QUARTZDYNE, INC.
A DOVER RESOURCES COMPANY
1020 ATHERTON DRIVE
SALT LAKE CITY, UTAH 84123 USA
801-266-6958; FAX 801-266-7985
www.quartzdyne.com

ENVIRONMENTAL TESTING OF QUARTZDYNE® PRESSURE TRANSDUCERS

October 1998

I. ABSTRACT

Since 1991, Quartzdyne has introduced several models of quartz pressure transducers to the downhole market. Prior to releasing any pressure transducer for manufacture, Quartzdyne subjects prototypes to a suite of environmental tests. As part of the verification process in the design phase, environmental testing helps to identify significant design weaknesses (if present), and also places added confidence in the robustness of the product, should it survive. In addition, transducer designs are occasionally requalified to justify the implementation of minor changes in components, soldering technique, and circuit mounting. The current suite of environmental tests for Quartzdyne® pressure gauges are as follows (the mechanical shock and vibration tests are performed on each orthogonal axis of the transducer):

1. Random vibration: 10 to 2000 Hz, 10.89 g_{rms}, 15 minutes
2. Sine Sweep: 10 to 2000 Hz, 10.0 g, 10 minute sweep, 5 minute dwell at any noted resonance(s)
3. Shock: 40 g, 11 ms half-sine, 20 bi-directional shocks
4. Thermal Shock: -55 to 150°C, 25 one hour cycles
5. Drop: 500 g, 2 ms half-sine, 25 drops

All models since the Series QD have received various levels of all five tests listed above. (The Series QD received neither the Sine Sweep nor the Thermal Shock test.) As a general practice, temperature and pressure frequencies are sampled before and after each test. To date, all transducers have survived a battery of environmental testing, or have been redesigned until survival was achieved.

II. RANDOM VIBRATION AND SINE SWEEP

Random vibration and sine sweep testing have proven to be excellent methods by which resonances under 2000 Hz can be quickly identified. Although the sine sweep test tends to be more thorough in isolating each resonance, random vibration can excite all resonances within the test envelope for the entire duration of the test. In avionic hardware qualification tests performed by Grumman Aerospace Corporation, the 'typical' random vibration spectrum achieved its maximum effectiveness in only 10 minutes of testing, rather than the one hour required by the sine sweep test[1]. The sum total of the energy transferred to the test specimen, commonly known as the g_{rms} level, is determined by calculating the area under the profile of Power Spectral Density vs. Frequency (see Figure 1). Quartzdyne started with the NAVMAT specification of 6.06 g_{rms} in 1990. Since that time, the g_{rms} level has been increased several times until September 1997, when the present 10.87 g_{rms} level (the fifth spectrum shown in Figure 1) was reached.

---

[1] NAVMAT P-9492. Navy Manufacturing Screening Program, Dept. of the Navy, May 1979. Page 10.

