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NBS InterAgency Transudcer Project Progress Report No. 5

J. S. Hilten, C. F. Vezzetti, J. F. Mayo-Wells, and P. S. Lederer

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

November 1, 1976

Progress Report Covering Period January 1, 1976 to June 30, 1976

This is a progress report. The work is incomplete and is continuing. Results and conclusions are not necessarily those that will be included in a final Report.

Prepared for

Naval Air Systems Command, U.S. Navy, and Transducer Committee, Telemetry Group, Range Commanders Council

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NBS InterAgency Transducer Project

Progress Report No. 5, for the Period
From January 1 to June 30, 1976

to the

Naval Air Systems Command,
U.S. Navy and Transducer Committee,
Telemetry Group,
Range Commanders Council

NBS Cost Center 4253434

Prepared by

J. S. Hilten, C. F. Vezzetti,
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ABSTRACT

Experimental efforts are described in the development and evaluation of means to reduce the effects produced by thermal radiant-energy transients on pressure-transducer response. Both unbonded strain-gage and piezoelectric pressure transducers were used in this work with protective coatings applied directly to the diaphragms. The test method employed is to expose a pair of transducers — one protected and the other unprotected, but otherwise nominally identical — to a known radiant-energy transient with an energy density of approximately 20 mJ/mm^2. The resulting zero shift is measured and taken as an index of coating effectiveness.

The effect of the presence of the coating on transducer dynamic response was investigated by means of a shock tube, with a protected and an unprotected transducer pair exposed to the same pressure step of approximately 280 kPa (40 psi). Each transducer output was recorded as a function of time.

Test results with nine coatings and two transducer pairs are presented.

Key words: coatings; dynamic; dynamic response; pressure transducer; protective coatings; shock tube; tape; thermal radiant-energy response; thermal transient response; transducer; zero shift.

1. INTRODUCTION

A brief background for the NBS InterAgency Transducer Project, its recent history, and the current objectives were given in a previous report [1]*. The task of developing a test method for evaluating the effects of short-duration, thermal radiant-energy transients on pressure-transducer response

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Numbers in brackets indicate literature references, section 7.

has been completed [2,3,4]. The Transducer Committee** and NAVAIR as cosponsors have assigned as a follow-on task for the project the evaluation of schemes in use, or proposed, to reduce such effects. The intent is to use the test method described in [4] for evaluating protection from radiant-energy transients and to modify this method as required for generating other thermal inputs to the test transducer and protection scheme. The task assignment calls for schemes to protect pressure transducers from "radiated and/or convected transients of various amplitudes and durations." The main concept to be taken into account is the "effect of any protection scheme on transducer performance, such as increased acceleration sensitivity, degradation in dynamic performance, etc."

Goals of the work include development, for users, of guidelines and protection schemes for the use of existing pressure transducers in applications in which thermal inputs are present and, for manufacturers, of recommendations relating to pressure-transducer design and construction.

The plan of work is first, to develop a method for evaluating coating performance; second, to test a number of coatings using this method; third, using the test method of [4], to determine the zero shifts of pairs of transducers — one with diaphragm protection and the other without; and fourth, to compare the dynamic response of the two transducers in each pair to pressure steps generated in a shock tube.

Work on the first two elements of the plan was conducted in the previous reporting period [5]. A series of tests was carried out to investigate the effects of a variety of protective coatings on the amount and rate of energy transmission through the diaphragm as revealed by measurements of the diaphragm back-side temperature. Mounted thin metal disks were used to simulate transducer diaphragms, and the temperature histories of both bare and protected disks were measured following exposure of the disks to thermal radiant-energy transients generated by No. 22 flashbulbs. The protection provided by 16 different coatings was thus evaluated.

2. EXPERIMENTAL DEVELOPMENT

Experimental work carried out during this reporting period was concerned with the third and fourth elements of the plan outlined above.

2.1 Application of Protective Coatings

For all tests, the protective material is applied directly to the transducer diaphragm. The exposed diaphragm surface is first cleaned with acetone and allowed to dry; then the transducer is installed in the mounting fixture with the diaphragm surface either flush or recessed, as noted below.

When the protective material is an adhesive tape, disks of tape are cut with a cork-boring tool and then pressed into place. The diameter of the disk is chosen to be the same as, or slightly smaller than, the diameter of the diaphragm end of the transducers. The transducer is mounted in the fixture so that the diaphragm surface is flush with the face of the fixture.

When the protective material is a viscous grease (such as silicone dielectric grease or silicone "heat-sink" compound), the transducer is mounted in the

**Transducer Committee, Telemetry Group, Range Commanders Council.

fixture so that the diaphragm surface is recessed from the face of the fixture by 0.8 mm. The recess is filled to overflowing with the grease and the excess removed by drawing a straight-edged knife blade across the face of the fixture with the blade held at about 60° from the perpendicular and with the edge of the blade in contact with the fixture at least for a few millimeters around the periphery of the recess. If the knife is used carefully, the exposed surface of the grease should be level with the face of the fixture and smooth in appearance.

When the protective material is a two-component room-temperature-vulcanizing (RTV) silicone rubber, the transducer is mounted recessed, the recess filled with mixed but uncured rubber, and the excess removed as for the viscous greases, except that the fixture must be supported so that the diaphragm is face up. The fixture is left in this position until the rubber has cured. (It was found convenient to prepare the transducer with RTV rubber coating near the close of business and to permit the rubber to cure ovenight.)

2.2 Zero-Shift Measurements

The observed change (zero shift) in transducer output in response to thermal radiant-energy transients with the transducers sensing atmospheric ambient pressure is determined and recorded according to a modification of the method of [4]*. In each test, a pair of transducers is used, one with a protective coating applied to the sensing diaphragm and the other unprotected, but otherwise nominally identical and, where applicable, supplied with nominally identical excitation voltages. The thermal source for these tests is a No. 22 photo flashbulb with the center of the bulb 70 mm from the transducer diaphragm. At this distance, the energy density (intensity) is approximately 20 mJ/mm^2. To permit the simultaneous exposure of test and control transducers, the mounting fixture developed for the original method was modified to accommodate the two transducers side by side.

As the dynamic performance of each pair of transducers is measured following the zero-shift measurements, it was found convenient to mount the fixture onto the hinged end plate of the shock tube used in the dynamic measurements (see 2.3). The flashbulb source is mounted on a bracket designed to be clamped to the end plate. This arrangement permits either dynamic or zero-shift measurements to be carried out with a minimum of effort required to shift from one test to the other.

The following procedure is used for each set of zero-shift measurements for a given coating:

1. Mount the transducer fixture (with test and control transducers installed) onto the end plate of the shock tube.

2. Attach the mounting bracket for the flashbulb socket to the end plate.

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*In the method of [4], test transducer output is monitored and displayed on the screen of a storage oscilloscope or otherwise recorded as the transducer is exposed to a thermal radiant-energy transient resulting from the ignition of a flashbulb or flashtube. As the transducer senses atmospheric ambient pressure, that is, a gage pressure nominally of magnitude zero, any observed change in output is taken as zero shift.

3. Adjust the distance from the center plane of the flashbulb to the plane of the diaphragms to be 70 mm. Tighten clamps.

4. Screw a No. 22 flashbulb into the socket.

5. Examine the flashbulb to determine in which direction the ignition electrodes (each in the shape of an inverted "L") point.

6. Rotate the socket so that the direction in which the electrodes point is approximately perpendicular to a line between the center of the flashbulb and a point on the face of the fixture midway between the centers of the two diaphragms and on the line joining these centers.

NOTE: On ignition, a black spot commonly appears on the bulb in the direction opposite to that in which the electrodes point. Step 6 prevents the spot from reducing the intensity experienced by the transducers.

7. Make or check the required electrical connections, including the flashbulb ignition-voltage source to the socket and to the trigger of storage oscilloscope, transducer outputs to storage oscilloscope, and, if required, transducer excitation-voltage source to transducers. Turn on equipment.

8. Set the oscilloscope sweep rate to 10 ms/cm and adjust triggering controls as required so that ignition of the flashbulb triggers the sweep. Adjust beam intensity to a level that experience has shown will result in a well-exposed photograph of the trace for a given film, shutter speed, and aperture.

