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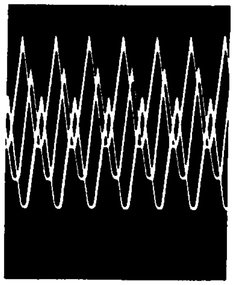

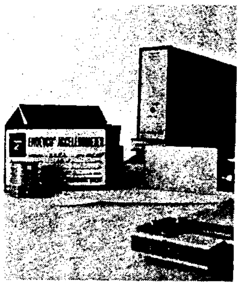

TP279

REDUCING TRANSIENT THERMAL SENSITIVITY OF SILICON DIAPHRAGM PRESSURE TRANSDUCERS

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INTRODUCTION

Subminiature pressure transducers respond well to pressures having high frequency content. However, because they are small, light weight, and stiff, they can also be quite susceptible to transient thermal inputs. In certain applications, this results in significant measurement error. Problems have been encountered in many situations such as pressure measurements in the presence of bright flashes from explosions, interrupted light from rotating turbine blades, hot gases impinging on to the diaphrams, sudden changes of pressure media, and rapid changes of structural temperature.

To eliminate errors in such situations, the measurement engineer might protect the transducer housing from the thermal changes and isolate the sensing element by placing a pressure cavity, or pressure line, in front of the sensor. Obviously this increases the size and reduces the frequency response. Many times the user cannot take such an approach, and over the past ten years or so, various methods have been explored to reduce the thermal errors from these miniature transducers.

This technical paper summarizes recent work to reduce thermal induced errors within the sensor while preserving the frequency response.

EVALUATION PROCEDURES

Several methods have been used to evaluate transducer response to transient thermal evironments. Most of these have been reported in the literature. They include:

1. Dunk suddenly into water at a higher temperature. (Ref. 1)
2. Expose to an incandescent lamp for a short time by opening and closing a shutter. (Ref. 2)
3. Expose to a #25 G.E. photoflash bulb at a distance of two feet. (Ref. 3)
4. Expose to a #2 Sylvania photoflash bulb at a distance of 2.75 inches. (Ref. 4)
5. Expose to flash from electronic photoflash unit.

This list is not meant to be inclusive of all methods used to evaluate transducers, however, it should be adequate to point out that there is no single standard test method. This fact is also evident from examination of commercial specifications for transducers. On the other hand, there is probably no single valid test method because of the many types of thermal inputs, and because

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transducer responses can be non-linear with energy level and with frquency content of the thermal input.

WHY TRANSDUCERS RESPOND TO TRANSIENT THERMAL INPUTS

Transient thermal environments can affect transducers in several ways. As a means to simplify laboratory simulations for the various thermal inputs, and to catagorize these, they can be divided into two primary modes. The first is heat transfer by conduction and convection, and the second, heat transfer by radiation. With conduction or convection, heat is simply transferred in or out of a transducer at a fast rate causing temperature gradients. For "flush" diaphragm type pressure transducers, this must be further refined to include the situations where heat is conducted into or out of the diaphragm through changes in the pressure media. These affect strain-gage type transducers in the following three ways.

1. Errors occur simply because the strain gage elements can be at a different temperature than their supporting structure or other temperature compensation elements.
2. Because the strain gage elements consume electrical energy which is removed by heat transfer, changes in the heat transfer characteristics of the pressure media can affect the equilibrium temperature.
3. As heat is transferred into the diaphragm, if it is not uniform to each of the resistors in the bridge, an unbalance in the bridge will occur.

These three factors not only cause a zero shift in the resistive bridge, but they can also change the sensitivity factor for the transducer. Both characteristics should be evaluated.

The second method is the effect from radiation. In general, radiation will heat the diaphragm surface of any transducer. If the diaphragm is made of metal, heating it usually causes a portion of the material to expand resulting in bending of the diaphragm and generation of an output. Any transducer which has small diaphragm movement with pressure will have an error from this, and this is very common for high sensitivity piezoelectric pressure transducers or microphones.

