

Pitot-Static Transducer

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Abstract

In many applications where weight and size are a primary concern, accurate measurement of airspeed is a requirement. To this end, Kulite has developed an ultra-small and lightweight pitot-static transducer. The unit includes a pitot-static tube for accurate measurement of both the total pressure and the static pressure as well as a resistive temperature device for a temperature measurement. These three measurements are required in order to calculate air-speed. This calculation may be performed either externally or within the unit itself, according to customer needs. The weight of the unit is below 90g and its total length is 5.5 inches. The low weight and small size of the transducer makes it ideal for the multitude of applications where size and weight considerations are paramount.

Introduction

The ability to determine air speed from the measurement of the static (barometric) air pressure and the pitot (total) air pressure, induced by the movement of a vehicle through air, has long been known from Bernoulli's theorem for total air pressure in an incompressible flow, such as through air below ~200 mph or any other incompressible fluid. Bernoulli states that the static pressure plus the dynamic pressure is equal to the total pressure¹:

$$P_s + \frac{1}{2} \rho v^2 = P_T, \quad (1)$$

where P_s is the static pressure, P_T is the total pressure, ρ is the density of the fluid, and v is the velocity of the fluid.

For an ideal incompressible gas we can use the relation for density:

$$\rho = \frac{P_s M}{RT}, \quad (2)$$

and obtain an equation for the velocity:

$$v = \sqrt{\frac{2RT}{M} \left(\frac{P_\Delta}{P_s} \right)}, \quad (3)$$

where P_Δ is the differential pressure (i.e. $P_\Delta = P_T - P_s$), M is the molecular mass, T is the temperature and R is the universal gas constant. P_Δ is known as the dynamic pressure.

At higher speeds Bernoulli's equation does not apply because the compressibility of air must be accounted for. In this case, a more complex equation must be used¹

$$v = \sqrt{\frac{2\gamma RT}{M(\gamma - 1)} \left[\left(\frac{P_\Delta + P_s}{P_s} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]}, \quad (4)$$

where γ is the ratio of the specific heat of the fluid at constant pressure to the specific heat of the fluid at constant volume and is approximately 1.4 for air. Equation 4 is valid so long as shock waves are not formed in the fluid, which occurs at air speeds approaching the velocity of sound. In either case, to obtain air speed v , one must accurately measure P_s , P_Δ and T and then perform the required computations. It is, of course, clear that the accurate determination of v requires very accurate measurements of the static pressure P_s and the differential pressure P_Δ .

The basic concept of obtaining air speed from pressure measurements is very old, and there are countless methods and structures for accomplishing the same. However, most previous structures are either too inaccurate, too large, too costly or too fragile and often all of the above. For example, a Pitot-static tube air speed indicator consists of two elements, where one is a dynamic tube which points upstream and determines the dynamic pressure and the other is a static tube which points normal to the air stream and determines a static pressure at the same point. These tubes are connected to two sides of a manometer or an inclined gauge such as to obtain a reading of velocity pressure, which is the algebraic difference between the total pressure and the static pressure. In any event, such tubes have been used in aerospace applications and can also be used as a liquid flow-measuring device, but because of their tendency to clog, cannot be used with liquids, which have suspended solid matter.

