3 below, the pressure and temperature conformance is explained:

Table 2: Quartzdyne Pressure Transducer (QPT) Conformance – Pressure Measurement

Conformance	Description	Mitigation
Accuracy ±0.02% of FS	The combined effects of repeatability, hysteresis, linearity, and bellows effects. Excludes DWT uncertainty and long-term stability.	See below
Repeatability < 0.01% of full-scale	Repeating the measurement under the same conditions should produce the same result.	Post-calibration “QA” procedure quantifies repeatability, hysteresis, linearity, and bellows effects.
Hysteresis	Measurement depends upon whether test conditions are increasing or decreasing.	4 increasing and 4 decreasing pressures are measured.
Linearity	Residual error after fitting the calibration data to a least-means-square polynomial.	Use 3rd or 4th order polynomial to prevent force-fitting calibration data.
Bellows Effects	An isolation device is placed between sensor and the pressure medium, creating an offset.	Device is installed prior to calibration. Accuracy below 100 psia is not guaranteed due to non-linear expansion of fill-fluid.
Long-term Stability < 0.02% FS / year	Measurement drift in a steady-state environment over months/years.	A 3-hour pre-calibration drift test at max. P/T screens for unstable units. A 2-hour post-calibration drift test is conducted at lower P/T with coeffs to screen for non-conforming units.
Resolution < 0.01 psia (1s sample)	The smallest discernable pressure change.	Quartz resonators and endcaps are measured for frequency and dimensional tolerance.

Table 3: Quartzdyne Pressure Transducer (QPT) Conformance – Temperature Measurement

Conformance	Description	Mitigation
Accuracy ±0.5°C	The combined effects of repeatability, hysteresis, and linearity. Excludes long-term stability.	See below
Repeatability < 0.01°C	Repeating the measurement under the same conditions should produce the same result.	Post-calibration “QA” procedure quantifies repeatability, hysteresis and linearity.
Hysteresis	Measurement depends upon whether test conditions are increasing or decreasing.	Hysteresis ignored due to broad accuracy specification.
Linearity	Residual error after fitting the calibration data to a least-means-square polynomial.	Use 3rd or 4th order polynomial to prevent force-fitting calibration data.
Long-Term Stability < 0.1°C / year at 177°C	Measurement drift in a steady-state environment over months/years.	A 3-hour pre-calibration drift test at max. P/T screens for unstable units. A 2-hour post-calibration drift test is conducted at lower P/T with coeffs to screen for non-conforming units.
Resolution < 0.005°C (1s sample)	The smallest discernable temperature change.	Quartz resonators are measured for frequency shift.

Specification sheets are located on the Quartzdyne website.