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SENSITIVITY OF QUARTZ, PIEZOELECTRIC PRESSURE TRANSDUCERS AS A FUNCTION OF TEMPERATURE FROM 20° TO 477° K

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

Quasi-static calibrations were performed to determine the sensitivity of quartz, piezoelectric type, pressure transducers in the temperature range of 20° to 477° K. Results were obtained which show that the sensitivity at 20° K differs from the sensitivity at room temperature by 4 percent maximum. The corresponding difference at 477° K is 9 percent. The change in room temperature sensitivity due to each temperature excursion was negligible. The conclusion is reached that this type of transducer is particularly applicable to dynamic pressure measurement at cryogenic temperatures.

INTRODUCTION

Pressure is one of the most important and ubiquitous parameters which must be measured in propulsion systems being developed within the aerospace technology. Frequently, dynamic pressure must be measured which requires close coupling of the transducer to the measurand. Therefore, the transducer is exposed to severe temperatures, ranging from cryogenic to the maximum temperature that it can tolerate. Thus, there is a need not only for transducers which will operate at these temperature extremes but also for a knowledge of their characteristics at these temperatures.

Limited data are available on the characteristics of dynamic pressure transducers over their usable temperature span particularly near the 20° K level. While there are some reported data on the sensitivity of strain gage transducers at cryogenic temperatures (refs. 1 and 2), no documented experimental data were found on the sensitivity of piezoelectric transducers at either end of their usable temperature span. This lack of data exists even though the piezoelectric transducer manufacturers claim operation from 20° to 530° K, and the transducers are indeed used frequently over this temperature range.

The frequent use of piezoelectric pressure transducers (usually quartz) results from the fact that they offer several distinct advantages over the strain gage transducers. The piezoelectric transducer is capable of operation at much higher frequencies and with greater accuracy over a wide range of pressure levels than is the strain gage. A single, typical piezoelectric transducer coupled with a charge amplifier is capable of measurements from less than 0.1 hertz to tens of kilohertz and over a range of full-scale pressures differing by a factor of 1000 with relatively constant accuracy.

This report gives the results obtained from a program conducted at the Lewis Research Center to measure the sensitivity of quartz piezoelectric pressure transducers at various temperatures. Five transducers were calibrated from 20° to 477° K with particular interest in the low temperature end. Changes in room temperature sensitivity resulting from large excursion temperature cycles were also measured. A description of the technique used and a discussion of the resulting accuracy are also included.

CALIBRATION TECHNIQUE AND APPARATUS

The basic calibration technique consisted of applying a pressure step to both the piezoelectric transducer at test temperature and to a parallel connected, strain gage, reference transducer at room temperature. Since a piezoelectric transducer with charge amplifier is capable of measuring dynamic pressure to low frequencies, this quasi-static technique could be employed to allow the use of a statically calibrated strain gage transducer as a reference. This is an advantage in that a strain gage transducer used to measure the full-scale static pressure at which it was calibrated is more accurate than a piezoelectric transducer and thus serves as an excellent reference. The outputs were read at a time after step application which was long enough for equilibrium to be reached yet short enough so that the charge amplifier output had not decayed appreciably. A step was applied for each test transducer at each test temperature.

In order to separate the effects of temperature on sensitivity from any permanent change in room temperature sensitivity caused by the transducer having been cycled to the test temperature and back, each transducer was calibrated at room temperature just prior to subjecting it to each test temperature.

A schematic drawing of the pneumatic configuration appears in figure 1. For tests at 20° K (liquid hydrogen) and 77° K (liquid nitrogen), the temperature chamber was a Dewar filled with the appropriate liquid, and the gas supply was helium. Before the Dewar was filled with coolant, the manifold and lines were evacuated and purged with helium to remove air. At all other test temperatures a temperature chamber was used, and the gas supply was nitrogen. Evacuation and purging were not needed because of the lack of air condensing problems at these temperatures.