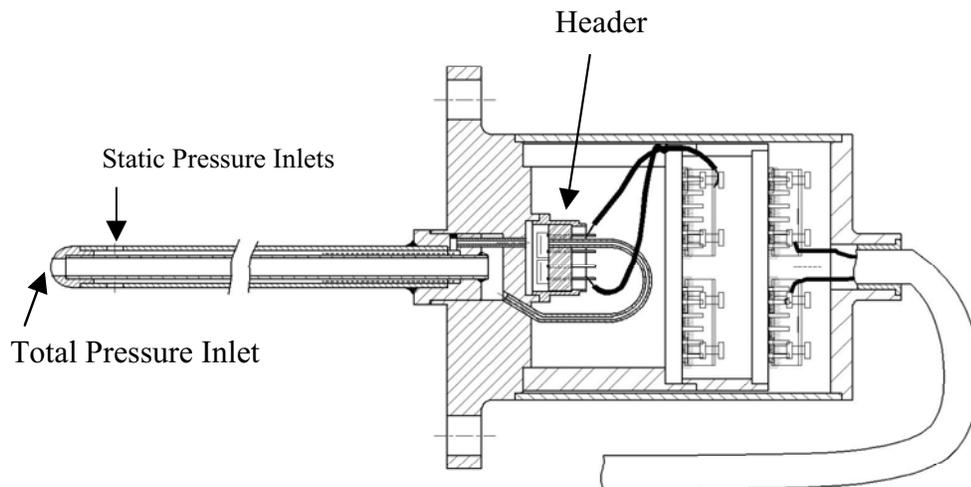
Kulite's new patented² pitot-static transducer is a smaller, cheaper, more rugged, highly accurate static pitot pressure transducer, which is also capable of accurately measuring air speed.

Device Description

This new device employs two uniquely designed dielectrically isolated leadless piezoresistive semiconductor sensors on a specially designed Pyrex glass. One of the sensors is designed to measure absolute pressure and, as such, has a sealed back cavity, while the other sensor is designed to measure differential pressure and has an aperture which permits the pressure media to reach both sides of the sensor. Each sensor is fabricated using Kulite's patented silicon-on-insulator sensor process^{3,4}. Kulite's process yields very small, robust, accurate micromachined sensors. Finite Element Analysis is used in the design of these sensors in order to optimize the output signal and its linearity. The header itself, which is shown in Fig. 1, has a through hole connected to a tube over which the differential sensor is affixed. By choosing Pyrex glass, which has a temperature coefficient of expansion similar to silicon, many temperature effects are eliminated. The header is attached to the back end of a pitot tube.

Figure 1. The header assembly with an absolute (bottom) and a differential (top) sensor. Note the wires coming through for electrical contacts and the reference tube for the pitot pressure on the differential sensor.

A pitot-static tube is a tube designed to capture the static and total (pitot) pressures from a fluid flow. The pitot-static tube itself is actually composed of two concentric tubes. The inner tube has an opening at the front in order to capture the total pressure. The outer tube is drilled with several holes on its side in order to capture the static pressure. The location of these holes as well as the dimensions of the tubes must be correctly designed in order to enable an accurate measurement of the static pressure. The header is then attached



such that the static pressure from the side of the tube is applied to the front of the header while the pitot pressure from the center of the tube is routed to the back of the differential sensor, as is shown in Figure 2. Also on the front of the transducer, a resistive temperature device (RTD) is affixed in order to measure ambient temperature.

Figure 2. Pitot-static transducer assembly drawing. Pressure from the side (static) is routed to front of header whereas pressure from the center (pitot) is routed to the reference tube.

With the static and differential pressures as well as the ambient temperature measured, the air speed can be calculated as described earlier. This can be done either within the unit itself or externally. Behind the header is a cavity in which electronics for calculating the airspeed can be placed. These electronics can consist of either an analog or

a digital method of computing the speed from the given measurements. In the analog method each of the pressure measurements is first digitally corrected and amplified for temperature changes using a dedicated digital correction microprocessor. While the correction is digital, all of the amplification is analog and so the analog path is kept intact. These compensation electronics ensure accurate pressure measurements across wide temperature ranges. The analog signals are then run through a series of analog multipliers and dividers in order to calculate speed. See the appendix for the exact details of these steps. The analog components are readily available from many sources. The final output of this device would then be a 0–5 Volt signal which would correspond to 0 to full speed.

The digital method for computing speed would involve a microprocessor that receives signals from analog to digital converters attached to the two diaphragms and the RTD. The microprocessor first compensates the pressure signals and then calculates the air-speed. The microprocessor could then either send this information out digitally or convert it back into an analog signal.

