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LOW PROFILE MICROSENSOR FOR AERODYNAMIC PRESSURE MEASUREMENT

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LOW PROFILE MICROSENSOR FOR AERODYNAMIC PRESSURE MEASUREMENT

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Abstract—Measurement of pressures and pressure induced loads on aerodynamic structures presents special challenges for the sensors being used. Transducers used for pressure measurements on aircraft surfaces, turbine blades, helicopter blades, and other thin structures undergo many environmental inputs which may cause errors in the measurement. These inputs include temperature, shock, vibration, bright sunlight and mounting stresses. In addition, the sensor may disturb the air flow which is to be measured, further complicating matters.

A very low profile (0.76mm high) pressure transducer designed for these measurements will be presented which offers excellent performance in these challenging environments. The unit is a recently improved version of a successful existing transducer offering better accuracy over flight test temperature ranges, lower sensitivity to light and improved moisture resistance compared to the previous design. Two ranges, 15 psia and 50 psia, are available.

ABBREVIATIONS

ZMO	Zero measurand output (zero pressure reading)
FSO	Full scale output with full scale pressure applied
psi	pounds per square inch (1 psi = 6.895 KPa)
psia	psi absolute (vacuum reference)
μE	microstrain (μ in/in)

INTRODUCTION

Pressure measurements play an important part in the development of many aerodynamic structures such as wings, propellers and turbine blades. Theoretical calculations need to be checked and calibrated with actual measured data for optimization of a design's performance. As is the case so often, measuring pressures in flow environments without changing that flow demands careful attention to many details. The sensors must be applied in such a way as to measure but not disturb the flow patterns over the surfaces of interest. The subject of this paper is a pressure transducer designed specifically for making accurate measurements in challenging aerodynamic environments with minimum distortion of flow and minimum modification of test items.

TRANSDUCER CONSTRUCTION

The transducer is a "flatpack" type named for its button like shape which measures 0.250 inches (6.3 mm) in diameter and 0.030 inches (0.76 mm) in thickness, as shown in Figure 1. It is designed to be mounted to a measurement surface via an adhesive. A flat four conductor ribbon cable also helps minimize flow disturbances. The heart of the transducer is a micromachined silicon diaphragm sensor of the piezoresistive type. The sensor, shown in Figure 2, has an integral vacuum reference chamber allowing absolute pressure measure-

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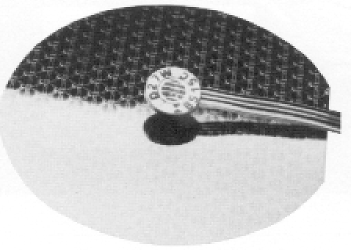


Figure 1: Transducer above a wafer

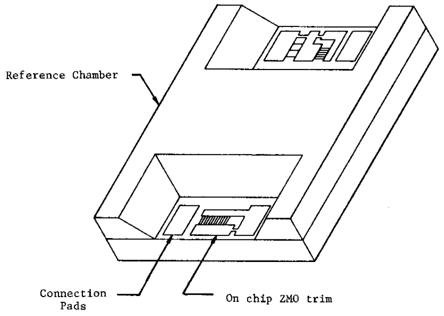


Figure 2: Sensor

ments. The reference chamber is rectangular and measures about 0.06 inches (1.5 mm) by 0.05 inches (1.3 mm). Since it is an absolute pressure transducer there is no need to route reference tubes throughout an airplane, wind tunnel model or other test items. It incorporates several features which allow excellent performance in a flight test environment.

One feature is its uniquely sculptured diaphragm shown in Figure 3. Two thick stiffening members sit at the center of the diaphragm and concentrate much of the diaphragm deflection in three thin areas where the four strain gages are located. This provides much higher output (200 mV nominal at full scale pressure) for low pressure measurements. The higher stiffness also gives very high resonances (180 Khz for 15 psia sensor) to provide excellent high frequency response where required. It also provides flat response down to steady state pressures. Another benefit is the ability to withstand high overpressures up to five times full scale making overpressure damage very uncommon.