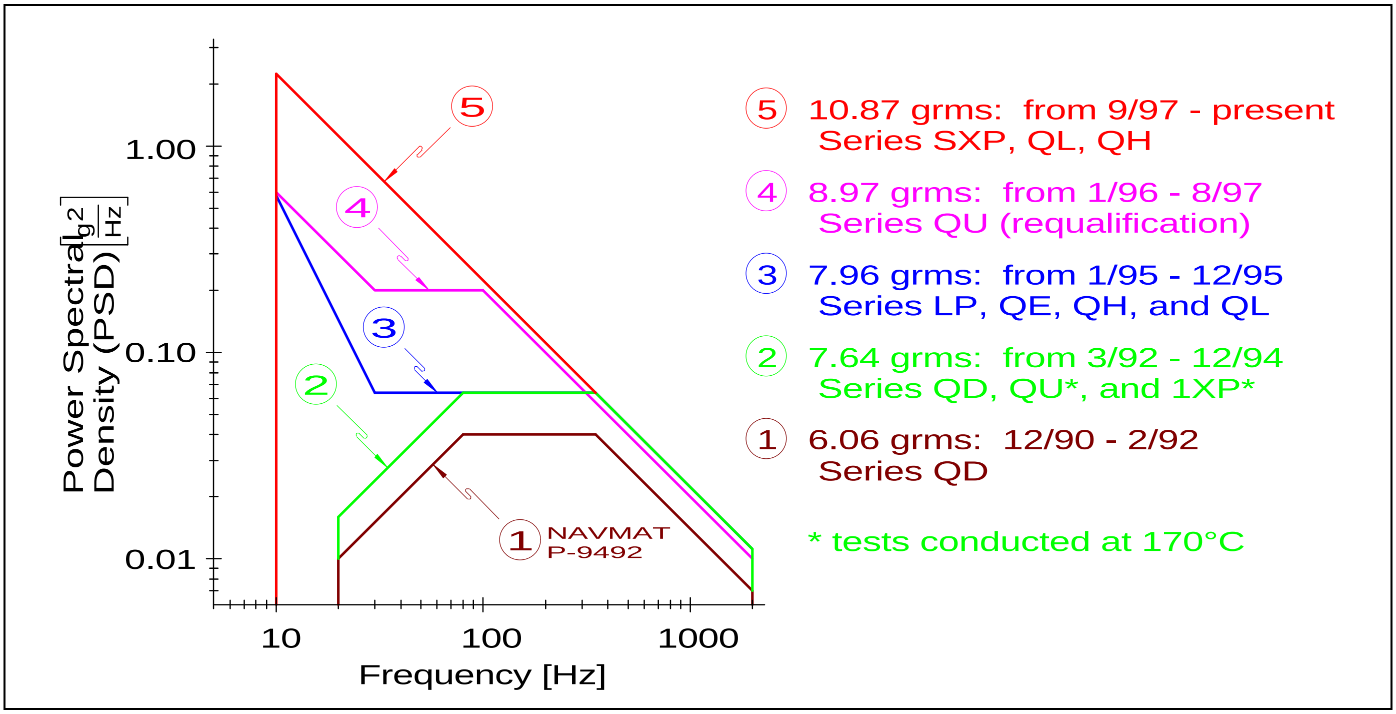

Figure 1: Historic random vibration profiles employed by Quartzdyne

Random vibration and sine sweep are performed using one setup. Transducers are placed in test fixtures and mounted to a shaker table as illustrated in Figure 2. Once the fixtures are securely mounted to the table, random vibration per Figure 1 (profile 5) begins, lasting 15 minutes. The sine sweep test is then initiated: 10 to 2000 Hz, 10.0 g, 10 minute sweep time. Any discernible, significant resonances receive a 10.0 g dwell for five minutes.

Because resonances are more likely to occur normal to the plane of the printed circuit board (PCB), orientation of the PCB is expected to play a substantial role. Axes are defined as follows:

- x-axis: normal to PCB plane
- y-axis: latitudinally parallel to PCB plane
- z-axis: longitudinally parallel to PCB plane

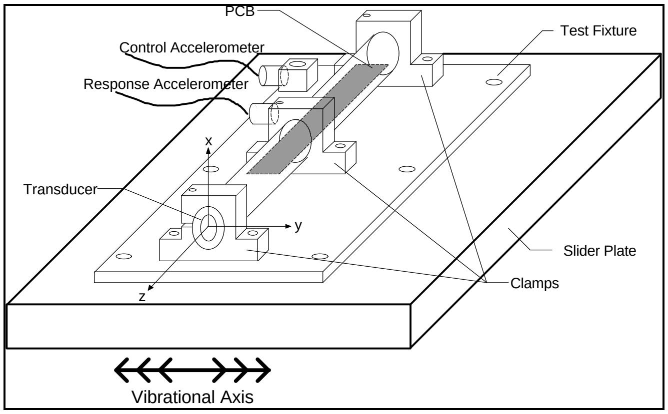

Figure 2

Axes are manipulated by either rotating the transducer in the fixture or by mounting the fixture longitudinally on the table. A past test setup (showing the SXP) was digitally captured, and is shown in Figure 3 and Figure 4.

The pressure and temperature frequencies of the transducers are checked before and after each test sequence. In some tests, the output frequencies are also monitored during the vibration testing.

