HYPersonic Wind Tunnel Acoustic Pressure Sensors

Written By
Bob Metz PCB Piezotronics, Inc.
Hypersonic boundary-layer transition on re-entry vehicles and lifting bodies is not a well understood phenomenon. During the study of test models in a hypersonic wind tunnel, the presence of small pressure fluctuations can complicate the understanding of the boundary layer transition phenomenon. These small, acoustic pressure oscillations that occur in the transition region tend to create heating and skin friction. As a result, the heat buildup can more than double. Transition can also affect other boundary layer properties such as flow separation on nearby control surfaces. Therefore, boundary layer transition is important to structural and thermal protection system design engineers. Increased heat transfer requires a more robust thermal protection system. A better understanding of boundary-layer transition will allow design engineers to improve the design of thermal protection systems by reducing the weight of the vehicle, decreasing fuel burn and increasing the payload carrying capability for the mission.

Second-mode frequencies on experimental tunnel models have been estimated as high as several hundreds of kHz, therefore it is required that pressure sensors have a resonant frequency greater than 1,000 kHz. In addition to high frequency response, the pressure sensors must be able to detection miniscule pressure changes in a low pressure wind tunnel environment; often on the order of a few hundred Pascal. Absolute pressure transducers using strain gage and piezoresistive technologies have been frequency limited to the use of various screens in front of their diaphragms which protect the transducer sensing element from potential particulate impacts. However, per manufacturer specifications, such screens limit the frequency response of the transducer to nearly 25 kHz.

Hot wire airflow sensors have been employed as anemometers for more than forty years and measure airflow through heat transfer. As heating occurs during airflow in a boundary layer transition a corresponding increase in resistance of the wire restricts the current flow in the wire. An integrated electronic circuit in such a sensor converts the current change into a corresponding voltage output. But hot wire sensors have proven too fragile for the environment. The sensor is also affected by density and humidity and require compensation. They also lack the fast response time required for a second mode analysis.

A new acoustic pressure micro sensing technology is now available that has allowed research of the hypersonic boundary-layer transition. Over the past five years, piezoelectric micro sensor model 132B38 manufactured by PCB Piezotronics has been used in hypersonic wind tunnel experiments because the pressure sensing technology has a resonant frequency greater than 1 MHz and an acoustic pressure resolution of 7 Pascal. The sensor was originally design for use as a shock wave sensor for use in wave front time of arrival and target scoring of projectiles, with resolution fine enough to detect the bow and stern shock waves. The sensor features a small size of 0.125 inch (3 mm) diameter and 0.3 inch (7 mm) length so it is very easy to mount in small models typical of a hypersonic wind tunnel.
The piezoelectric micro sensor uses a very small pressure-sensing crystal that is less than 1 mm in diameter. The small size of the sensing element, and lack of mass in front of it in the form of a diaphragm, imparts extremely fast response time to the micro sensor. The charge generated from the piezoelectric element when subjected to shock pressure creates a voltage on the input capacitance at the gate of the Integrated Circuit Piezoelectric (ICP) amplifier. The ICP amplifier, in conjunction with the source element, transforms the input into a low-impedance output signal of equal amplitude. A DC bias voltage that exists on the signal lead wire is removed from the output signal by a coupling capacitor in the ICP power supply signal conditioner. Resistors in the internal ICP amplifier of the micro sensor set the internal discharge time constant, which determines the high pass characteristic (low-frequency response) of the micro sensor. In the case of the subject sensor model 132B38, the high pass frequency is 11 kHz.

The micro sensor allows for flush mounting on the model surface, and the incident rise time of mounted in this manner is less than 3 micro seconds. Alternatively, it can be mounted in a pitot configuration to monitor overall tunnel noise. In this configuration, the rise time is less than 0.5 micro seconds. Such response characteristics are possible from the close proximity of the ceramic sensing element to the shock wave. The sensor is not inhibited with a diaphragm or screen; rather the rigid crystal structure directly bears the surface loading during shock wave propagation.

This novel micro sensor offers another tool for investigating second mode shock wave frequencies in hypersonic wind tunnels. It is now possible to get a better understanding of how small pressure fluctuations affect the boundary layer transition region of a hypersonic wind tunnel model.

MTS Sensors, a division of MTS Systems Corporation (NASDAQ: MTSC), vastly expanded its range of products and solutions after MTS acquired PCB Piezotronics, Inc. in July, 2016. PCB Piezotronics, Inc. is a wholly owned subsidiary of MTS Systems Corporation; IMI Sensors and Larson Davis are divisions of PCB Piezotronics, Inc.; Accumetrics, Inc. and The Modal Shop, Inc. are subsidiaries of PCB Piezotronics, Inc.