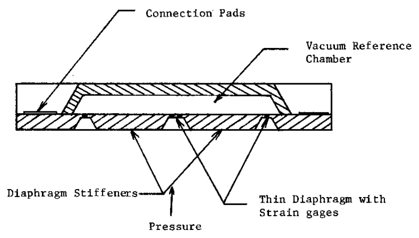


Figure 3: Sensor Cross Section

A new feature for this transducer is the incorporation of on chip zero compensation and a modified more linear doping level achieved by ion implantation. Ion implantation is a very precise method of doping the silicon which provides much less scatter in characteristics. Putting zero compensation on the sensor allows the compensation resistor to have the same temperature coefficient as the sensor. The good temperature tracking and tighter doping control make for small thermal errors over wider temperature spans than was possible previously. The modified doping level also allows sensitivity compensation without the use of nonlinear temperature sensitive components. This again helps provide very linear and predictable changes with temperature. In addition it prevents problems in thermal transient or high flow convection situations when compensation components and the sensor may not be at the same temperature.

Table I shows data on ZMO and sensitivity errors over temperature for a sample of fifteen 15 psia transducers. The table data is for the standard 0° to 200°F (-18°C to +93°C) temperature compensation range. Further testing has shown the units to be well behaved over the -65° to 250°F (-54°C to +121°C) flight test range as well with typical ZMO and sensitivity errors remaining below 2%.

TABLE 1
Sample of 15 Units

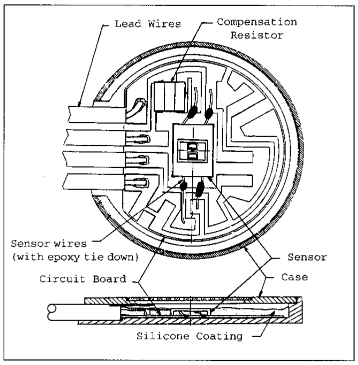
	Average	High	Low
Thermal Sensitivity Shift %	-1.4	-1.9	0.7
Thermal Zero Shift % FSO	-.9	-1.4	-.6

One final new feature on this sensor is a thin film reflective coating on its exposed surface.

This reduces its sensitivity to bright lights to a very low level, typically about 0.25 equivalent psi when tested at two feet from a Blue Dot flash bulb. This eliminates errors when an aircraft changes its attitude towards the sun in flight, or errors due to bright illumination for photography on a wind tunnel model.

The sensor is mounted on a thin kapton circuit board inside a shallow stainless steel case, as shown in Figure 4. Total height of the transducer is only 0.030 inches (0.76 mm) for minimum intrusion into a flow. The sensitive diaphragm is just below a screen on the face of the case which allows pressure in but excludes debris and further reduces light sensitivity. Even further protection from light and debris is possible with a special screen which lets air in only through a circular pattern of small holes situated just outside the sensor.

Figure 4:
Internal
Construction



The transducer is extremely light at 0.08 grams which prevents significant mass loading of the structure it's mounted on. This is especially important when mounted on high speed compressor blades in an engine and experiencing over 10000 g of steady acceleration. Vibrating helicopter blades also benefit from the light weight and rugged construction.

The transducer design minimizes the number of components in order to enhance reliability in harsh vibration environments. Usually there is only one chip resistor external to the sensor for compensation, four solder joints to the cable, and four aluminum wires connecting the sensor which are epoxied to the board for added protection. This is all that is necessary for a fully temperature compensated pressure sensor which can operate in 10000 g shock or 1000 g sinusoidal vibration environments. The sensor has a closed bridge so none of the connections are inside the Wheatstone bridge to affect zero stability.

MOUNTING

A critical step in preparing to make an accurate measurement is proper mounting. Mounting can affect the measurement itself, but there are other considerations as well. On a large structure, such as an airplane, more conventional threaded transducers could be installed from beneath the skin and flush mounted for accurate measurements. However that entails drilling holes in the skin, installing mounting brackets, routing internal wiring and problems with working in some areas not easily accessible. The flat pack transducer can be mounted on the surface of the plane, which is easily accessible, with adhesives such as epoxy, silicones, cyanoacrylates or even double backed tapes. The flat ribbon cable can be held with duct tape and routed to a few central locations for connection to instrumentation. After the test the units can be carefully removed and reused if appropriate adhesives were used; and there are fewer holes left in the skin, perhaps none. Two mounting methods are illustrated in Figure 5.