After temperature equilibrium was reached, a pressure step was applied and trapped by a valve. The pressure step applied was in all cases nominally 6.9×10^{5} newtons per square meter (100 psi). The pressure deviated from one test to another by as much as

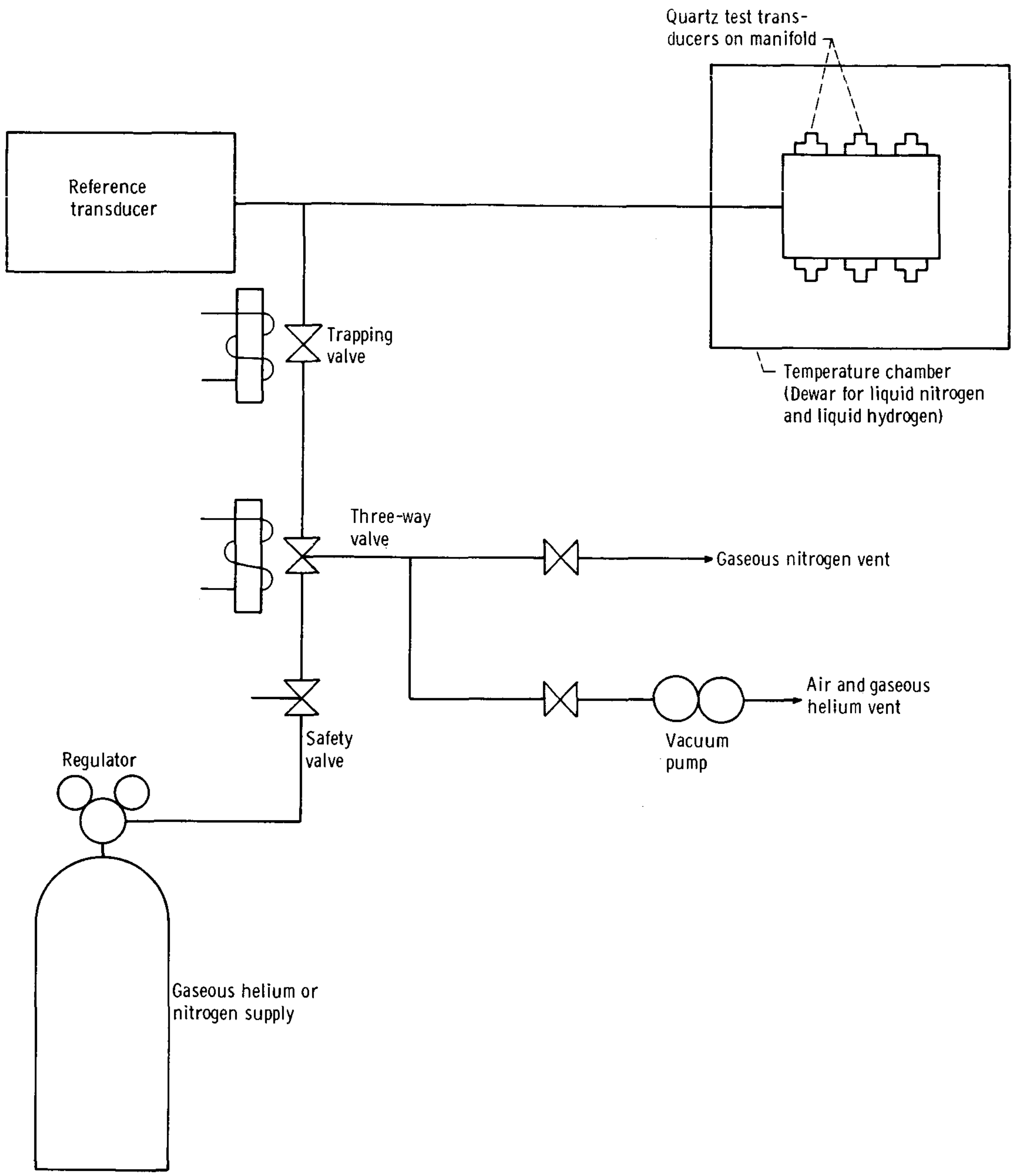

Figure 1. - Schematic drawing of pneumatic system.