9. Load the camera with film and adjust the camera shutter speed and aperture.

10. Fire the flashbulb.

11. Observe the resulting traces on the oscilloscope screen. If they are satisfactory, proceed to step 12. If they are not satisfactory, determine the cause. Make whatever adjustments may be necessary and remove the spent flashbulb. Repeat steps 4 through 8 and fire the flashbulb. Repeat until satisfactory traces are obtained.

12. Photograph the traces.

13. Remove the spent flashbulb and repeat steps 4, 5, and 6. Set the oscilloscope sweep rate to 100 ms/cm. Repeat steps 10, 11, and 12.

14. Examine the photograph taken in step 13. If the traces show that both transducer outputs have started to decay, consider the set to be complete with two photographs. If either transducer output has not started to decay, remove the spent flashbulb and repeat steps 4, 5, and 6. Set the oscilloscope sweep rate to 1 s/cm. Repeat steps 10, 11, and 12.

NOTE: The procedure given above results in a set of either two or three photographs of the oscilloscope traces. The zero shift is determined by scale measurement of the photographed traces. The measurements are made from whichever photographs provide the greatest time resolution and incorporate peak voltage values. The reference voltage levels are those levels, nominally zero, corresponding to the output of each transducer before ignition of the flashbulb. For each transducer, the zero shift is measured as the difference between the peak voltage and the reference voltage level. The time of the peak voltage is also determined. If positive- and negative-going peaks are present in a single trace, both peak values (and times) are determined.

For each trace, amplitudes and times are measured at inflection points and at a sufficient number of other points to enable a reasonable facsimile of the oscilloscope trace to be reproduced, as shown in figures 1 and 2.

2.3 Dynamic Response Measurements

The effects of test coatings on the transducer dynamic performance are evaluated by comparing the simultaneous outputs of a pair of transducers — one protected, the other not, but otherwise nominally identical — in response to pressure steps generated in a shock tube. Transducer outputs are recorded and analyzed to determine the effects of coatings on such parameters as ringing frequency, rise time, and amplitude response.

The shock tube employed in this work has previously been used to evaluate the dynamic performance of pressure transducers, as has been described [6]. The shock tube is capable of providing a calculable pressure step with a rise time on the order of 10 ns and a duration of approximately 4 ms. (The duration is limited by a rarefaction which occurs at the end of the test section at approximately 4 ms.) Some variation in pressure-step amplitude as seen at the end of the test section results from the method of generating the pressure wave, which is the rupture of a cellulose-acetate diaphragm interposed between the high-pressure and low-pressure sections. This variation may be as much as 5 percent and may be accompanied by a variation in waveform, especially during the first 0.5 ms. This consideration led to a decision to expose test and control transducers to the same pressure step and therefore to record the outputs simultaneously. An incidental advantage of this procedure is that any error introduced by the calibration of the recording means (estimated to be ±1 percent for the oscilloscope, for example) may be ignored for the comparison measurement.

For these tests, the low-pressure section (i.e., the section downstream from the diaphragm) is operated at atmospheric ambient pressure to simplify operation. With the gas fill used in the high-pressure section (upstream section), the amplitude of the pressure step is approximately 280 kPa when the tube is run at the laboratory ambient temperature of 21°C.

A detailed procedure for the zero-shift method has been given in the preceding section, as the information contained in that procedure may be used as a guide for the use of whatever apparatus is available to accomplish the same purpose. This statement is not true for the operation of the shock tube, for which the procedure is specific to the particular device employed, and therefore no procedure is given here. The methods used to determine rise time, average amplitude, and ringing frequency depend on the transducers used in the test.

For the unbonded strain-gage instruments, the outputs of the test and control transducers exposed to the pressure step are both displayed on the screens of two storage oscilloscopes, one operating at a sweep rate of 0.1 ms/cm and the other at 1.0 ms/cm (total sweep times of 1 and 10 ms, respectively). The traces are photographed. Information from the slow-sweep traces is used for monitoring the system behavior and for determining the duration of ringing and, therefore, for providing an estimate of the degree of damping. Rise times are determined from the photograph of the fast-sweep trace (see figure 3) as the difference between the times at which the initial transducer pulse in response to the pressure step reached 10 percent and 90 percent of its peak value.

NOTE: It has been found convenient to simplify this measurement somewhat. For a given transducer-coating combination, once the 10 percent and 90 percent amplitudes have been determined, the rise time may be estimated by calculating the difference between the distances from any appropriate vertical graticule line to the two points on the rising portion of the trace of the initial pulse at which the amplitude of the trace is equal respectively to the 10 percent and 90 percent amplitudes.

Since the output signal exhibits ringing, an averaging calculation is used to provide the average amplitude as follows: A value of average amplitude is determined from scale measurement of (1) two consecutive minima at about 150 μs and (2) the included maximum. The average value of the two minima is calculated. The average of this average and the maximum is calculated to give the average amplitude.

The procedure is repeated at about 500 μs.

For determinations of ringing frequency, a two-channel transient recorder is used to record the two transducer outputs resulting from exposure to the pressure step. The recorded signals are then supplied sequentially to a frequency analyzer-oscilloscope combination adjusted to operate over a frequency range of 0 to 40 kHz and with a sensitivity of 4 kHz/cm of displayed trace. Each resulting trace of the frequency spectrum is photographed. Ringing frequency is determined by inspection.

For the quartz-crystal instruments, no measurement of ringing freqeuncy is possible as available equipment has an upper frequency limit of 100 kHz, while the manufacturer reports a transducer natural frequency of 400 kHz.

The rise time is determined in a manner similar to that described for the strain-gage transducers, except that the sweep rates are 0.01 and 1.0 ms/cm.

Average amplitudes are estimated by scale measurement of both the fast- and slow-sweep traces between (1) the base level established by the transducer output before the pressure step occurs and (2) points judged to be at mid-amplitude of the ringing. These measurements are carried out at 15 and 50 μs on the fast-sweep trace and at 12, 2, and 3 ms on the slow-sweep trace.

3. COATING EVALUATION

3.1 Coatings Used

Nine protective coatings were evaluated. The test coatings were selected from those evaluated in the previous reporting period and represent various degrees of thermal protection capability and several types of coating material. Included as test coatings are a two-component RTV silicone rubber, a silicone "heat-sink" compound, a silicone grease, one and three layers of black vinyl ("electrician's" tape), one and three layers of white vinyl tape, and one and three layers of thermal fiberglass tape.

The various tape coatings were chosen because (1) tape is commonly used as a protective coating by a number of transducer users (in particular, these users report employing black vinyl tape), (2) tape is easy to apply and overall thickness can be readily varied through the use of multiple layers, and (3) tapes showed considerable variation in protective ability in the tests performed earlier. One and three layers of vinyl tape represent thicknesses of 0.15 and 0.45 mm, respectively, which are typical thicknesses reported in use at several laboratories. A single layer of fiberglass tape is 0.23-mm thick.

The silicone rubber was chosen because (1) silicone rubber is commonly used by a number of transducer users, and (2) this particular red RTV silicone rubber had performed relatively well in the earlier evaluation. Transducer users cite applications for which thicknesses varying from 0.10 to 2.0 mm are used. The 0.8 mm thickness used in these tests is considered reasonable for initial testing purposes.

The "heat-sink" compound was chosen because it also performed relatively well in the earlier evaluation. By contrast, silicone grease was chosen because, although reported in use by a number of transducer users, it performed relatively poorly in the earlier evaluation.

After each set of tests with a given coating, the coatings were removed and the transducers cleaned. The silicone materials were applied after the tapes, with the RTV silicone rubber applied last.

3.2 Transducers Used

Two pairs of transducers were used in the coating evaluation tests. The two types, unbonded strain-gage and quartz-crystal, are representative of those reported in use.

The strain-gage model used has unbonded strain gages attached to a structure composed of four support members; this assembly is attached to a push rod that in turn is fastened to the transducer diaphragm. An analysis of this geometry indicated that performance should not be appreciably affected by thermal transients of short duration. The pressure range is 0 to 345 kPa.

The quartz-crystal model used incorporates an impedance-matching amplifier as part of the transducer. This model was also not expected to have its performance appreciably affected by thermal transients. The pressure range is 0 to 6.9 MPa.