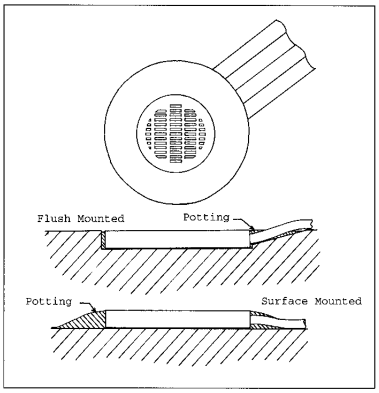


Figure 5:
Mounting
Methods

On smaller structures such as scale models or very thin members, conventional transducers are too long to be mounted. Even miniature transducers are usually at least 0.75 (19 mm) inches long, and small members may not be that thick. One alternative is to run small tubes from remote transducers to the measurement sites; but this severely limits frequency response, often to an unusable level. In these cases the miniature flat pack may be the only acceptable alternative for measuring pressures with sufficient accuracy.

Another aspect to consider for small models, especially with high flow rates, is that even this small transducer may cause significant disturbance to the flow. In such cases it is common practice to mill recesses for the transducer and cable so they will be flush with the surface. Any gaps can be filled in with a potting material so that the original shape of the model is preserved. A technique which has been used on larger structures is the application of potting around the transducer to make a circular ramp from the top surface of the transducer gradually sloping down to the test surface.

One drawback to this type of transducer is the possibility of zero shift caused by bending or other strain induced from the mounting surface. The effect is usually quite small but is worse when the curvature of the mounting surface increases. Typical shifts on a 0.5 inch thick bending beam stressed to 250μE are 0.004 psi when RTV mounted and 0.007 psi when hard mounted for the 15 psia unit. Maximum equivalent shifts on a 0.12 inch thick beam at 600 μE were 0.012 psi.

A potential source of error is acceleration sensitivity of the sensor since the diaphragm does have some mass. Fortunately the mass is very small and so is the acceleration sensitivity. When accelerated on the axis of the diaphragm the sensitivity is only 0.0002 equivalent psi per g of acceleration.

ENVIRONMENTAL CAPABILITIES

The transducers have been tested and shown to operate well during a number of hostile environments including temperatures from -65° to 250°F (-54 to 121°C), shock to 10000 g, vibration to 1000 g, and air flow rates to 650 knots. The standard version has a moisture proofing thin film coating but is generally not recommended for wet environments. An optional conformal coated version has been tested for 72 hours in a Mil-Std-810C humidity chamber. The test included humidity to 95% and temperature cycles from 86° to 149°F (30°C to 65°C). Water actually condensed over the entire units. Readings were taken before during and after the exposure and all five units tested maintained stable readings within a ±1.25% FSO band throughout the test.

SUMMARY

The transducer described here solves many problems typically encountered in flow induced pressure measurements. It is available in 0 to 15 and 50 psia ranges and is furnished fully tested and characterized as to performance over its compensated temperature range. Figure 6 is a sample test report which accompanies each unit. The transducer is recommended for surface pressure measurements wherever small size and low profiles are required or where surface mounting is more convenient than intrusive methods.

Table II
Partial Specification List
8515C Pressure Transducer

Parameter	Units	Model 8515C-15	Model 8515C-50
Pressure Range	psia	0-15	0-50
Full Scale Output, Typ. (min) with 10 Vdc input	mV	200 (130)	200 (130)
Compensated Range	°F (°C)	0° to 200° (-18 to +93)	0° to 200° (-18 to +93)
Operating Range	°F (°C)	-65° to 250° (-54 to +121)	-65° to 250° (-54 to +121)
Thermal Sensitivity Shift max (typ)	%	3 (1.2)	3 (1.2)
Thermal Zero Shift max (typ)	% FSO	2.5 (0.7)	2.5 (0.7)
Sensor Resonance	kHz	180	320
Nonlinearity max (typ)	% FSO	0.5 (0.2)	0.5 (0.2)
Pressure Limit	psia	75	250