The final assembled pitot-static transducer is shown in Figure 3. The weight of the unit is below 90g and its total length is 5.5 inches including the tube itself.

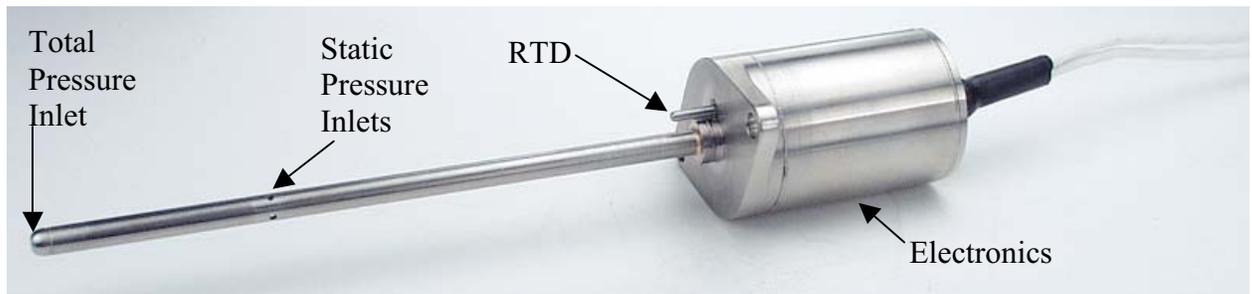


Figure 3. Pitot-static transducer

Measurements

Kulite measured the two sensors in the pitot-static transducer, the results of which are shown in Fig. 4 for the differential (dynamic pressure) sensor and Fig. 5 for the absolute (static pressure) sensor. The differential sensor exhibits a maximum non-linearity of 0.31% and a worst-case error of 1.8% over the temperature range (0-100°C). The absolute sensor exhibits a maximum non-linearity of 0.15% and a worst-case error of 0.2%. The absolute transducer error is much smaller than that of the differential transducer because the differential pressure to be measured is quite small so even small pressure differences appear as large errors. The speeds associated with the different measured

dynamic pressures at a static pressure of 16 PSIA is shown in Figure 6. It can be seen that all the temperature agree fairly well over the entire speed range.