3.3 Tests Conducted

3.3.1 Zero-Shift Measurements — Eleven sets of tests were carried out using the pair of unbonded strain-gage transducers. Each set consisted of two tests with the results displayed at two sweep rates, as described in 2.2. Two of the sets were conducted with both test and control transducers unprotected; each of the remaining sets was conducted with one of the nine selected coatings applied to the test transducer. Ten sets of tests were carried out using the pair of quartz-crystal transducers. Each set again consisted of two tests with results displayed at two sweep rates. One set was conducted with both transducers unprotected; each of the remaining sets was conducted with one of the nine coatings applied to the test transducer.

3.3.2 Dynamic Response Measurements — Twenty sets of tests were carried out in all, ten sets with each transducer pair. These ten sets consisted of one test with both control and test transducers unprotected and one or more tests each with one of the nine selected coatings applied to the test transducer. Repetitive tests were conducted with the tape coatings in attempts to resolve discrepancies in the results.

3.4 Results

3.4.1 Zero-Shift Measurements — For the 11 tests with unbonded strain-gage transducers, the control instrument had an average maximum zero shift of approximately 7.3 percent of the full-scale reading (sample coefficient of variation 7.3 percent) with an average time of occurrence of 60 ms (sample coefficient of variation 8.2 percent). For the two tests in which the test transducer was not protected, the average maximum zero shift was 7.6 percent of the full-scale reading with an average time for the peak zero shifts of 65 ms. These values are considered to be in reasonable agreement.

While an insufficient number of tests was run to draw any statistical conclusions, the data show that coatings of one layer of white tape, three layers of white tape, one layer of thermal fiberglass tape, three layers of thermal fiberglass tape, and silicone grease do not delay the time of occurrence of the maximum zero shift. However, all but the silicone grease reduce the magnitude of the zero shift appreciably. The use of one layer of black tape, three layers of black tape, "heat-sink" compound, and red RTV silicone rubber all delay the time of occurrence of the maximum zero shift and reduce the magnitude of the zero shift as well. Comparisons of the effectiveness of a single layer of tape with the silicone materials should take into account the fact that the tape has one-fourth the thickness of these materials.

The data are presented in detail in table 1 and in figures 1A and 1B.

In all cases, zero-shift tests with quartz-crystal transducers resulted in the production of a negative shift followed by a positive shift of comparable magnitude. For the ten tests, the control instrument had an average maximum negative zero shift of 5.2 percent of the full-scale reading (sample coefficient of variation 7.4 percent) and an average maximum positive zero shift of 2.8 percent (sample coefficient of variation 8.3 percent). The average time at which the negative peak zero-shifts occurred was 36 ms (sample coefficient of variation 5.2 percent) and the average time at which the positive peak occurred was 112 ms (sample coefficient of variation 5.2%).

In the test in which the test transducer was uncoated, the negative zero shift was 5.3 percent of full scale at 36 ms, and the positive zero shift was 5.5 percent of full scale at 110 ms. While the positive zero shift for the test transducer was significantly larger than that for the control transducer, differences of this magnitude are not uncommon in transducers of the same model, as shown in [4].

As in the tests with the unbonded strain-gage transducers, one layer of white tape, one layer of thermal tape, three layers of white tape, three layers of thermal tape, and silicone grease do not delay appreciably the time of occurrence of the maximum zero-shift; all but the silicone grease reduce the magnitude of the zero shift appreciably. The use of one layer of black tape, three layers of black tape, "heat-sink" compound, and red RTV silicone rubber delay the time of occurrence of the zero shift (both positive and negative peaks) and the magnitude of the zero shift as well.

These data are presented in table 2 and in figures 2A and 2B.

3.4.2 Dynamic Response Measurements — Figure 3 shows the response behavior of two unbonded strain-gage transducers to a pressure step of 280 kPa with both test and control instruments unprotected. Comparison of the traces representing one instrument with the traces for the other shows slight variations in degree of damping, ringing frequency, and sensitivity. (For example, the control transducer exhibits a ringing frequency approximately 7 percent higher than that of the test transducer; on the other hand, the sensitivity of the control instrument is some 2 percent lower.) This degree of variation may be expected with instruments of this type.

Figure 4 shows the same two transducers in a similar pressure-step test in which the diaphragm of the test transducer is protected by three layers of black vinyl tape; there is a slight reduction in the ringing frequency of the test transducer and a noticeable increase in damping, but rise time and amplitude changes are too small to be detected. None of the nine different coating materials is observed to produce a significant change in the dynamic characteristics of the protected transducer. Table 3 summarizes the data in detail.

In the series of pressure-step tests using the various tapes as protective coatings, the dynamic responses of the quartz-crystal transducers show a wide variation in rise time and amplitude. The observed amplitudes range from 20 percent above to on the order of 90 percent below that of the unprotected transducer outputs. Figure 5 shows two examples of the variety of responses recorded for the tape coatings. An explanation of these results may lie in the design of this model of transducer and in the fact that tapes are applied to the entire sensing face of the transducers. The instrument has a ridge around the periphery of the diaphragm, as shown in figure 6. If the tape is applied across the entire face of the diaphragm, i.e., over the ridge, there may be a tendency for air to be trapped along the inner edge of the ridge. Such trapped air would be expected to "cushion" the pressure step in an uncontrolled manner, causing variation in the pressure seen by the transducer diaphragm (and hence by the transducer) compared to the pressure of the step. Detailed information concerning the construction of these transducers was not available at the time of the tests.

In the pressure-step tests with quartz-crystal transducers and using silicone materials as protective coatings, there was not significant variation between the outputs of protected and unprotected instruments. The data are given in table 4.

4. CONCLUSIONS

The observed performance of the nine coatings evaluated as protection for the diaphragms of two different pressure-transducer types verified the results obtained in the simulated diaphragm tests described in the previous report [5]. That is, some coating combinations appeared to be an order of magnitude more effective than others in delaying and reducing zero shift, at least as determined on the basis of a small number of trials.

"Heat-sink" compound, red RTV silicone rubber, and black vinyl tape (one layer and three layers) were observed to be effective in delaying the time at which the maximum shift occurred and, with the exception of one layer of black vinyl tape, in reducing the magnitude of the zero shift with the transducers tested. Silicone grease, white vinyl tape (one layer and three layers), and thermal fiberglass tape (one layer and three layers) were observed to have little or no effect in delaying the time of the maximum shift but, with the exception of silicone grease, were moderately effective in reducing the magnitude of the zero shift. Of the coatings tested, silicone grease and one layer of black vinyl tape were least effective in reducing the magnitude of the zero shift.

The nine coatings were not observed to downgrade the dynamic performance of the unbonded strain-gage transducer as evaluated with a pressure step of 280 kPa in the shock tube.

For the quartz-crystal pressure transducer, the ridge around the outer portion of the diaphragm appeared to cause air entrapment at the time tapes were applied; this entrapped air could account for the large variations observed. The three coatings of silicone material was observed to have little effect on the rise time and amplitude characteristics of the quartz-crystal transducers.

5. PLANS FOR THE REPORTING PERIOD JULY 1, 1976 TO DECEMBER 31, 1976

(1) Additional replicate tests are planned to provide a more satisfactory statistical base.

(2) The quartz-crystal pressure transducers will be exposed to pressure steps of greater amplitude as a means of checking that response data taken with a pressure step equal to 4 percent of the full-scale reading are representative of the transducers' dynamic performance.

(3) Pairs of transducers expected to have substantial response to thermal transients will be used in the tests, as to date only pairs not expected to exhibit such response have been tested.

(4) The position of the test and control transducers (with both unprotected) will be interchanged left-to-right in the shock tube as a means of checking that there is no side-to-side pressure gradient at the test end of the tube.

(5) The effect on the acceleration response of coating the diaphragm of the transducer will be determined to check that acceleration sensitivity is not significantly increased.

6. RECOMMENDATIONS

Recommendations for future work include the following:

(1) Tests to determine the significant effects of varying the protective coating thickness, to provide information to permit an optimum choice of thickness for a given coating;

(2) Tests using a convective heat source;

(3) Evaluation of the durability of the protective coatings; and

(4) Investigation of the use of path-geometry protective schemes (such as mechanical screens).

