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Improvements to the Long Term Stability of Quartzdyne® Pressure Transducers

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BACKGROUND

Quartz-crystal based pressure transducers have a notable reputation in the oilfield for providing high quality data. Leveraging the elasticity, resolution, and stability of crystalline quartz, Quartzdyne has been manufacturing high accuracy quartz crystals for 12 years. (Quartzdyne founders have been working in the quartz crystal industry for 25 years.) In early 1999, we began a program to quantify and improve the long-term stability (drift) performance of our pressure transducers.

To some, it may come as a surprise that our transducers drift at all. Clearly, at temperatures lower than 50°C (120°F), the drift is difficult to quantify using even the best calibration equipment available. Since the rate of drift increases with temperature, we have focused our efforts on minimizing the drift at temperatures of 150°C (300°F) and higher.

The sources of drift in the pressure measurement are (1) the quartz pressure crystal, (2) the quartz reference crystal, (3) the oscillator circuit, and (4) the bellows. Due to robust construction, design, and material/component selection, the contribution of the latter two are insignificant. The quartz pressure crystal is responsible for the majority of drift, while the quartz reference crystal makes a smaller contribution through the mixed pressure frequency ($f_{p,\ mix} = f_{p,\ raw} - f_r$).

Through design and process changes, we successfully reduced the drift in our pressure transducers, typically by a factor of 4 to 10. These lower drift crystals now provide our customers with superior long-term accuracy. Coincidentally, they provide us with improved yields in manufacturing and calibration, indicating that drift reduction has come without other performance compromises.

Quartz transducers are more expensive than strain or piezoresistive gauges. (Quartz crystals are made by people, not machines.) With its long-term stability and accuracy, quartz retains its value over time through extended recalibration intervals. Thus, a tool using our quartz pressure transducer will remain in service for a longer period of time than a piezoresistive tool, earning more revenue for the service provider. Hence, we emphasize *life-cycle* costs with our customers, not initial costs.

TEST METHODS

The challenge of measuring drift lies primarily in the stability of the test system. Without strict control of the temperature and pressure conditions, it becomes difficult to distinguish between drift and system conditions. In these stability tests, we used the following equipment:

- DH Instruments 5306 Manual Deadweight Tester, 0.01% of reading
- Theta Systems PM170 Series Hydraulic Pressure Controller
- ESS 1350 Oven
- Agilent 5335A / 53131A Universal Counter with GPS Linked Timebase
- Agilent 34970A Data Acquisition Unit with 34901A Multifunction Module
- Mensor 2104 Barometer

Since air ovens are not ideal for temperature stability, we employed an innovative approach to maintain better thermal control around the instruments. Inside the air oven, the instruments were placed within a cylinder full of small copper-coated metal balls. The surrounding thermal mass provided an adequate thermal stability of ±0.02°C within the setpoint temperature.

For pressure stability, the Theta Systems Hydraulic Pressure Controller maintained the float level of the spinning weights on the piston cylinder using a stepper-motorized screwpress. (Theta Systems is now owned by SI Instruments, Ltd.) Stepper-motor pressure corrections were typically 0.1 psi or less. The deadweight tester piston temperature and atmospheric pressure measurements were monitored for accurate computation of applied pressure.

For data acquisition, the Agilent Universal Counter measured the output frequencies of the Quartzdyne pressure transducers. Bridge and differential voltages from the piezoresistive devices were measured using an Agilent 34970A, which required a minor correction for room temperature variation.

RESULTS AND DISCUSSION

Early in the study, we ran drift tests spanning several weeks. After noting a rapid decay in the drift, we observed little value in the data after three days. Furthermore, limiting the tests to three days permitted us to qualify more variations. We have conducted over 100 drift tests; a sample of the data is provided as follows:

Figure 1: Drift Improvements to the 16K sensor
Figure 2: Drift Improvements to the 10K sensor
Figure 3: Drift Comparison between the 10K sensor and piezoresistive sensors.
Figure 4: Drift Comparison between the 16K sensor and piezoresistive sensors.