1 percent; however, it remained constant during a particular test because it was trapped by the valve. All data were normalized to 6.89×10^5 newtons per square meter by the known calibration of the reference. The same charge amplifier was used for all test transducers and all voltages were read with a digital voltmeter. The charge amplifier was adjusted for zero output prior to each pressure step application.

Sources of error in the data were (1) reference transducer inaccuracy, (2) readout error, (3) charge amplifier output exponential decay and gain instability, and (4) thermally produced charge fluctuation (particularly at the higher temperatures). The readout was a digital voltmeter accurate to within 0.01 percent; the reference transducer was accurate to within 0. 1 percent. These first two sources of error were thus considered negligible.

The error caused by the exponential decay of the charge amplifier output was negligible because the time constant of the charge amplifier transducer combination used was of the order of 10^5 seconds over the whole temperature range applied to the transducer. This finite time constant resulted in an exponential decay of the output so that it was down about 0. 5 percent 8 minutes after application of the pressure step. The time required for pressure stabilization (as determined by the stability of the reference transducer output) and subsequent readout was less than 1 minute. Instability of amplifier gain also proved a negligible source of error for this order of time period.

The last source of error was thermally generated charge fluctuation in the transducer and connecting cables. An attempt to evaluate the magnitude of this error was made by taking repeated data at the highest temperature where its effect was a maximum. The results showed that the data repeated to within ±0. 5 percent. No attempt was made to define the exact source of this effect.

In summary then, the data points are in error by no more than ±1 percent. The error is probably less than ±0. 5 percent at all but the highest temperature. A more certain error figure cannot be given because of the limited information about what appeared to be the controlling error source, thermally caused charge fluctuation.

RESULTS

Figure 2 compares the sensitivity of each of the five transducers at room temperature with its sensitivity at the various temperatures. The spread of the sensitivity changes at 477° K (about 15 percent) was approximately three times as great as that at 20° K (about 5 percent). The sensitivity changes at 20° K are comparable with those reported for a number of strain gage transducers commonly used at 77° K (refs. 1 and 2). These strain gage transducers' sensitivities change by up to about 6 percent (3. 8 percent rms) for temperature variation from room to 20° K.

The change in room temperature sensitivity resulting from each temperature cycle proved to be small. The maximum change measured (1. 2 percent) resulted from exposure of one of the transducers to the 477° K temperature. In general, the changes noted averaged less than 0. 5 percent and were fairly random.

The repeatability of the data from day to day was excellent at all but the highest temperature. For example, the data at 477° K repeated to within the ±0. 5 percent already stated, but the data at 20° K repeated to within one-tenth of this spread.