For silicon diaphragm transducers, there is a different mechanism which causes error. Silicon absorbs short wavelength electromagnectic energy, most of which is in the visible light spectrum of about 3000A to 10,000A wavelength. This temporarily upsets the electronic structure of the material. One result is photoconductivity. Another is a photodiode effect in the junction isolation between the gages and the bulk material. The ratio of importance between these two aspects likely changes with the degree of doping for the gages. If the four arms of the bridge have equal resistance, and are geometrically the same with respect to ground, these effects might be balanced out in the bridge. This, however, is not what happens, and, in addition, often times the light intensity is not uniform over the entire bridge anyway. Tests show that about two-thirds of our diaphragms have a negative output when tested by discharging a #2 flashbulb 2.75 inches from the diaphragm, while the remaining go positive. Some transducers have a single pulse output, and others have two pulses. The amplitudes of the pulses are also quite non-linear with light intensity and even the waveshapes can change. Because the absorption coefficient of silicon changes with wavelength, the response is different for different light sources; silicon is quite transparent to the longer wavelengths in the infrared region.

In short, flash sensitivities of silicon diaphrams vary widely from unit to unit, and it is rather easy to obtain a full scale output from a flash of light.

TYPICAL METHODS TO REDUCE TRANSIENT THERMAL RESPONSE

Several methods have been available in the past to reduce thermal transient inputs into miniature pressure transducers (Ref. 5, 6). For example:

1. Protect or shield the diaphragm from the transient with a baffle or shadowing screen.
2. Place an opaque grease in front of the diaphragm.
3. Add an opaque material which adheres to the diaphragm such as black tape or RTV.

RECENT DESIGN IMPROVEMENTS FOR SILICON DIAPHRAGM TRANSDUCERS

Two silicon diaphragm configurations have been in use, the flat diaphragm and the sculptured diaphragm. With the sculptured diaphragm as described by Wilner in 1977 (Ref. 7), the effects from transient temperature are reduced because the diaphragm is considerably thicker over most of its area. In short, diaphragm bending is considerably less from any surface heating than when using the flat diaphragm. Because the diaphragm is thicker, there is also much greater thermal mass to dissipate the self-generated heat from the strain gages. This means that changes in the pressure media will cause less strain-gage temperature change. The effects of this were documented by K. Souter and H. Krachman (Ref. 8). Laboratory evaluations have also been conducted by suddenly immersing the transducer into hot water. Test results for several transducer designs are shown in Figure 1.

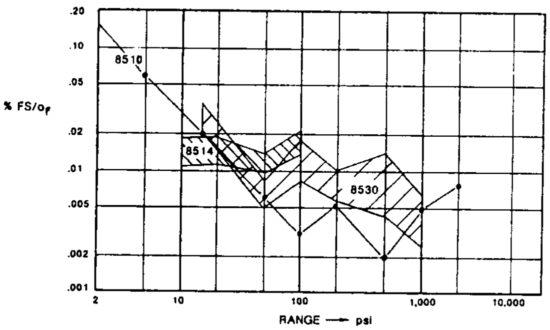


Figure 1. Effect On Zero Output From Sudden Temperature Change
(75°F Air to 190°F Water-ISA 37.10, Para. 6.7)

The construction approach for the Wilner design has also helped to reduce its response to transient thermal inputs. The diaphragm is positioned behind a screen, essentially within a small cavity. Figure 2 shows three typical

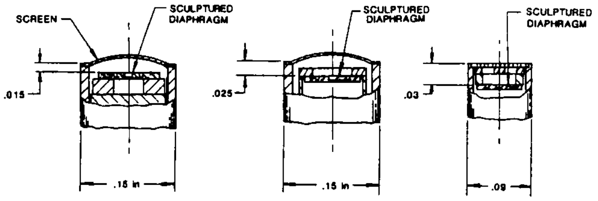


Figure 2. Typical Configurations

construction approaches. These provide some protection and screening from transient thermal energy. Because a cavity is placed in front of the diaphragm, the response time to pressure inputs is made more complex. Tests in pressure shock tubes, however, show that the rise time is fast and the resonant frequencies of these cavities are usually over 100 000 Hz with all of the screen holes open. When more than about one-half of the holes are closed, the rise time increases. Figure 3 shows the shock tube response of an 8510-15 with 3 different screen arrangements: the standard screen, a special screen with one-tenth the hole area, and a screen with only one .008 in. diameter hole. The rise time for the single hole configuation is extremely slow, corresponding to frequency response of only a few Kilohertz. The advantage of a few small holes is that such screens can be used to better block the strain-gages from the thermal input. Figure 4 shows that the response of an 8510-15, using the standard screen which has over 50 access holes, can exceed full scale when flashed with an electronic photoflash at 1 inch. The screen on this unit was replaced with a special screen having 6 holes of .006 inch diameter situated to the side of the gages. With the flash placed directly in front of the transducer, the response was reduced to 10% of full scale. With the flash unit simply rotated 45° to direct the light through a portion of the holes