Quartzdyne sensor drift can be predicted--and compensated for--using the following algorithm:

$$P_{drift} = k\left(\frac{P_a}{P_{FS}}\right)\left(\frac{t}{t_p}\right)^{0.5}$$

where,

- P_{drift} is the predicted drift during time t [psi]
- k is determined experimentally as the amount of drift over t_p [psi]
- P_a is the applied pressure during the test [psi]
- P_{FS} is the full-scale pressure rating for the sensor [psi]
- t is the elapsed time [days]
- t_p is the drift test period [days]

For example, using the average of the improved lines in Figure 1, the drift over 1 year would be:

$$P_{drift} = -0.25\left(\frac{16000}{16000}\right)\left(\frac{365}{3}\right)^{0.5} = -2.8\,\frac{psi}{year}$$

Note that piezoresistive sensor drift in Figures 3 and 4 is unpredictable. Piezoresistive sensor drift increases exponentially with increasing temperature.

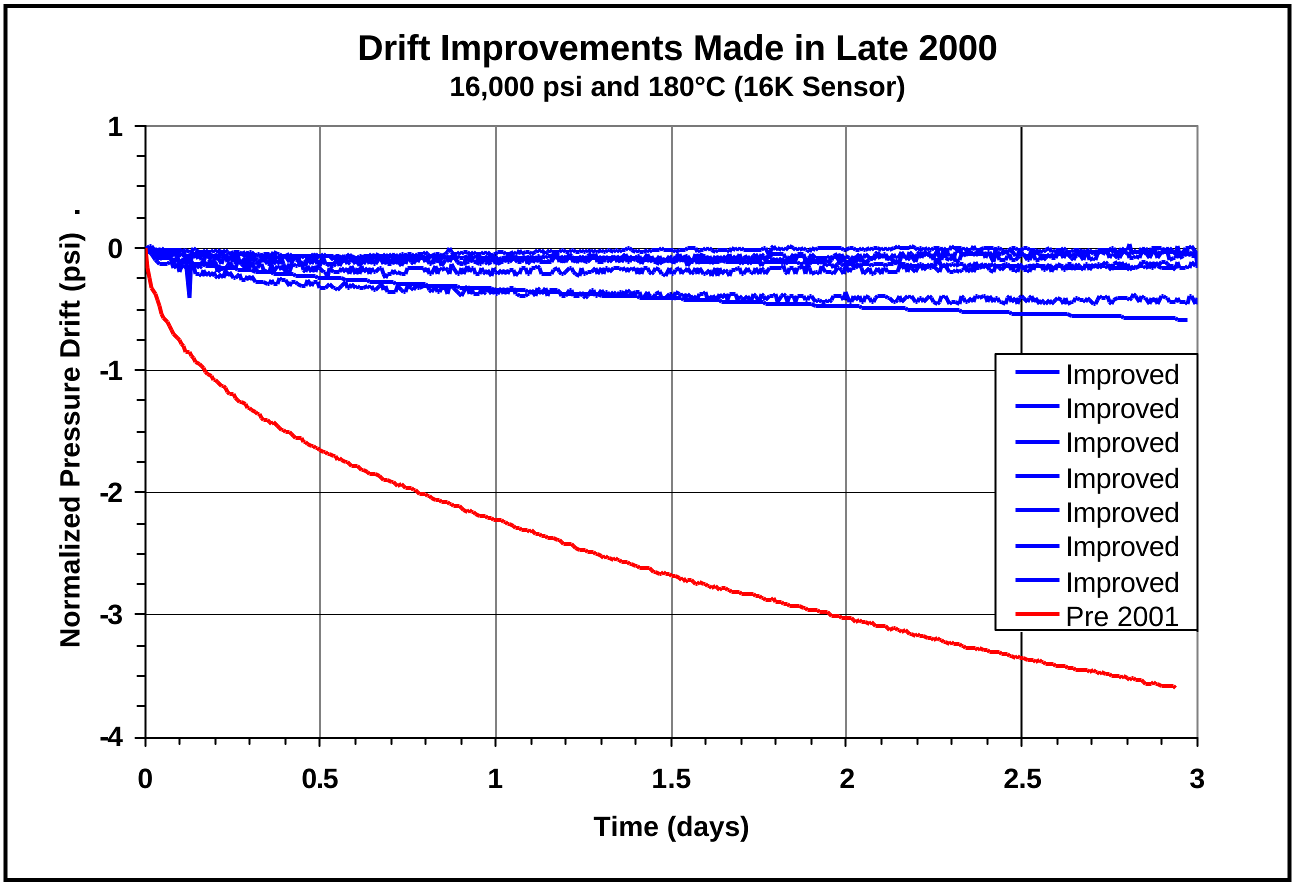

Figure 1: Drift Improvements Made to the 16K Sensor