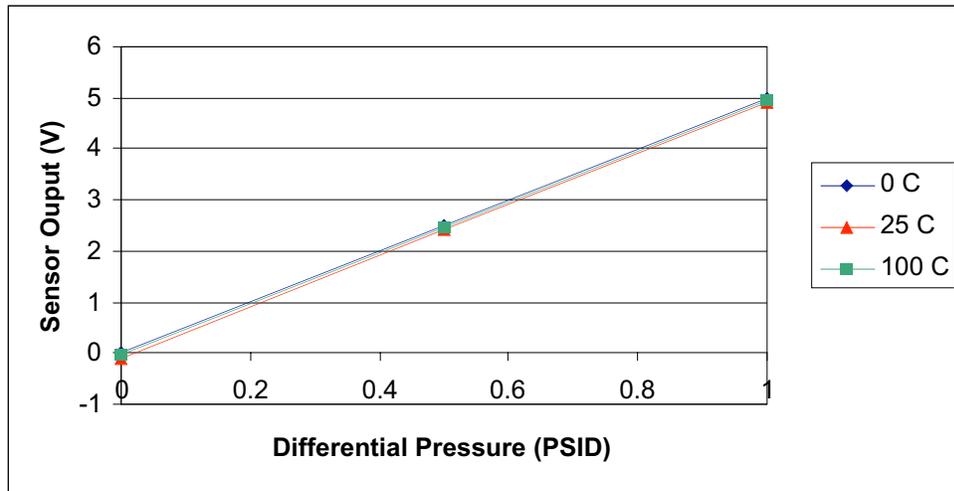


Figure 4. Differential Pressure Sensor Output

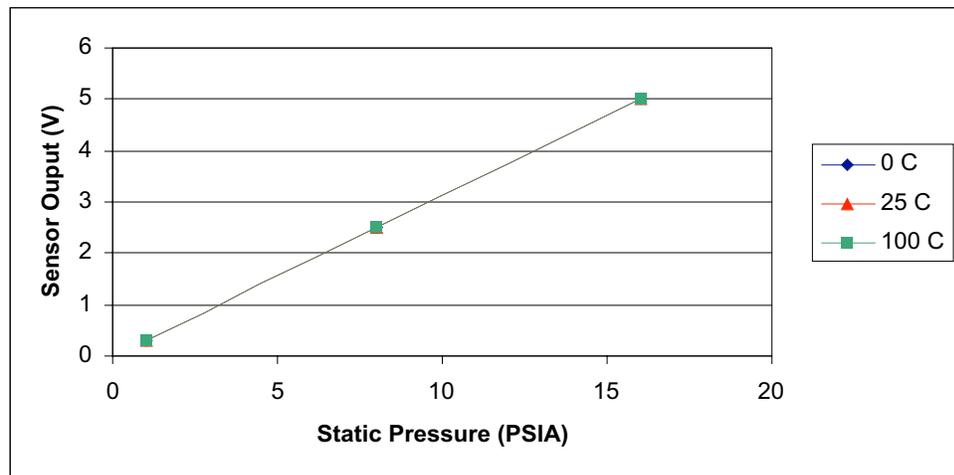


Figure 5. Static Pressure Sensor Output

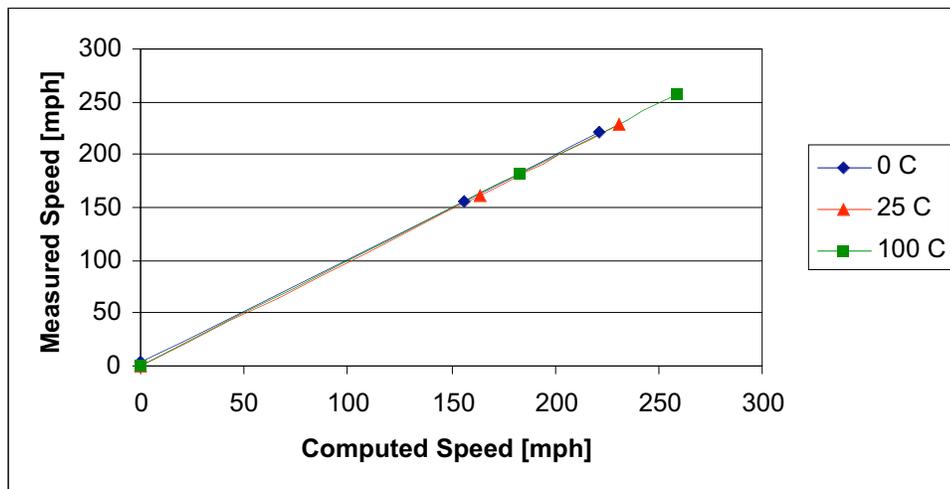


Figure 6. Error in Speeds Measured from Applied Pressures

Conclusion

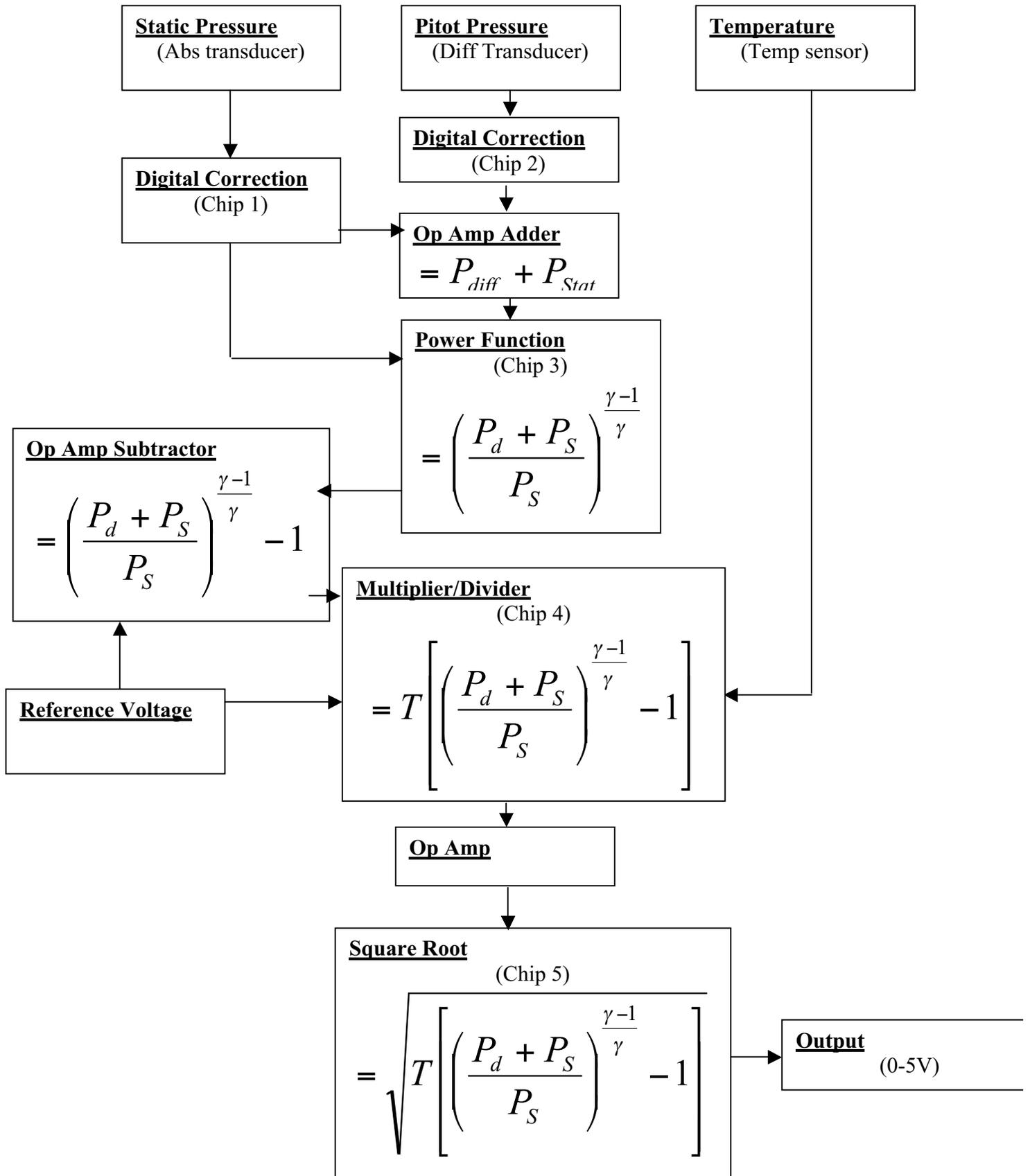
Kulite has developed a method of including an absolute and a differential pressure transducer, as well as a temperature sensor, in the space normally used for one pressure transducer. This allows Kulite to make a very small and rugged air speed measurement based on a pitot-static tube. The use of electronics to correct the sensors and compute airspeed allows for a very convenient way to measure air speed both for air and ground applications. Because of the pitot-static transducer is so light (<90 g) and so small (5.5 inches), it is ideal for use in the myriad applications for which weight and size are a primary concern.

Bibliography

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Appendix

Block Diagram of High Speed Circuit



Block Diagram of Low Air Speed Measurement