7. REFERENCES

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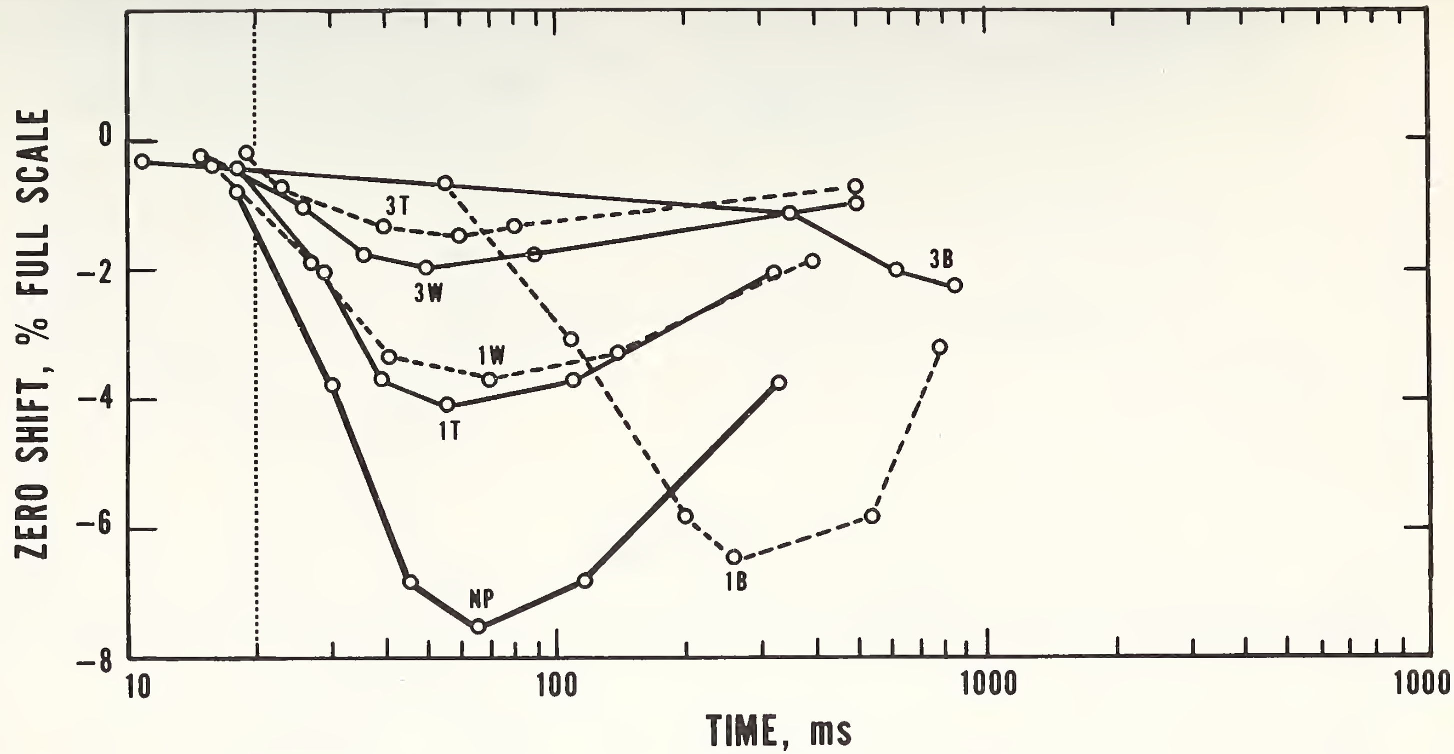

Figure 1-A: Response of an unbonded strain-gage pressure transducer with selected protective coatings applied to the diaphragm outer surface to a thermal radiant-energy transient of approximately 20 mJ/mm^2. The plots are of transducer zero shift (percent of full-scale reading) as a function of time (ms), with time on a three-cycle logarithmic scale. The peak of the transient occurs at approximately 20 ms, as indicated by the dashed line. The heavy-line plot (NP) represents the transducer zero shift with no protective coating.

Coating identification code:

1B - one layer of black vinyl tape
1W - one layer of white vinyl tape
1T - one layer of fiberglass thermal tape
3B - three layers of black vinyl tape
3W - three layers of white vinyl tape
3T - three layers of fiberglass thermal tape

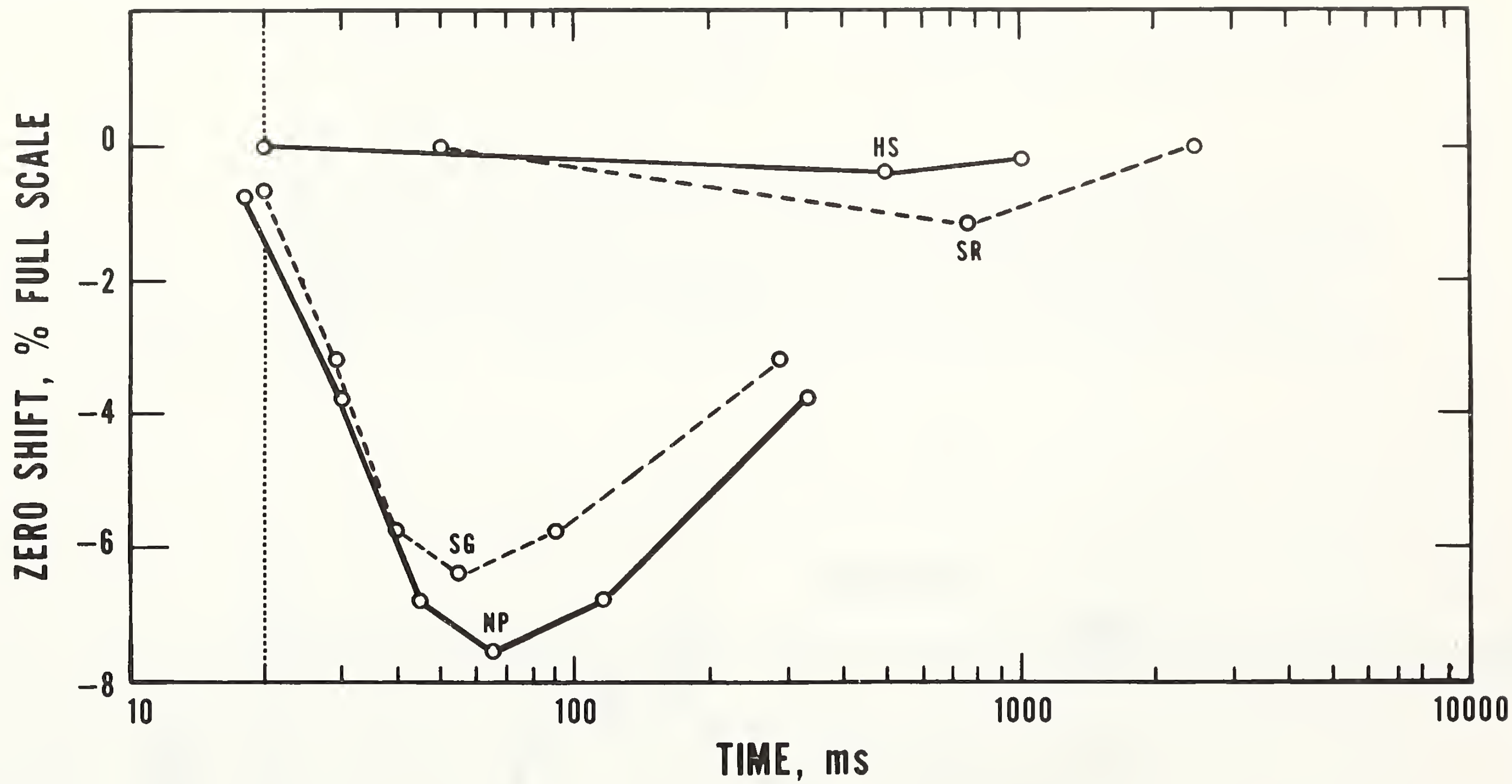

Figure 1-B: Response of an unbonded strain-gage pressure transducer with selected protective coatings applied to the diaphragm outer surface to a thermal radiant-energy transient of approximately 20 mJ/mm^2. The plots are of transducer zero shift (percent of full-scale reading) as a function of time (ms), with time on a three-cycle logarithmic scale. The peak of the transient occurs at approximately 20 ms, as indicated by the dashed line. The heavy-line plot (NP) represents the transducer zero shift with no protective coating.

