Short Abstract

One of the most crucial requirements of a traditional thermal probe is its ability to accurately reproduce thermal quantities of interest such as transient surface temperature history and heat flux data when engaged in a transient environment. Some of the prominent fields where thermal sensors have been subjected to are Internal Combustion (IC) engine, heat exchanger, steam/gas turbines, shock tunnel/tube applications etc. As such, a thermal sensor is required to operate upon harsh conditions such as impact load in shock tube/tunnel for short duration, pulsating load in IC engines, continuous high temperature load in gas turbine applications etc. Moreover, upon inevitable structural failure, it is highly desirable to reproduce the probe with a minimum investment of paraphernalia cost. Lastly, it is vastly noble if the same cost-efficient and robust thermal probe can be shown to serve the dual purpose of accurate measurement of temperature data as well as the low/high frequency measurement.

Focussing on the need for advancement in high-speed measurement techniques and the requirement to bridge the gap listed in the above paragraph, an attempt has been made to develop an in-situ thermal sensor, which would serve the primary purpose of accurate measurement of heat transfer history as well as frequency measurement.

Considering the hypersonic flows, which are produced for short duration timescale in impulse facilities such as shock tunnels, free-piston shock tunnels and expansion tubes. The test times are in the order of few milliseconds in the shock tunnels and for expansion tubes, it is still less (in the range of 50 µs). The fundamental measurements in these facilities include the prediction of aerodynamic forces and surface heating rates for various generic aerodynamic configurations. During the force/heat transfer measurements in short duration facilities, the model never attains steady state due to very less test times available for experiments. In continuation, the measurement diagnostics must account for this fact while recovering the histories of an unknown force and surface heat transfer rates. Therefore, the fundamental experiments involve localized measurements of temperature histories for surface heating measurements. These sensors has to be mounted in flush on any generic aerodynamic models under study. In this backdrop, the thermal sensors such as coaxial surface junction thermocouples (CSJT) and thin film gauges (TFGs) are highly useful in recovering transient surface temperature. Subsequently, with appropriate heat conduction modelling, the convective surface heat loads on the aerodynamic surfaces can be predicted from the recorded temperature history.

Usually, the transient measurement of temperatures is performed by mounting the thermal sensors embedded on the surface of the heated material. The surface heat fluxes are then

estimated from the temperature history, analytically/numerically by various heat transfer modelling (such as one-dimensional/ two-dimensional/axisymmetric). Moreover, there certain practical situations in which it may not be feasible to keep the thermal sensors on the surface; rather they are mounted at some interior points inside the medium, where inverse heat transfer modelling helps one to estimate the temperature history at that particular location. The thermal sensors such as coaxial thermocouples are advantageous in the manner that it can be mounted in any harsh condition. The thermocouples design involves two dissimilar metals, which are joined together to form a junction and when exposed to a temperature gradient, a corresponding voltage is generated (Seebeck effect). The voltage difference generated can be measured and the corresponding temperature gradient is estimated with the help of the sensitivity of the sensor. The purpose of this thesis is to get greater insight into the fabrication of coaxial surface junction thermocouples, which includes modelling, its calibration, XRD analysis, real-time experimental exposure for supersonic and hypersonic speed, into the internal combustion engine and lastly into the gas turbine engine applications.

Greater efforts have been laid down to acquire good expertise in the fabrication of CSJTs and ultimately develop CSJT in the form of the product. The initial phase of research includes designing of the coaxial thermocouple, which caters carrying out simulation to validate the dimension of the sensor as well as the assumption of one-dimensional heat conduction for semi-infinite theory. Further, based on the simulation results, various sensors namely, E (chromel-constantan), K (chromel-alumel), T (copper-constantan) and J (iron-constantan) types are fabricated in the laboratory. In continuation, X-Ray Diffraction (XRD) analysis has been attempted to study the deformation characteristics of the surface junction.

Further, calibration study based on known temperature and known heat flux has been performed. The known temperature based calibration (static calibration) is carried out to determine the sensitivity of the individual thermocouple using the oil-bath experimental set-up as well as the alumina-based fluidized bath. Additionally, the known heat flux based calibration included the exposure of the fabricated sensor to a known wattage of the laser source, with an intention to determine gauge response in real-time experiments.

Furthermore, few calibration methodology has been undertaken to estimate the thermal product value, which is a property of the material and is a variable under highly transient measurement. The thermal sensor does not predict heat flux directly, it rather gives the voltage-time signal, which with further post-processing gives the heat flux. The heat flux equation (Duhamel Superposition Equation) includes the thermal product value. It is highly desirable to estimate thermal product value for individual thermocouple, as uncertainties up to 25% can be incorporated. Few of the experiments are executed using the Water droplet technique and Water plunging technique and, also using the shock tube based technology for the determination of thermal product.

The latter part of the study includes exposure of the thermal sensor to the real-time flow environments such as shock tube for studying the low supersonic environment heat flux estimation, shock tunnel for hypersonic flow based heat flux determination, internal combustion engine to study the heat flux phenomenon inside the combustion chamber and for the exhaust environment. Lastly, the study focuses on the detection of combustion instability (screech phenomenon) in the gas turbine engine, to check the capability of thermal sensor beyond heat transfer measurement along with the packaging assembly of the thermal sensor.