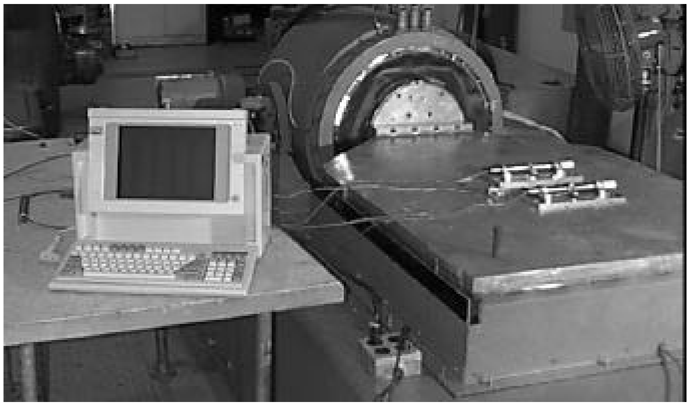

Figure 3: Test Setup for x- and y-axes

Figure 4: Close-up of Test Setup for z-axis

During the many vibration tests conducted over time, response accelerometers on transducers have reported resonances at various frequencies. However, filtering out the system and fixturing resonances to isolate purely transducer resonances is a difficult challenge. Reported resonances from one visit to the environmental lab have often mysteriously disappeared on a subsequent visit. Generally, as a rule of thumb, resonances with a 2:1 ratio (amplitude of vibration being twice the drive amplitude) are considered “significant.” To date, no “significant” resonances have been identified under 1000 Hz. Nevertheless, <u>any</u> resonances having amplitude ratios greater than 1.3:1 receive a 5 minute, 10 g dwell at the noted frequency.

III. 40 g SHOCK:

The 40 g, 11 ms half-sine shocks are performed using the same setup as in random vibration and sine sweep (see Figure 2). Twenty shocks are applied bi-directionally to the three axes of each transducer.

IV. DROP TESTING (500g SHOCK):

Quartzdyne technicians have noted that pressure transducers occasionally experience uninstrumented shocks which appeared to be quite severe. For instance, upon occasion a transducer rolls off the benchtop, striking a vinyl-tiled wood or concrete floor. Since transducers always survive this (apparently severe) shock, there was a desire to confirm the survivability of the gauge to a more controllable shock specification.

The drop testing apparatus is shown in Figure 5. An aluminum fixture for clamping a transducer either vertically or horizontally is mounted on a vertical rod with two Teflon journal bearings. The drop terminates on a padded granite block.

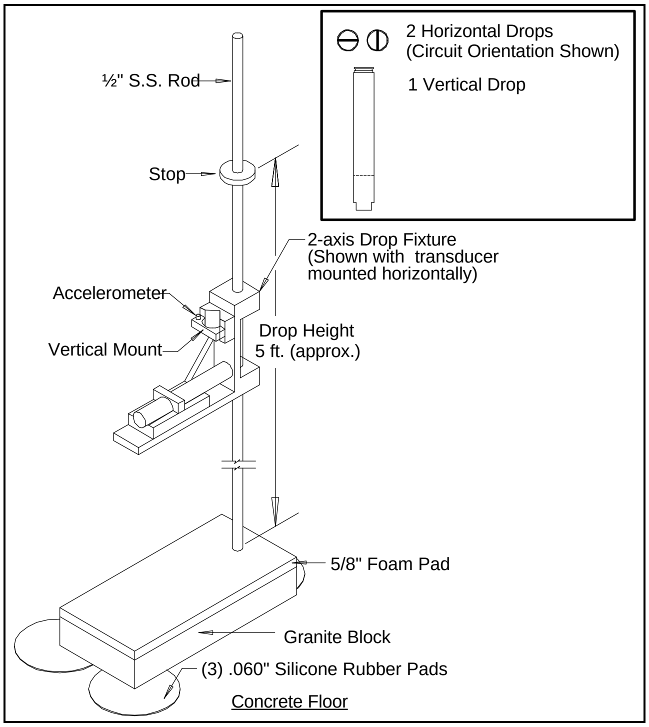

Figure 5

Test shocks are measured using a BBN Instruments model 501ER piezoelectric accelerometer. In March 1992, the output waveforms were captured using a Nicolet FFT analyzer (time input mode). The sensitivity of the accelerometer was confirmed to be 2 mV/g by comparison with an NIST traceable calibrated PCB accelerometer. The peak amplitude of the initial shock was measured at 500 ± 50 g over a 2 ± 1 ms duration. Several photographs of the FFT screen were taken. Figure 6 reveals data for a typical drop (manually digitized). It is plotted against a 2 ms half sine. A 30% pulse width and a 10-90% rise time were assumed to be descriptive of a half-sine shock. As can be seen, the digitized data closely resembles a 2 ms half-sine waveform at levels above 200 g. Below 200 g, the acceleration rolls off slowly. This was considered to be an acceptable deviation.