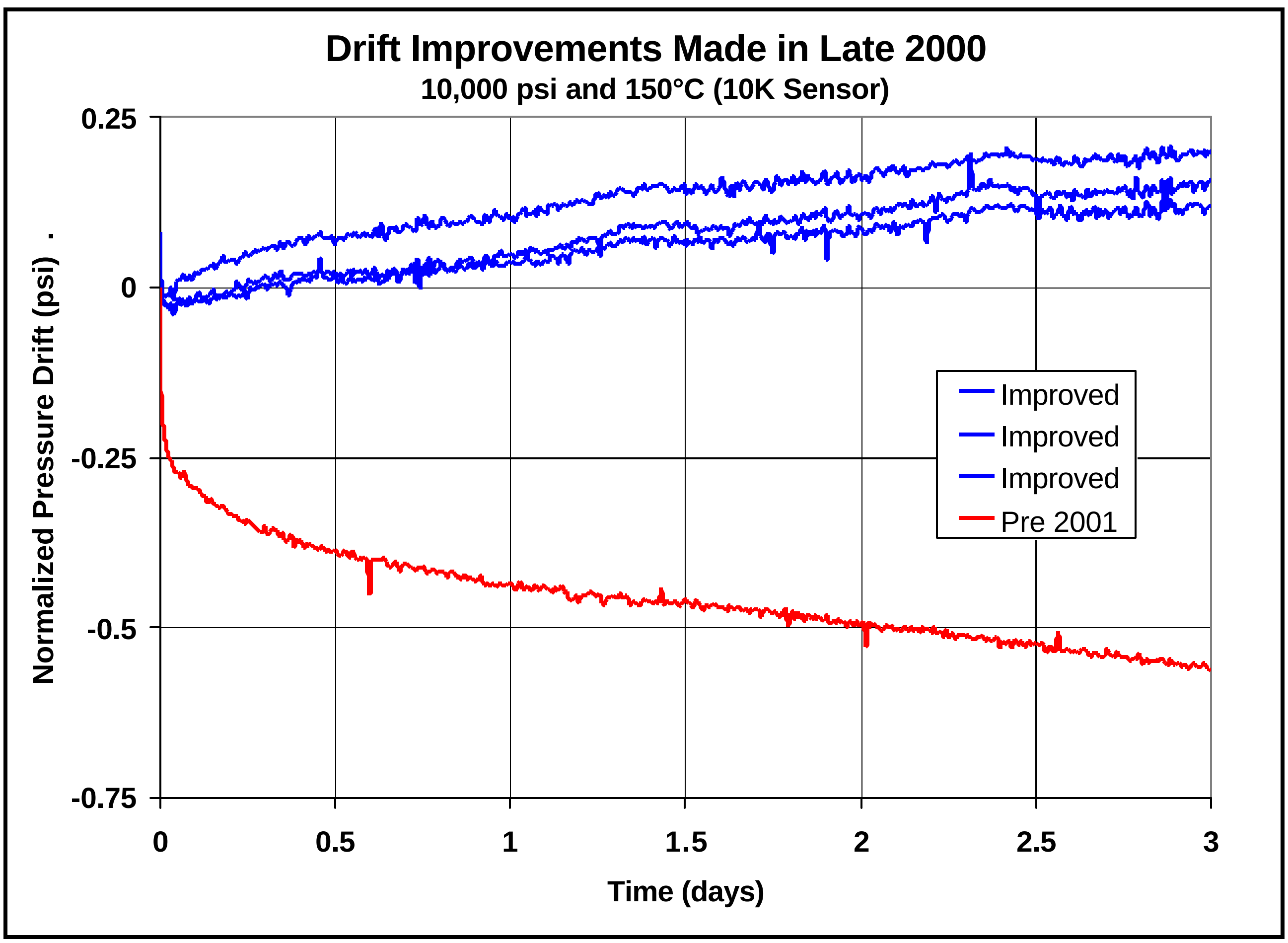

Figure 2: Drift Improvements Made to the 10K Sensor

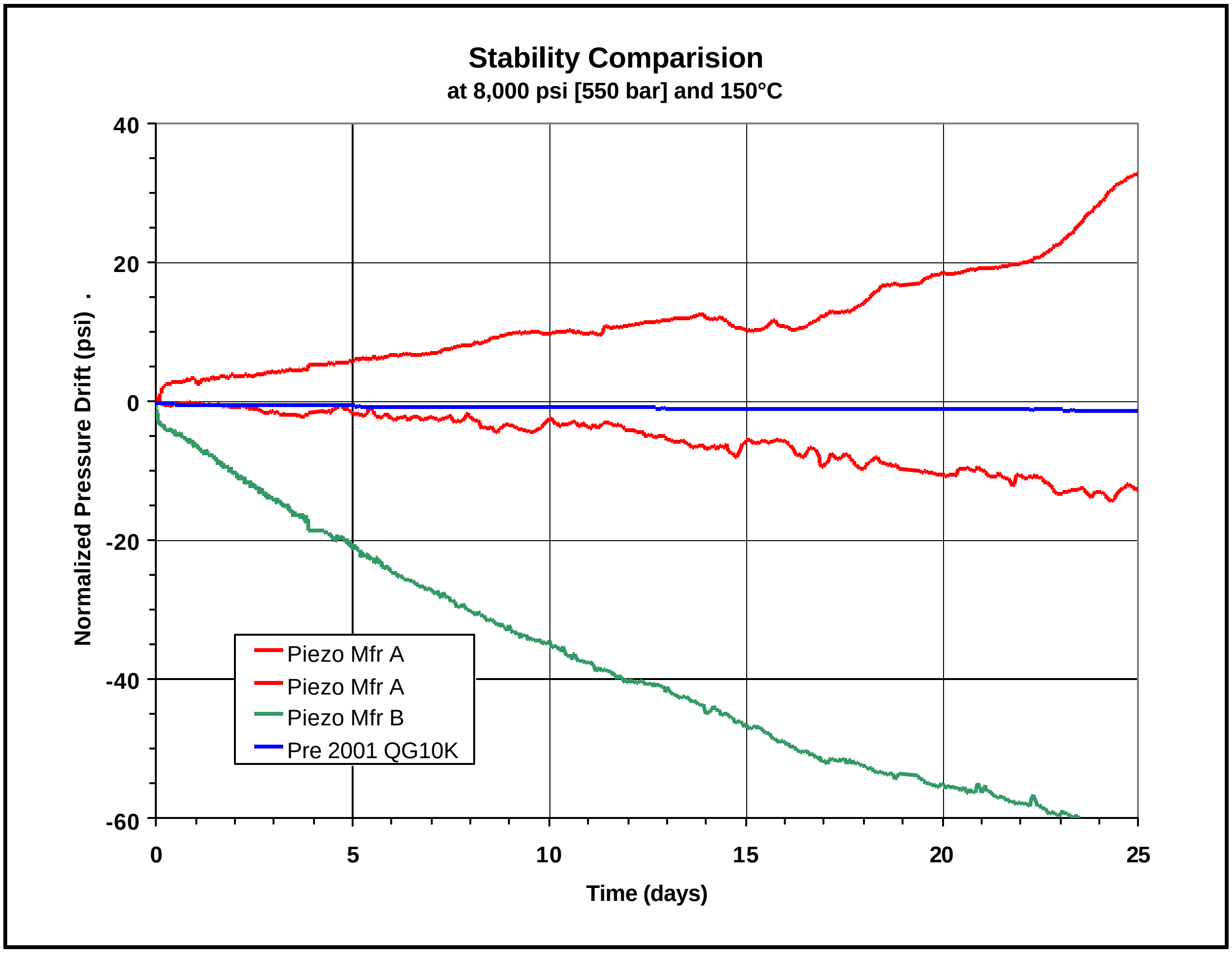

Figure 3: Drift Comparison Between Quartzdyne 10K and Piezoresistive Sensors

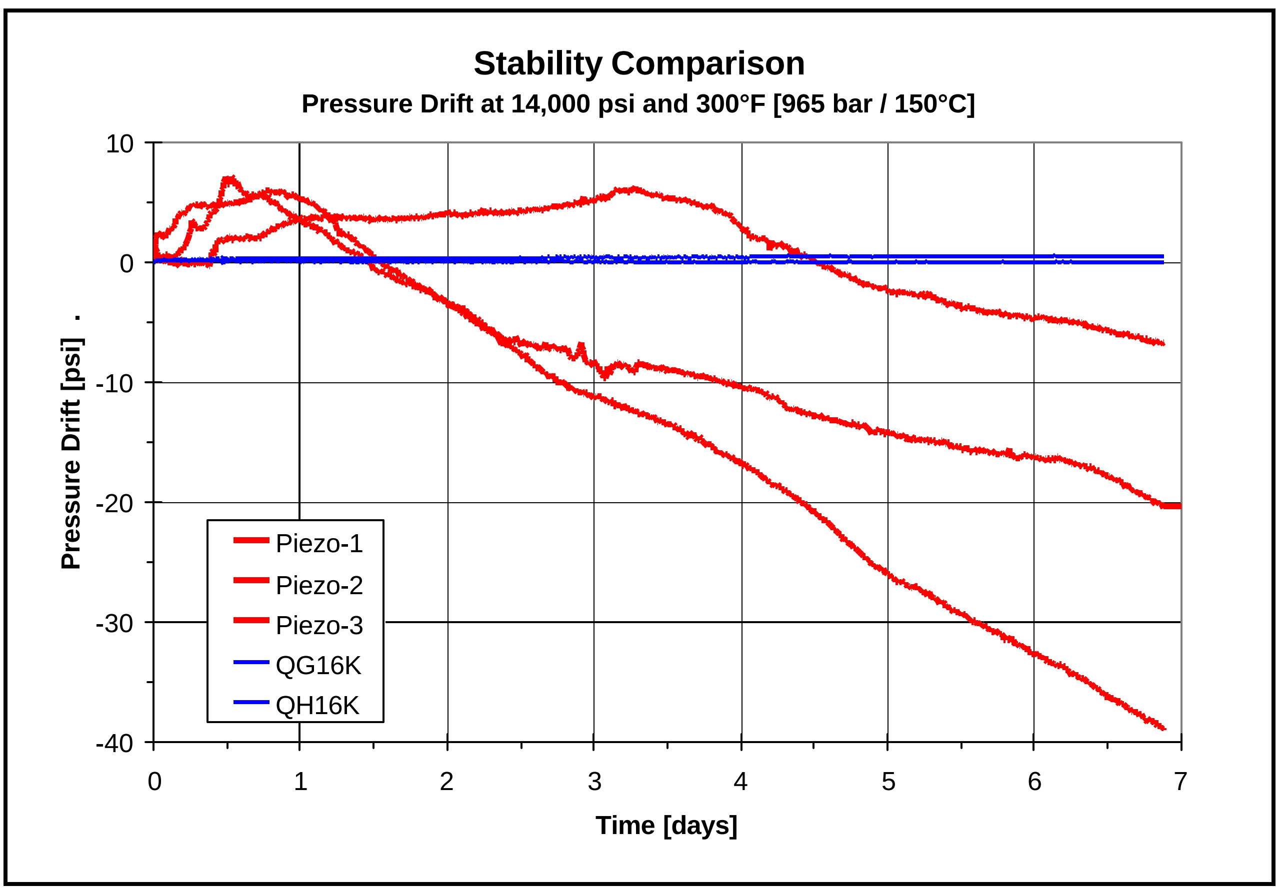

Figure 4: Drift Comparison Between Quartzdyne 16K and Piezoresistive Sensors