Coating identification code:

HS - "heat-sink" silicone compound
SG - silicone grease
SR - red RTV silicone rubber

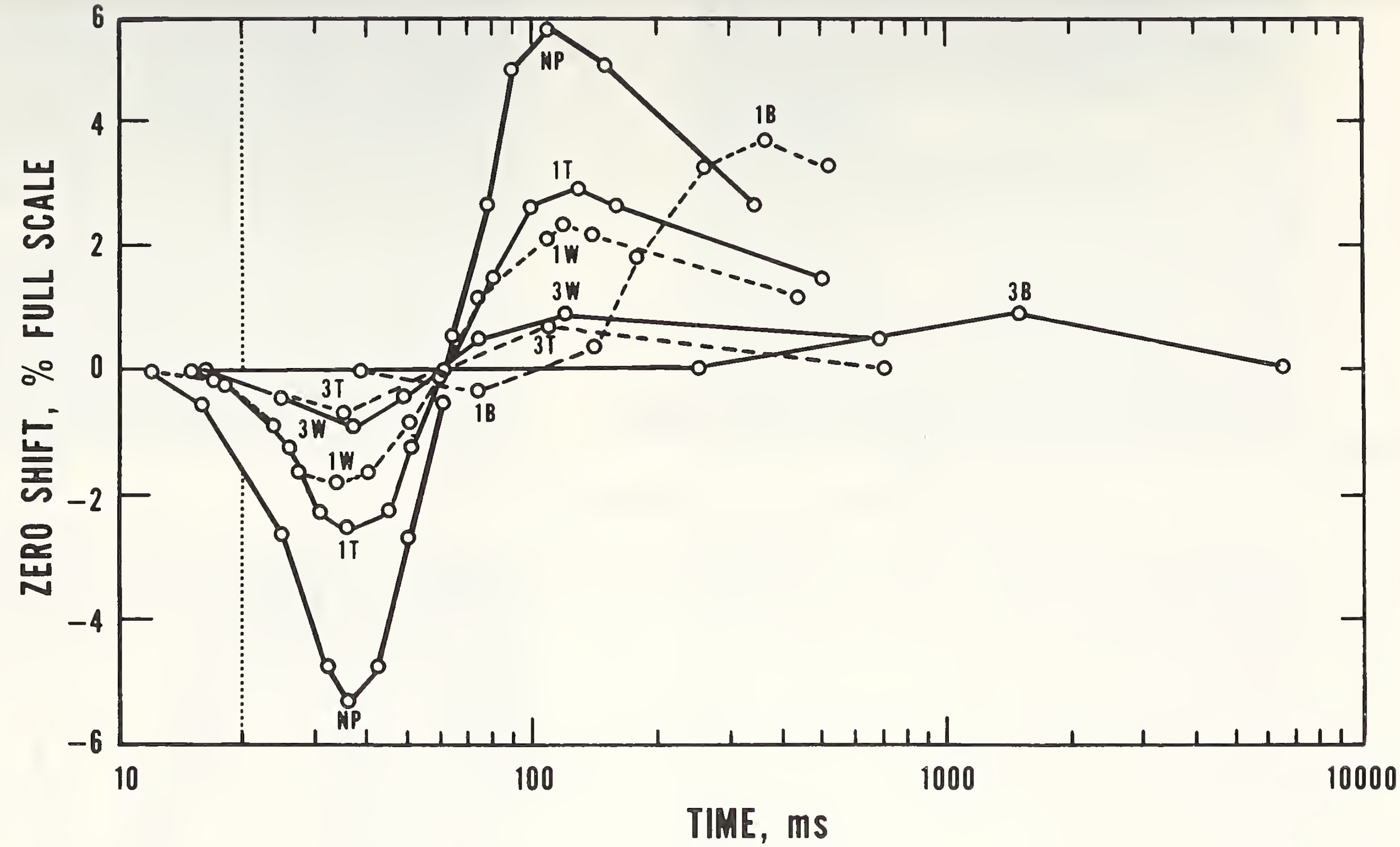

Figure 2-A: Response of a quartz-crystal pressure transducer with selected protective coatings applied to the diaphragm outer surface to a thermal radiant-energy transient of approximately 20 mJ/mm^2. The plots are of transducer zero shift (percent of full-scale reading) as a function of time (ms), with time on a three-cycle logarithmic scale. The peak of the transient occurs at approximately 20 ms, as indicated by the dashed line. The heavy-line plot (NP) represents the transducer zero shift with no protective coating.

Coating identification code:

1B - one layer of black vinyl tape
1W - one layer of white vinyl tape
1T - one layer of fiberglass thermal tape
3B - three layers of black vinyl tape
3W - three layers of white vinyl tape
3T - three layers of fiberglass thermal tape

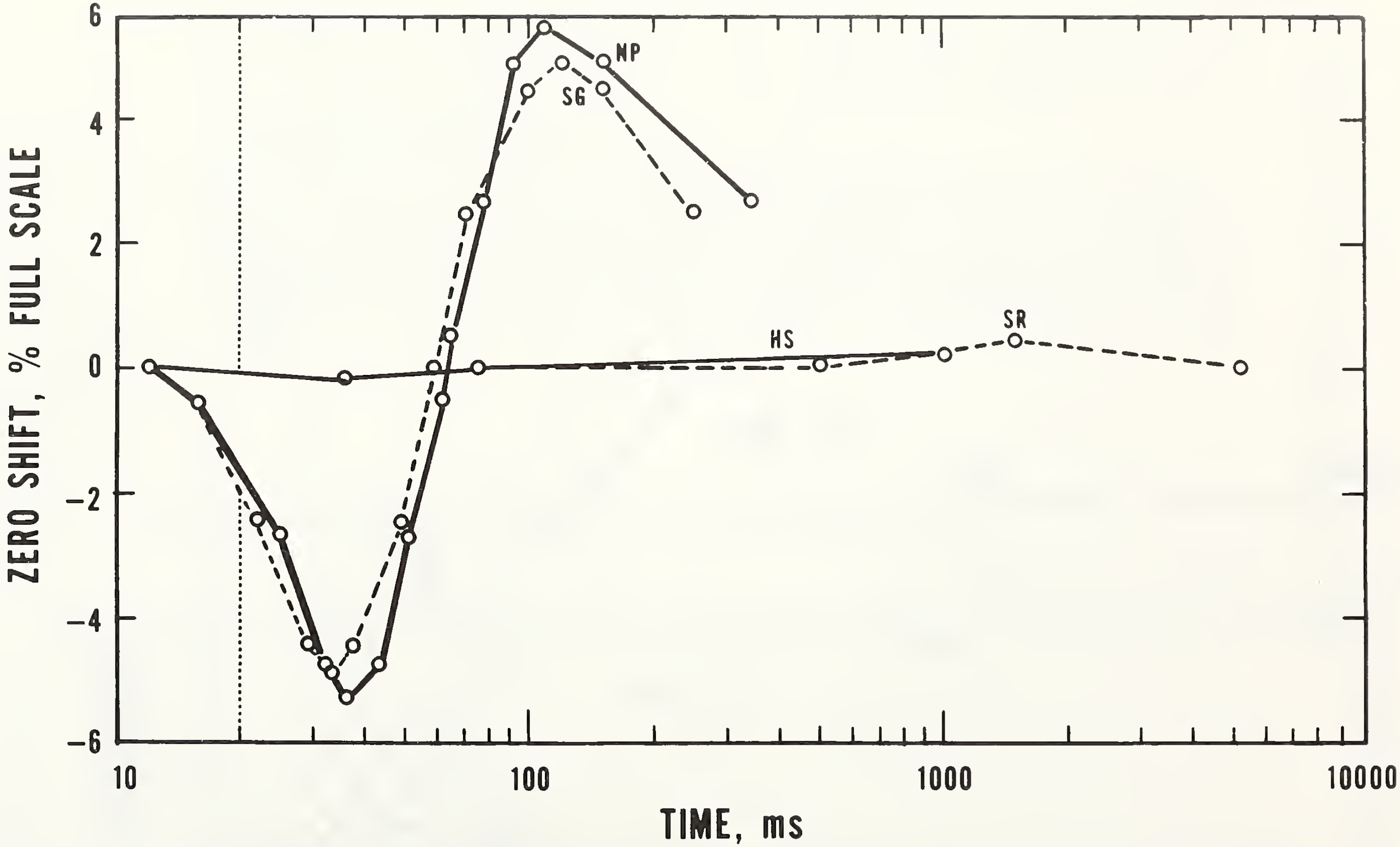

Figure 2-B: Response of a quartz-crystal pressure transducer with selected protective coatings applied to the diaphragm outer surface to a thermal radiant-energy transient of approximately 20 mJ/mm^2. The plots are of transducer zero shift (percent of full-scale reading) as a function of time (ms), with time on a three-cycle logarithmic scale. The peak of the transient occurs at approximately 20 ms, as indicated by the dashed line. The heavy-line plot (NP) represents the transducer zero shift with no protective coating.