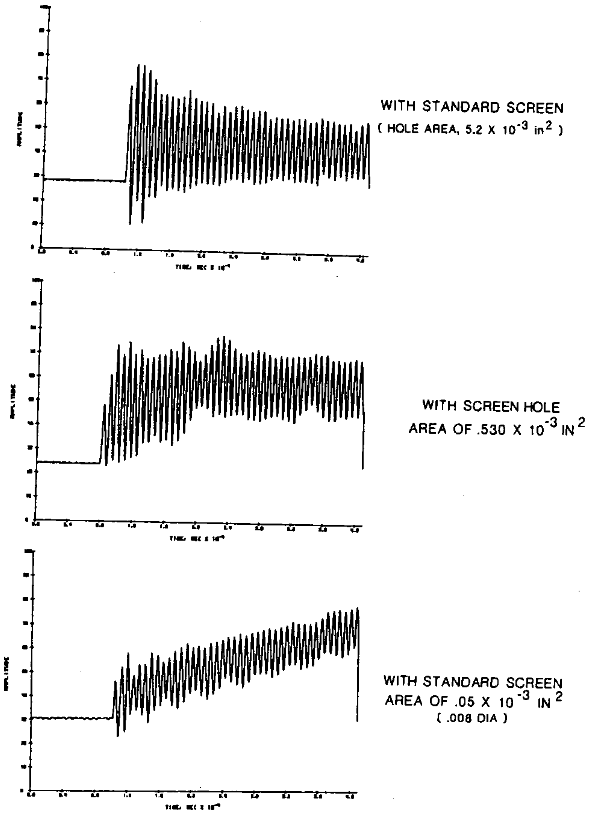
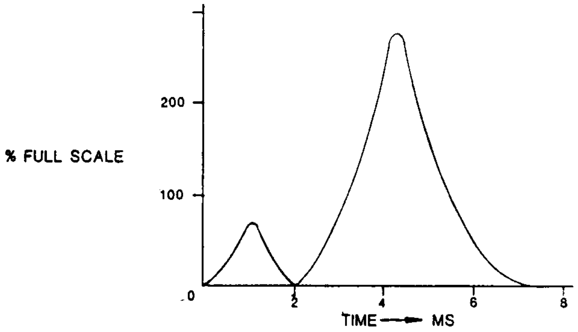
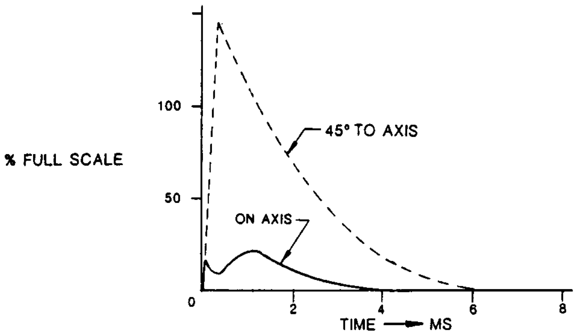


Figure 3. Shock Tube Response, 8510-15
(Screen Thickness .002 in.)

in the screen towards the center of the diaphragm, the response again exceeded full scale.



a.) FROM STANDARD 8510, 15 psi RANGE



b.) FROM 8510-15 AS ABOVE EXCEPT WITH SPECIAL 6 HOLE SCREEN

Figure 4. Output From Electronic Flash (At a Distance of 1 inch)

As with the flat diaphragm transducers, improvements for transient thermal conditions can also be achieved by placing grease or rubber in front of the diaphragms. Our tests have shown that rubber can generally be used for designs having ranges of 100 psi and greater; below that, the addition of a gummy or high hysteresis material will affect the accuracy of the transducer. For the lower ranges, black grease has been successfully used. For either of these approaches the acceleration sensitivity increases, and the resonant frequencies decrease because of the added mass on the diaphragm.

