Extrapolation of Pressure and Temperature Measurements using Quartzdyne® Pressure Transducers

INTRODUCTION

Quartzdyne transducers provide customers with excellent accuracy (0.015 – 0.02%FS) over a wide range of pressure and temperatures. Each transducer has a maximum rated pressure and temperature, such as 10,000 psi & 150°C. There are times where customers wish to use the transducer at higher temperatures than the specified maximum. Using transducers in this fashion is possible, but there are many factors to consider ensuring accurate readings from the transducers.

HIGH TEMPERATURE RISKS TO QUARTZDYNE TRANSDUCERS

The first factor to consider is whether the transducer will be damaged by excessive temperature. Generally, all transducer can be used up to 15°C higher than their maximum rating without suffering damage. The lone exception is transducers rated to 30,000 or 35,000 psi and 200°C. Excessive temperature on these devices can cause the pressure sensor to be irreparably, catastrophically damaged due to quartz twinning (https://en.wikipedia.org/wiki/Crystal_twinning). Secondly, excessive temperature and pressure can cause a transducer's calibration to shift yielding a static offset error in the reported pressure. While this risk is minimal, it is important to consider before exposing transducers to excessive temperature. Lastly, one must consider the accuracy of the reported pressure beyond the calibrated range of the transducer. Quartzdyne transducers use a polynomial curve fit to translate frequency counts into engineering units. Once outside the calibrated range, the data reported by the transducer are using extrapolation of these polynomials rather interpolation. In general, extrapolation is much less accurate than interpolation and must be well understood before assuming reported pressure information is accurate. The following information will attempt to bound the risks of extrapolation and provide recommendations to Quartzdyne's customers that wish to use transducers outside their calibrated temperature ranges.

INTERPOLATION AND EXTRAPOLATION

Polynomial curve fitting is a common technique for estimating a function based on a finite number of measured values. Interpolation is used when the curve fit polynomial is used to estimate the function *between* the measured values. Extrapolation is used to estimate the function *outside* the measured values.

Interpolation works quite well for most functions when the measured values are spaced closely enough to adequately sample the function. Quartzdyne uses interpolation to accurately describe the pressure and temperature response of crystals within 0.01%FS.

Extrapolation performance is highly dependent upon the nature of the function and the order of the polynomial curve fit used. It is best to match the rates of change of the polynomial and the function at the endpoints. In general, extrapolation works best when the function response is mostly linear at the endpoints. In this case, the rate of change is constant.

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EXTRAPOLATION USING QUARTZDYNE TRANSDUCERS

Quartzdyne transducers provide accurate readings under most pressure conditions up to 15°C higher than maximum calibrated pressure. Quartzdyne tested extensively to verify performance and found that extrapolation is model dependent. However, extrapolation generally works best for all models at higher pressures. At low pressure (< 4,000 psi), transducers are commonly out of spec when extrapolating up to 15°C beyond the calibrated range. The following results will provide model dependent details and provide explanations for the behaviors shown.

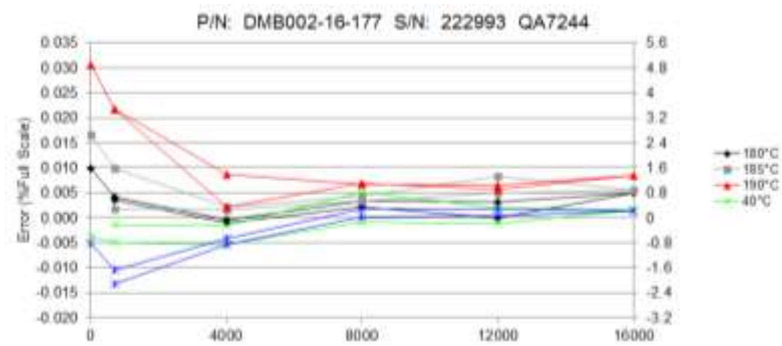

Figure 1. QA loops of DMB002-16-177 transducer. Three additional loops are added to test extrapolation. Performance at low pressure is clearly diminished.