Coating identification code:

HS - "heat-sink" silicone compound
SG - silicone grease
SR - red RTV silicone rubber

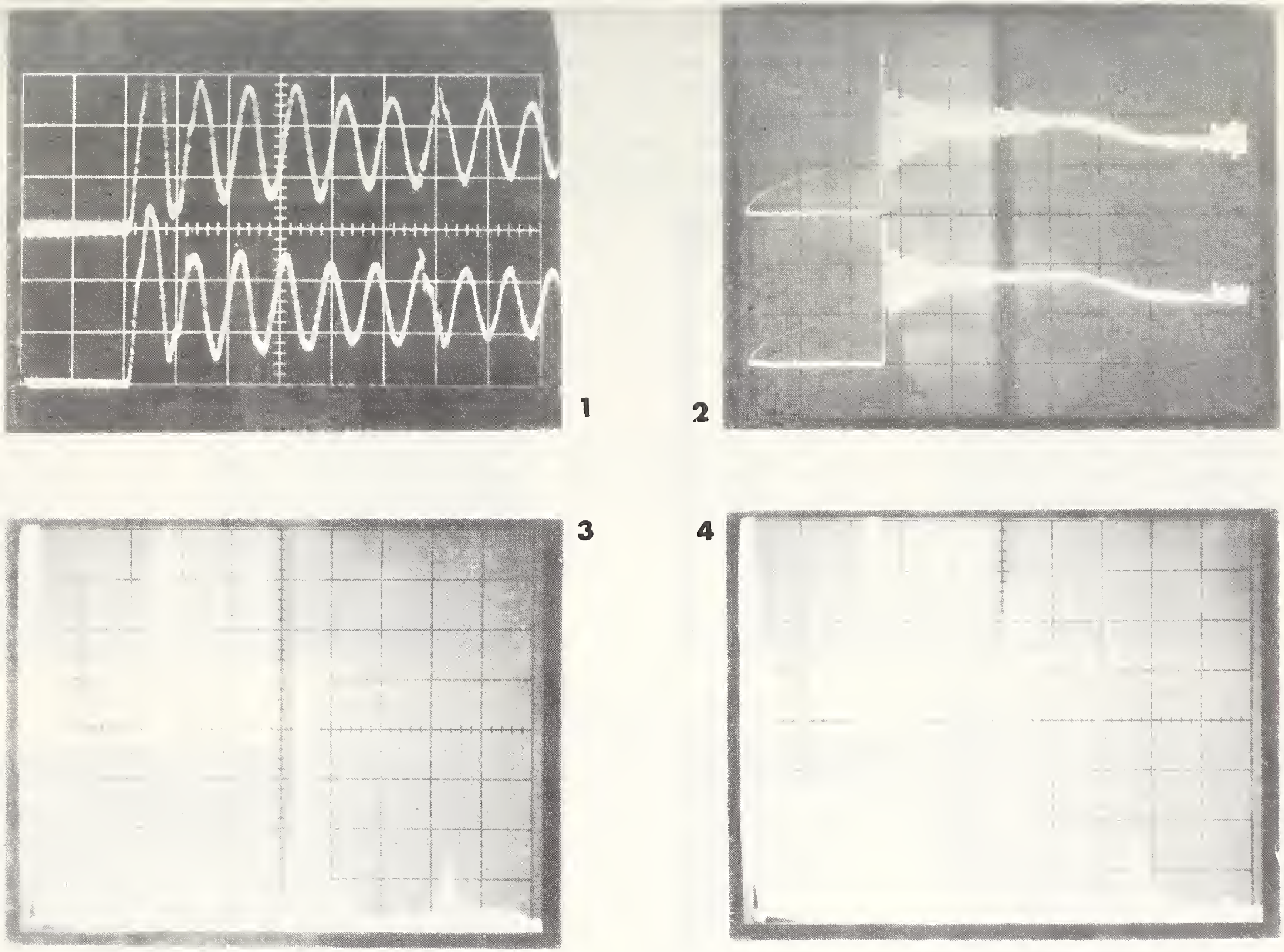

Figure 3: Response to a pressure step of 280 kPa by two unbonded strain-gage pressure transducers. In these tests neither test nor control transducer had a protective coating applied to the diaphragm. Photographs 1 and 2 are of oscilloscope traces displaying the outputs of the test (upper trace) and control (lower trace) transducers. The time scale of the traces in photograph 1 is 0.1 ms/division, and 2, 1.0 ms/division; for the traces in both photographs a deflection of one division in the vertical direction corresponds to 10 mV. Any variation between the upper and lower traces in either photograph would be expected to be attributable to the differences in performance that are commonly observed between two individual transducers of the same model. Photographs 3 and 4 are of traces displaying the frequency spectrum of the traces in 2, that is, relative intensity at a given frequency as a function of frequency. The frequency range (horizontal axis) is linear and extends from 0 to 40 kHz.