To further reduce the sensitivity of the sculptured silicon diaphragm transducer to radiated inputs, a method was developed to significantly reduce radiation transmission to a silicon material. This was accomplished by adding a metallic coating to the front side of the diaphragm.

For our first attempt, we vapor deposited aluminum and for our second, pure nickel. Both approaches were only marginally acceptable. Once an adequate thickness was deposited to eliminate light transmission, the coatings were found to affect the temperature coefficients, linearity, and hysteresis. In addition, because of the significant difference of coefficient of expansion for the materials and silicon, temperature cycling would sometimes cause a loss of adhesion.

A much better method was developed using a nickel alloy with a coefficient of expansion close to silicon. The material has high reflectivity, and the material adheres well to silicon. It is applied by a sputtering process since vapor deposition of alloys changes their composition. (Generally sputtering also provides better adhesion than vapor deposition.) The thickness of the metallic coating can be varied, depending on the thickness of the diaphragm and the application. The increase in the thickness of the diaphragms from adding these coatings is less than 3%. The accuracy of the transducers is not degraded by the metallic coating although the sensitivity is slightly reduced for the lowest range, 2 psi, because of the increased stiffness. It should also be mentioned that if the coefficient of expansion did not closely match that of silicon, the temperature performance would be significantly affected.

The addition of this special coating typically reduces the flash sensitivity of these transducers by at least 100 times. Figure 5 shows the response to 3 different flash inputs for a 5000 psi 8511, before and after receiving its metallic coating. Note that when uncoated,

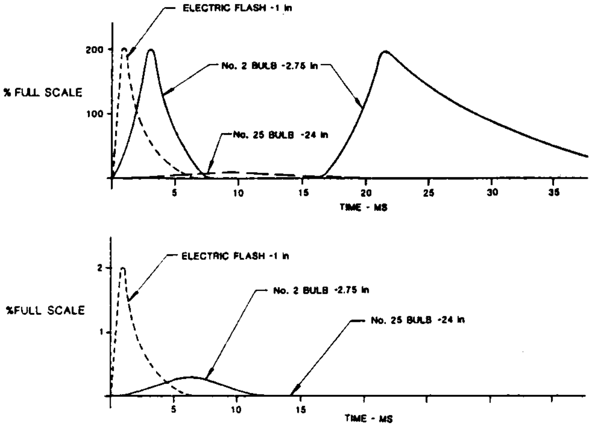


Figure 5. Comparison of Outputs From Different Flashes (Using 5 000 psig 8511)

the wave shapes are entirely different between the flash bulbs at 2.75 inches and 24 inches even though the burn times of the bulbs are similar. The light intensity is simply much less at 24 inches with the smaller bulb. With the diaphragm coated it appears that the remaining sensitivity is from the shortest wavelengths coming from the electronic flash. Even there the magnitude is quite low. This same metallized transducer was then coated with black grease, about 0.02 inches thick. There was no measurable response from either the #25 bulb at 24 inch, or the electronic flash a 1 inch. With the #2 bulb at 2.75 inch, there was only about 0.2% F.S. signal.

CONCLUSION

Based on the various tests that have been conducted, the sculptured diaphragm appears to offer advantages over the flat diaphragm when they are exposed to sudden temperature changes. However, left unprotected both diaphragms are sensitive to light. Flash sensitivity has a wide variation in amplitude and waveshape from unit to unit, probably because it is caused by several phenomena. One can attempt to isolate the diaphragm from light by using a protective screen or opaque low strength covering, but the best method apprears to be to add a thin metallic coating to the diaphragm.

Metallic coatings can be added without affecting the performance of the transducers. The metallic coatings which we are using appear to not only greatly reduce light transmission to the strain gages, but they do not result in an output due to surface heating such as is often seen with metal diaphragm transducers.

Our thermal transient sensitivity tests have been conducted using several procedures, and there appears to be no standard recommended technique within the industry. Because transient thermal characteristics are important to miniature transducers, common techniques should be used to permit comparison between designs, and the characteristic should be included in product specifications.