Extrapolation above max temperature performs worst at ambient pressure. Consider the plot in Figure 1. The QA data of a DMB002-16-177 transducer are shown which has an accuracy spec of 0.02%FS. Three extra temperatures have been added to the normal QA plot at 180, 185 and 190°C. Note these additional data are well within specified limits for pressures above 4,000 psi, but diverge at low pressures. Below 1,000 psi at 190°C, the unit is out of spec.

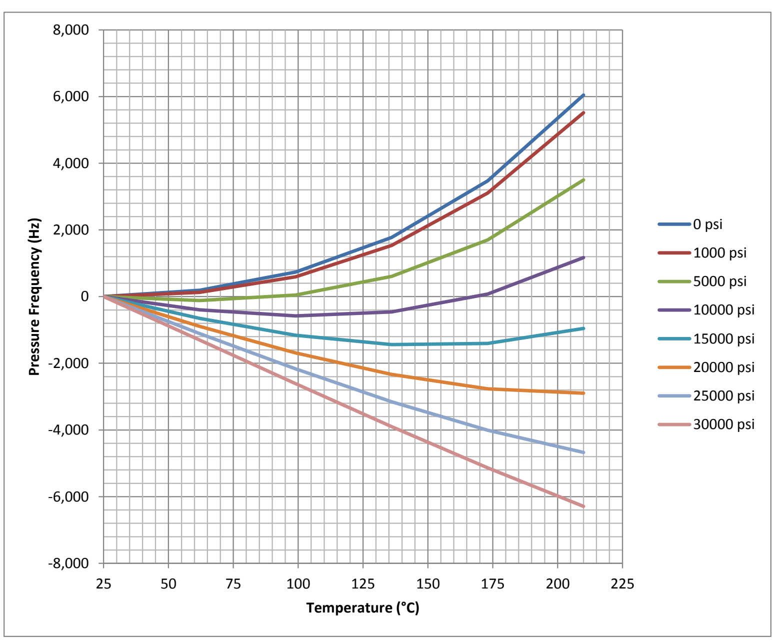

Figure 2. 30 kpsi pressure crystal temperature curves at various pressures. Linearity increases with pressure.

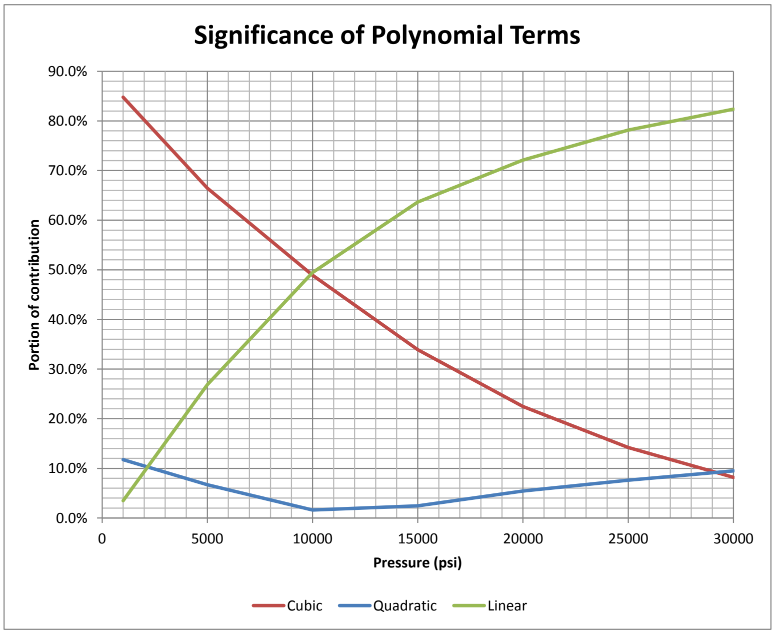

Figure 3. Significance of polynomial terms for pressure crystal curve fit. The cubic term is much stronger than the linear term at low pressure supporting the observed curvature in Figure 2.