1 2

3 4

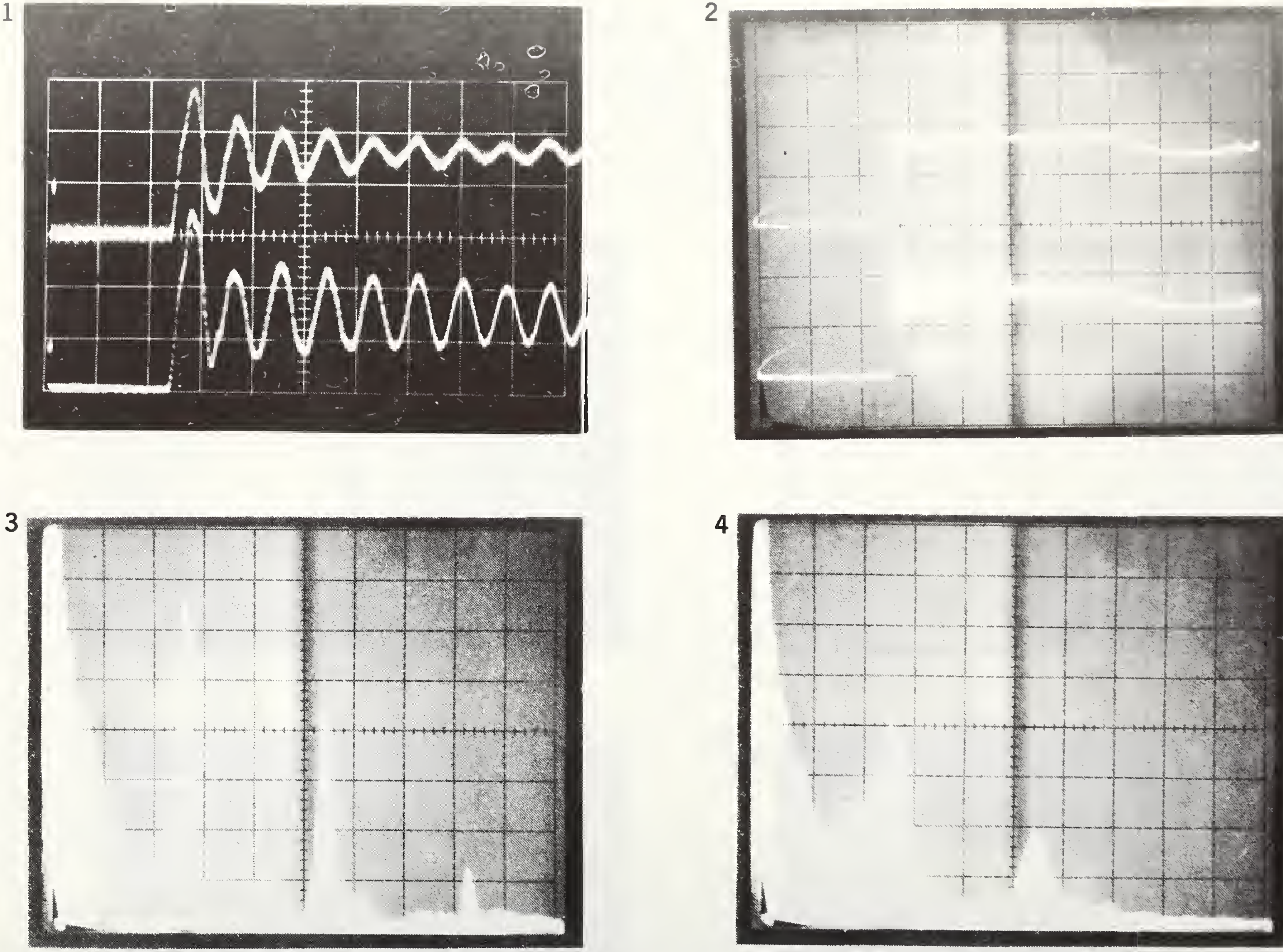

Figure 4: Response to a pressure step of 280 kPa by two unbonded strain-gage pressure transducers. In these tests the test transducer had a protective coating of three layers of black vinyl tape applied to the diaphragm; the control had no protection. Photographs 1 and 2 are of oscilloscope traces displaying the outputs of the test (upper trace) and control (lower trace) transducers. The time scale of the traces in photograph 1 is 0.1 ms/division, and in 2, 1.0 ms/division; for the traces in both photographs a deflection of one division in the vertical direction corresponds to 10 mV. Photographs 3 and 4 are of traces displaying the frequency spectrum of the traces in 2. The frequency range (horizontal axis) is linear and extends from 0 to 40 kHz.

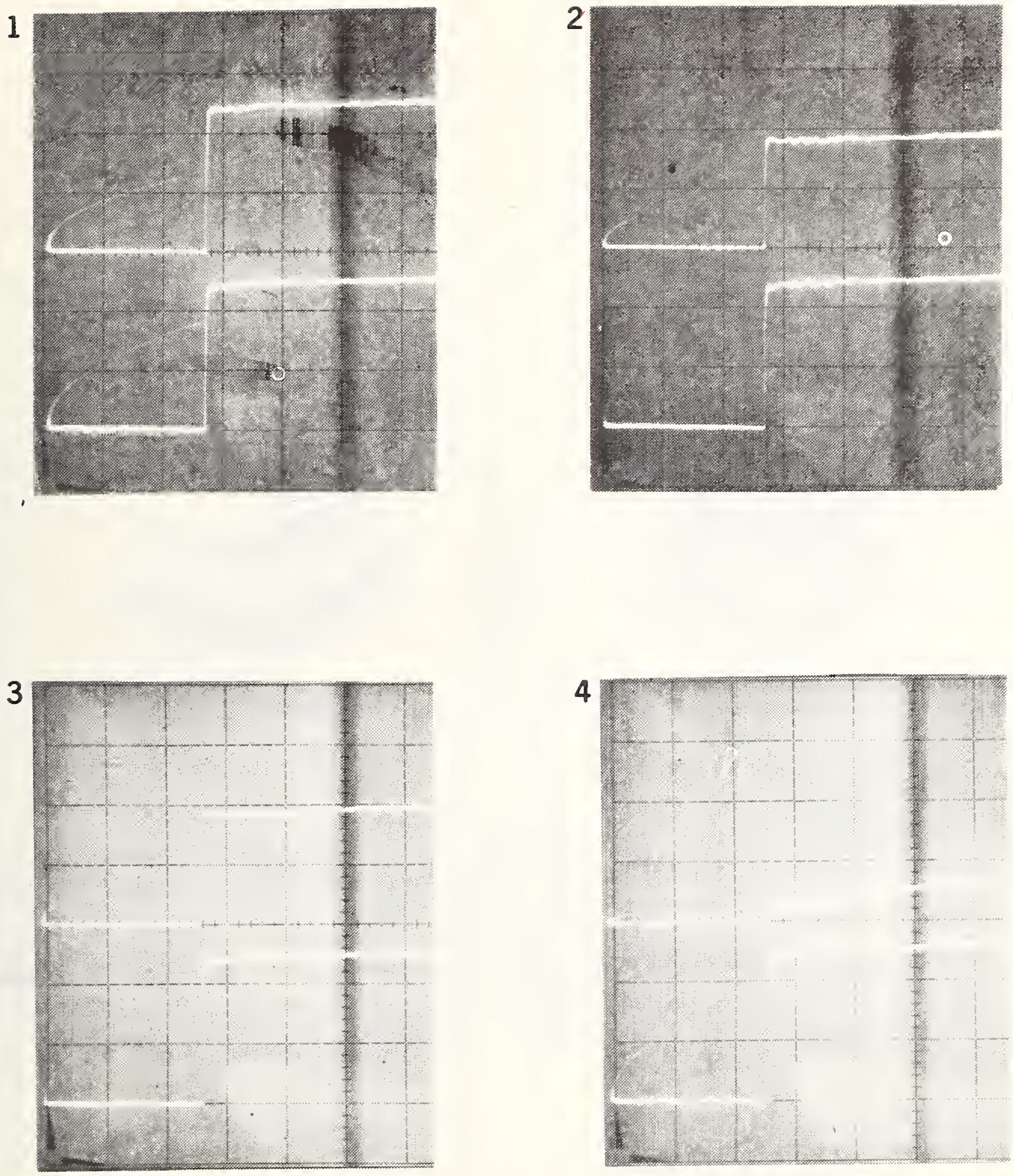

Figure 5: Response to a pressure step of 280 kPa by two quartz-crystal pressure transducers. In the tests represented by photographs 1 and 3 the test transducer had a protective coating of three layers of black vinyl tape applied to the diaphragm; in the tests represented by 2 and 4, the coating was three layers of white vinyl tape. The control transducer received no protective coating in either set of tests. The photographs are of oscilloscope traces displaying the outputs of the test (upper trace) and control (lower trace) transducers. The time scale for all traces is 1 ms/division; a vertical deflection of one division corresponds to 100 mV. It would be expected that the four test transducer traces be in general agreement, as the color of the tape should not affect the rate at which the energy in the pressure step is transmitted through the tape to the diaphragm and as the density and texture of the black tapes and the white tapes are similar. A possible explanation for the variations shown here is advanced in 3.4.2.

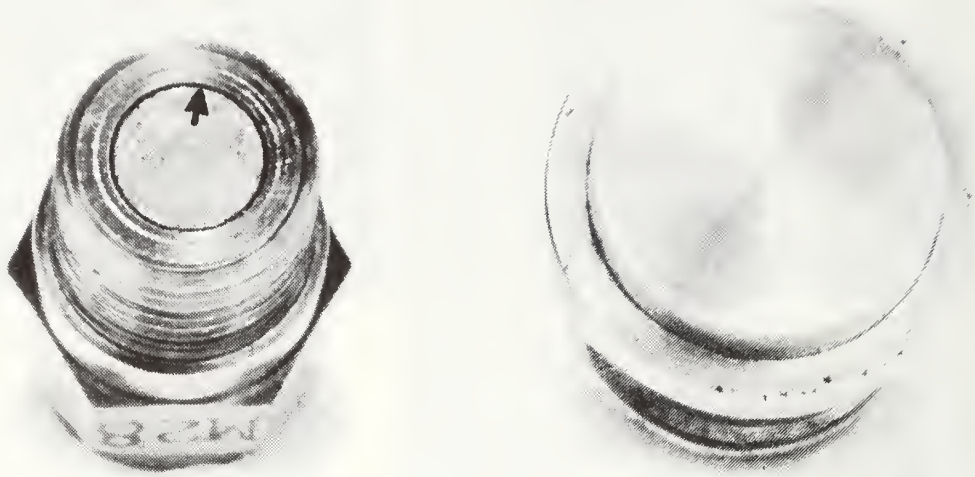

Figure 6: Photographs of the faces forming part of the sensing assembly of a quartz-crystal (left) and an unbonded strain-gage (right) pressure transducer. Part or all of these faces are the outer surfaces of the respective instrument diaphragms. Note the presence of the annular ridge (arrow) on the face of the quartz-crystal instrument. This ridge marks the periphery of the diaphragm; the significance of the presence of the ridge is discussed in 3.4.2.