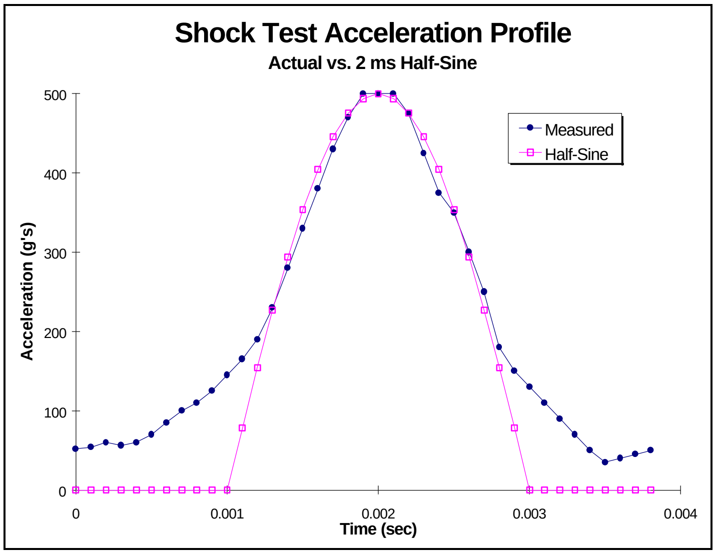

Figure 6

Each test transducer is subjected to 25 drops in the x- and y-axes, and 50 drops in the z-axis orientations, as shown in Figure 5 (inset). Note that horizontal drops are made so that the circuit is shocked both normal to and parallel to its planar surface.

V. THERMAL SHOCK

Thermal shocking is done using a forced air thermal shock chamber, where the upper chamber is kept at 150°C and lower chamber is kept at -55°C. Pressure transducers are attached to a elevator carriage, which moves between chambers in less than five seconds. In the heating and cooling phases, the exterior of the transducer is heated/cooled to 90% of the setpoint within five minutes (37°C/minute or faster). Twenty-five cycles are completed, each cycle lasting approximately 1 hour.

VI. CONCLUSIONS

Prototypes from all Quartzdyne® pressure transducer models have survived environmental testing procedures which include vibration, mechanical shock, dropping, and thermal shock. Pressure transducers have exhibited no significant resonant frequencies below 1000 Hz. Resonances above this level appear to be partially due to fixturing, but receive a 10 g, five minute dwell nonetheless.

VII. APPENDIX A: HIGH TEMPERATURE RANDOM VIBRATION

In September 1993, two transducers (a 1XP and a QU) were subjected to a high temperature vibration test. The vibration spectrum was the 7.66 g_{rms} profile shown in Figure 1. The transducers were heated to an internal temperature of 170 to 177°C. The thermal energy to the transducers was supplied via two 350 W band heaters, which were clamped to the exterior of the transducer.

Four resonant frequencies were observed above 1200 Hz in the x- and y-axes. The frequencies shifted slightly in each test, depending on where the band heaters were clamped. These resonances were also present in the test determining fixturing resonances (using a ‘dummy’ transducer without a PCB); it was therefore determined that the PCB was free from any significant resonances within the 20 to 2000 Hz frequency band.

Temperature and pressure frequency outputs during testing remained stable for all three axes. Both 1XP and QU units survived the testing and functioned properly thereafter.

In this high temperature random vibration test, Series 1XP and QU transducers exhibited no significant resonances at frequencies below 2000 Hz. Most importantly, random vibration testing above 170°C did not influence accurate temperature and pressure measurement, irrespective of axis, and no component failures were experienced.