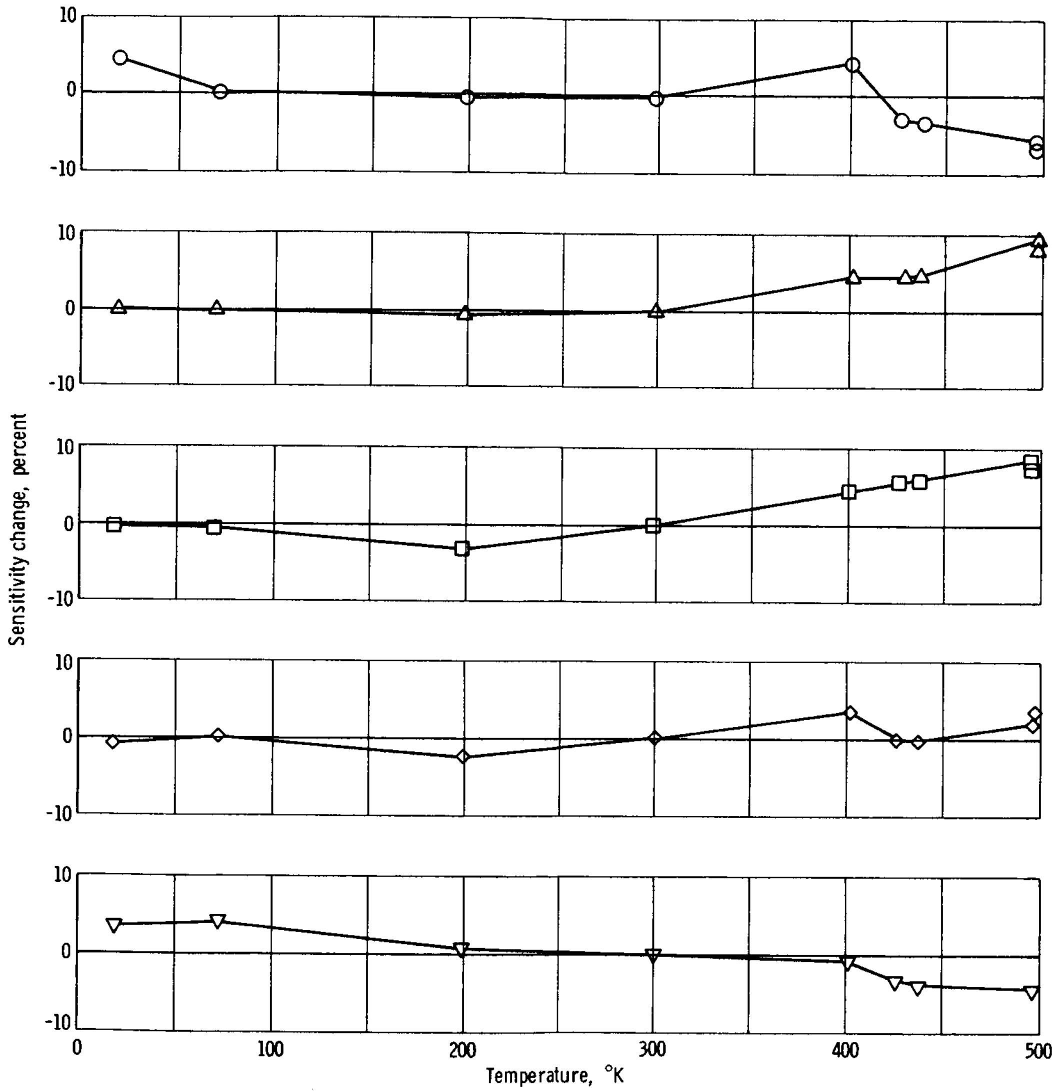

Figure 2. - Quartz piezoelectric pressure transducer sensitivity change (room temperature reference) as function of temperature for five transducers.

TABLE I. - ACTUAL SENSITIVITY OF

TRANSDUCERS AT ROOM

TEMPERATURE

Transducer	Sensitivity[a]	Difference from specification, percent
1	1.0995	9.95
2	.9936	-.64
3	1.0176	1.76
4	.9924	-.76
5	.8990	-10.10

[a]1 pC/psi = 1.45×10^{-4} (pC)(m^2)/N.

Table I shows that the charge sensitivities of the five transducers tested varied approximately ±10 percent from the nominal 1.45×10^{-4} (picocoulomb)($meter^2$)/newton (1 pC/psi), with the rms deviation being 6.7 percent of this value. It should be pointed out that the transducers tested had an unknown history of use which could conceivably explain the two units with large deviation.

CONCLUDING REMARKS

The results of these tests on the sensitivity of quartz, piezoelectric pressure transducers as a function of temperature from 20° to 477° K showed that

1. The sensitivity at 20° K was no more than 4 percent different from that at room temperature.

2. The sensitivity at 477° K was no more than 9 percent different from that at room temperature.

3. The day to day repeatability of the data at 477° K was within ±0.5 percent and within one-tenth of this at 20° K.

4. The change in room temperature sensitivity caused by large temperature excursion cycles was negligible.

The conclusion is reached that, based on the results of these tests, this type of transducer appears to be particularly good for low temperature applications.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 11, 1967,
125-24-03-03-22.

REFERENCES

1. Corruccini, R. J.; et al: Fifth Progress Report to National Aeronautics and Space Administration on Cryogenic Research and Development for Period Ending March 31, 1962. Rep. No. 7246, National Bureau of Standards, Mar. 31, 1962.

2. Corruccini, R. J.; et al: Sixth Progress Report to National Aeronautics and Space Administration on Cryogenic Research and Development for Period Ending June 30, 1962. Rep. No. 7279, National Bureau of Standards, June 30, 1962.