TABLE 1

Zero Shift Resulting from Thermal Radiant-Energy Transient
Applied to Protected and Unprotected Unbonded-Strain-Gage Pressure Transducers

		Test Transducer		Control Transducer	
Test No.	Protective Coating on Diaphragm of Test Transducer	Maximum Negative Zero Shift % FS*	Time to Maximum Negative Zero Shift, ms	Maximum Negative Zero Shift % FS*	Time to Maximum Negative Zero Shift, ms
1	None	7.4	65	6.4	65
2	One Layer Black Vinyl Tape	6.5	260	7.3	60
3	Three Layers Black Vinyl Tape	2.2	860	7.1	55
4	One Layer White Vinyl Tape	3.7	70	6.5	65
5	Three Layers White Vinyl Tape	2.0	50	7.4	50
6	One Layer Thermal Fiberglass Tape	4.1	55	7.7	55
7	Three Layers Thermal Fiberglass	1.5	60	7.3	60
8	None	7.7	65	7.1	65
9	Silicone Grease	6.4	55	7.1	60
10	Silicone "Heat-Sink" Compound	0.4	500	8.3	60
11	Two-Component Red RTV Silicone Rubber	1.2	750	7.6	64
			Average	7.3	60
			Coefficient of Variation, %	7.3	8.2

*FS = full-scale reading of the transducer

TABLE 2

Zero Shift Resulting from Thermal Radiant-Energy Transient
Applied to Protected and Unprotected Quartz-Crystal Pressure Transducers

Test Transducer					
Test No.	Protective Coating on Diaphragm	Maximum Negative Zero Shift % FS*	Maximum Positive Zero Shift % FS*	Time to Maximum Negative Zero Shift, ms	Time to Maximum Positive Zero Shift, ms
12	None	5.3	5.5	36	110
13	One Layer Black Vinyl Tape	0.4	3.6	74	370
14	Three Layers Black Vinyl Tape	0.0	0.9	—	1100
15	One Layer White Vinyl Tape	1.8	2.4	34	120
16	Three Layers White Vinyl Tape	0.9	0.9	37	120
17	One Layer Thermal Fiberglass Tape	2.5	2.9	36	120
18	Three Layers Thermal Fiberglass Tape	0.7	0.7	35	110
19	Silicone Grease	4.9	4.9	33	120
20	Silicone "Heat-Sink" Compound	0.2	0.2	36	1000
21	Two-Component Red RTV Silicone Rubber	0.0	0.4	—	1500

Control Transducer					
Test No.	Protective Coating on Diaphragm	Maximum Negative Zero Shift % FS*	Maximum Positive Zero Shift % FS*	Time to Maximum Negative Zero Shift, ms	Time to Maximum Positive Zero Shift, ms
12	None	4.7	2.7	38	105
13	None	5.8	3.1	39	120
14	None	5.5	2.9	38	120
15	None	4.5	2.4	35	105
16	None	5.1	2.5	36	110
17	None	5.1	2.7	38	120
18	None	5.3	2.9	35	110
19	None	5.1	2.5	34	110
20	None	5.3	2.9	34	110
21	None	5.5	2.9	35	110
	Average	5.2	2.8	36	112
	Coefficient of Variation, %	7.4	8.3	5.2	5.2

TABLE 3

Response of Two Unbonded Strain-Gage
Pressure Transducers, One Protected and the Other
Unprotected, to 280-kPa Pressure Step

Test No.	Protective Coating on Diaphragm	Rise Time 10-90% μ sec	Amplitude* at 150 μs, 500 μs, 1 ms, 2 ms, 3 ms	Major Resonant Frequencies kHz
	Test Transducer			
1	None	14	37.1, 38.6, 38.0, 38.5, 39.0	9.8, 20.4, 31.0
2	One Layer Black Vinyl Tape	14	35.3, 36.7, 39.0, 30.0, 40.0	10.0, 20.8, 31.8
3	Three Layers Black Vinyl Tape	16	32.9, 36.3, 36.0, 37.0, 37.0	10.0, 21.8, —
4	One Layer White Vinyl Tape	16	34.3, 37.3, 37.5, 38.0, 38.0	9.8, 10.4, 31.2
5	Three Layers White Vinyl Tape	16	32.5, 36.5, 38.0, 38.3, 38.5	9.8, 20.8, —
6	One Layer Thermal Fiberglass Tape	16	35.0, 37.9, 38.0, 38.0, 39.0	9.6, 10.2, 30.6
7	Three Layers Thermal Fiberglass Tape	14	32.3, 36.8, 36.5, 37.5, 37.5	9.2, 19.6, 29.4
8	None	16	34.4, 37.0, 38.0, 38.0, 38.0	9.6, 20.2, 31.0
9	Silicone Grease	16	32.9, 34.8, 35.5, 35.5, 36.0	9.9, 19.6, 29.4
10	Silicone "Heat-Sink" Compound	14	33.3, 36.1, 37.5, 37.5, 38.5	8.8, 18.4, 28.0
11	Two-Component Red RTV Silicone Rubber	14	33.3, 34.3, 36.0, 36.0, 37.3	9.2, 19.4, 29.2
	Control Transducer			
1	None	9	35.3, 38.0, 39.1, 39.8, 39.1	10.6, 21.6, 33.2
2	None	14	34.5, 37.7, 39.1, 40.1, 40.9	10.6, 21.8, 33.2
3	None	11	33.4, 37.4, 37.7, 38.2, 37.7	10.6, 21.8, 33.2
4	None	14	33.7, 36.6, 37.7, 38.7, 38.7	10.4, 21.8, 33.2
5	None	11	32.2, 36.7, 38.0, 37.7, 37.7	10.6, 21.8, 33.2
6	None	14	33.1, 37.0, 39.1, 38.7, 38.7	10.6, 21.6, 33.0
7	None	11	33.1, 35.5, 36.9, 37.7, 37.7	10.6, 21.8, 33.0
8	None	14	33.1, 36.0, 38.7, 38.7, 38.7	10.0, 21.6, 32.6
9	None	11	33.2, 34.8, 37.1, 37.1, 37.1	10.6, 21.8, 33.2
10	None	16	32.1, 35.6, 36.6, 36.6, 37.7	10.6, 21.8, 33.2
11	None	11	32.8, 35.6, 36.6, 36.6, 37.1	10.6, 21.8, 33.2
	Average	12	33.3, 36.5, 37.9, 38.2, 38.3	10.6, 21.8, 33.1
	Coefficient of Variation, %	17	3.8, 2.8, 2.6, 3.1, 2.8	1.8, 0.6, 0.6

*Recorded trace deflection in units of 0.02 in (0.05 cm).

TABLE 4

Response of Two Quartz Pressure Transducers, One Protected and the Other Unprotected, To 280-kPa Pressure Step

Test No.	Protective Coating on Diaphragm	Rise Time 10-90% μ sec	Amplitude* at 15 μs, 50 μs, 1 ms, 2 ms, 3 ms
	Test Transducer		
1	Silicone Grease	1	54, 52, 52, 53, 54
2	Silicone "Heat-Sink" Compound	1	49, 49, 52, 53, 53
3	Two-Component Red RTV Silicone Rubber	4	51, 52, 52, 53, 53
	Control Transducer		
1	None	1	53, 50, 53, 53, 53
2	None	1	49, 48, 53, 53, 54
3	None	1	52, 52, 52, 53, 54
	Average	1.3	51, 50, 53, 53, 54
	Coefficient of Variation, %	43	4.1, 4.0, 1.1, 0, 1.1

*Recorded trace deflection in units of 0.02 in (0.05 cm).

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Experimental efforts are described in the development and evaluation of means to reduce the effects produced by thermal radiant-energy transients on pressure-transducer response. Both unbonded strain-gage and piezoelectric pressure transducers were used in this work with protective coatings applied directly to the diaphragms. The test method employed is to expose a pair of transducers — one protected and the other unprotected, but otherwise nominally identical — to a known radiant-energy transient with an energy density of approximately 20 mJ/mm^2. The resulting zero shift is measured and taken as an index of coating effectiveness.

The effect of the presence of the coating on transducer dynamic response was investigated by means of a shock tube, with a protected and an unprotected transducer pair exposed to the same pressure step of approximately 280 kPa (40 psi). Each transducer output was recorded as a function of time.

Test results with nine coatings and two transducer pairs are presented.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Coatings; dynamic; dynamic response; pressure transducer; protective coatings; shock tube; tape; thermal radiant-energy response; thermal transient response; transducers; zero shift.

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