To understand this phenomenon, consider the response of a QD crystal as shown in Figure 2. The plot shows temperature responses of a 30 kpsi pressure crystal at distinct constant pressures. These data were generated using a Quartzdyne curve fit polynomial. Note that each response is normalized to zero at 25°C. Observe that the curve for 0 psi is much more curved than that of 30,000 psi. Linearity appears to increase with pressure. To verify this observation, consider Figure 3 which demonstrates the significance of each term in the curve fit equation over pressure. The significance of the linear and cubic terms increase and decrease as pressure increases, respectively. As stated above, extrapolation works best when the function is mostly linear at the endpoints. Figures 2 and 3 indicate that the crystal response is largely cubic at low pressure leading to larger extrapolation error as shown in Figure 1.

EXTRAPOLATION PERFORMANCE BY MODEL TYPE

Extrapolation performance of Quartzdyne transducers is dependent up the maximum pressure and temperature rating. As shown in the section above, transducer temperature responses become more linear as pressure increases. As a result, 10 kpsi transducers extrapolate differently than 25 kpsi ones. Additionally, the accuracy specification is defined as percent of full scale (%FS) leading to varying absolute accuracies for each maximum pressure rating. For example, both 16 kpsi and 25 kpsi transducers are rated to 0.02%FS. In this case, absolute accuracies are ±3.2 and ±5.0 psi, respectively. For these reasons, several transducer types were used to determine extrapolation performance.

Each transducer type performed similarly during tests. With temperature above the maximum, transducers became inaccurate at low pressures but remained accurate at high pressure. In the following, data are presented which indicate the lowest usable pressure ensuring accurate measurements from the transducer. For example, the lowest usable pressure at 180 and 185°C in Figure 1 is 0 psi in order to meet the accuracy specification of

0.02%FS. A minimum cutoff of 0 psi indicates that this transducer can be used at all pressures at 185°C and below. However, the minimum usable pressure is 4,000 psi at 190°C. Below 4,000 psi, transducer measurements exceed the accuracy specification of 0.02%FS. Table 1 demonstrates a summary of Quartzdyne transducer extrapolation performance for several maximum rated pressures and temperatures.

Table 1. Minimum usable pressures ensuring accurate measurements when using extrapolation with Quartzdyne transducers.

Minimum recommended pressures ensuring accuracy				
Max Rating	Accuracy	T_{max} + 5°C	T_{max} + 10°C	T_{max} + 15°C
10 kpsi / 150°C	0.015% (±1.5 psi)	0	0	1,000
10 kpsi / 177°C	0.02% (±2.0 psi)	0	4,000	8,000
16 kpsi / 150°C	0.02% (±3.2 psi)	0	0	0
16 kpsi / 177°C	0.02% (±3.2 psi)	0	0	2,000
20 kpsi / 177°C	0.02% (±4.0 psi)	0	1,000	2,000
25 kpsi / 177°C	0.02% (±5.0 psi)	0	1,000	2,000

All transducers can be used up to 5°C above max temperature without exceeding accuracy specifications. In general, all transducers at 10-15°C above max temperature are accurate above 1,000 – 2,000 psi. There are two lone exceptions in 10kpsi / 177°C and 16kpsi / 150°C. 10 kpsi / 177°C transducers become very inaccurate for most pressures when extrapolating beyond 5°. Clearly, the polynomial endpoints for these transducers are not very linear causing extrapolation to fail very quickly. Conversely, 16 kpsi / 150°C transducers can be used up to 15° above max temperature at all pressures.

SUMMARY AND CONCLUSIONS

Quartzdyne transducers reliably provide accurate pressure measurements in extremely harsh conditions. Occasionally, it is desirable to run transducers at temperatures above the maximum rating. Great care must be taken when operating under these conditions to avoid damage and ensure accurate information. High temperature extrapolation can lead to inaccurate readings at low pressure. Fortunately, typical applications don't normally have low pressure at high temperature enabling extrapolation as a viable method to extend the temperature range of a transducer.