TO DEVELOP A COAXIAL THERMOCOUPLE SENSOR FOR TEMPERATURE MEASUREMENT IN SHOCK TUBE

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***Abstract*— The aim of this work is to fabricate a CSJTs'(co-axial surface junction thermocouple). The preliminary testing is to be performed to demonstrate the performance of the thermocouple for measuring the surface temperatures and heat transfer rates under transient conditions. The Shock tube available is of 80 mm internal diameter and is qualified for test up to 200 bars. Therefore, this paper describes the design, construction, and testing the performance of the co-axial sensor in a harsh environment (i.e. shock tube facility) with the objective of measuring the surface temperature.**

Keywords*— Co-axial Thermocouple, E-type Thermocouple, Burst Temperature, Heat Transfer Measurement.

I. INTRODUCTION

Ability to sense transient temperatures in an ultrashort duration is an essential of heat transfer investigations in hypersonic test facilities, as these are of impulse type where the test duration is of a few hundreds of microseconds. The ultrashort test duration is inevitable, as the total enthalpy of the hypersonic free stream in these facilities is so high that the thermal survival becomes infeasible otherwise. Platinum thin film sensors are employed to sense the transient temperatures on the surfaces of models in shock tubes and tunnels, because of their rapid response and suitability of positioning. Platinum sensors are the paint residues, and are prone to wear due to abrasion during a high-speed flow over them, necessitating frequent replacements during an investigation. The frequent replacement of the sensors is quite cumbersome and might seriously affect the accuracy/repeatability of the measurement. Fine-wire thermocouples are also used for similar short duration measurements, but their use is unsatisfactory in certain applications due to the lack of strength and difficulties in positioning. The coaxial surface junction thermocouples are the alternative sensors, which have been acclaimed to be accurate and reliable for short duration transient temperature measurements. The CSJT is chosen in this work to perform because it is easy to build and it has low cost. Therefore, this project describes the design, construction, and testing the performance of these sensors in a harsh environment (i.e. shock tube facility) with the objective of measuring the surface temperature history.

II. MATERIALS AND EXPERIMENTS

A constantan wire of 1.25 mm diameter is inserted coaxially into a machined Chromel cylinder of 3.25 mm diameter .The two thermocouple elements are electrically insulated from each other by a light coating of araldite. The thermocouple junction is formed by lightly abrading one end of this assembly with a miniature file, such that a small plastic deformation of the materials occurs, which covers the gap created by the insulator, forming a microscopic sensing junction at the surface of the assembly. A schematic of the thermocouple assembly is shown in Fig.3. The thermocouple junction created through this procedure has a depth of the order of 20–40 _m, and has a very low thermal inertia. The connecting leads are then soldered to each of the thermocouple wires for data acquisition, as shown in the schematic. The sensor has overall dimensions of 3.25 mm diameter and 15 mm length. The thermocouple was calibrated with one of its junctions in a variable temperature oil bath and the other in ice _0 °C, reference temperature_, for a range of temperatures that are typically experienced in the tunnel test section. The sensitivity of the thermocouple for the range of temperatures was found to be 43.9 _V°C, based on repeated trials.[1-6]

III. DESCRIPTION OF SHOCK TUBE

The shock tube is an instrument used to replicate and direct blast waves at a sensor or a model in order to simulate actual explosions and their effects, usually on a smaller scale. Shock tubes (and related impulse facilities such as shock tunnels expansion tubes, and expansion tunnels) can also be used to study aerodynamic flow under a wide range of temperatures and pressures that are difficult to obtain in other types of testing facilities. A shock wave inside a shock tube may be generated by a small explosion (blast-driven) or by the buildup of high pressures which cause diaphragm(s) to burst and a shock wave to propagate down the shock tube (compressed-gas driven).[7-9]

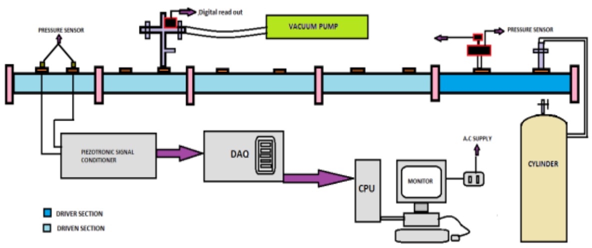


Fig 1: Block diagram of shock tube setup

IV. FACILITY OF SHOCK TUBE IN KARUNYA UNIVERSITY

Shock tube available at is of 80 mm internal diameter and is qualified for test up to 200 bars. The shock tube has a driver as well as a driven section. The driver section is pressurized with high pressure nitrogen, helium or air. The driven section is maintained vacuum with the help of a vacuum pump for the development plan, Shock Tube can be converted into Shock tunnel for simulating re-entry condition. The shock tube is shown in the fig.2

Fig2. Shock tube at Karunya University

IV. DESCRIPTION OF CSJT's Design And Fabrication

The fabrication of a small CSJT requires some precision work due to the small dimensions of the inner element coating and the wall thickness of the external tube. The basic steps in the fabrication process are as follows: preparation of the external element, preparation of the internal element, preparation of the sensing end of the assembly. The thermocouples are of the chromel /constantan elements (type-E). They consist of 1.25 mm wire of one element disposed symmetrically and coaxially into a hollow machined cylinder of the other element whose outside diameter is 3.25 mm. The two thermocouple elements are separated by a thin film of an electrical insulation with few micrometers thickness. The schematic diagram of the thermocouple assembly is shown in Fig. 1. The thermocouple junctions are formed by gently sanding the end surface of the thermocouple to be exposed to the flow using abrasive papers with different grit sizes. Although the thermocouple junction is formed through a direct mechanical contact between the two metals, (small scale plastic deformation of the thermocouple material at the surface), the thermocouples have shown to be quite robust (rise times less than 100 μs) in a harsh environment such as shock tube where the erosion of surface material creates new, low thermal inertia junctions during the process. The greater robustness of the thermocouple may be due to, in part, to the lower temperature attained by the thermocouple junction when exposed to the same flow.

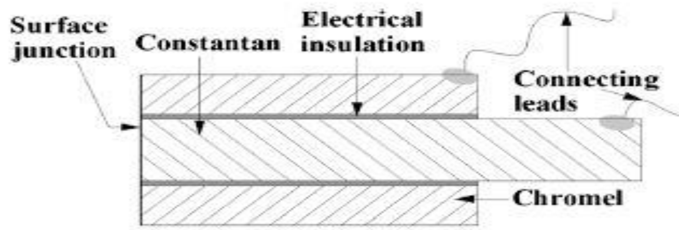


Fig 3: Layout of the Coaxial Thermocouple (Type E)

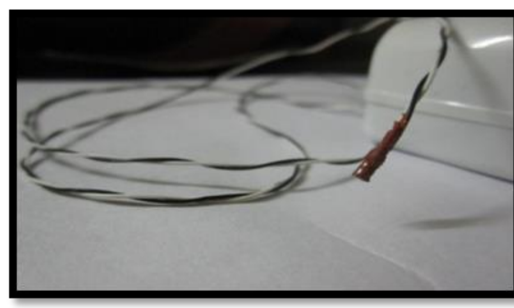


Fig 4. The Schematic Diagram of the thermocouple Assembly

A. Lead and electrical connections:

Standard Teflon wire (34 AWG) was welded at the ends of the thermocouple elements to serve as an extension wire. In fact, any kind of conductive wire can be used as an extension wire, according to the law of intermediate materials. A problem had occurred concerning the welding between the extension wire and the inner element. This problem was solved with the application of a resin right after the welding process, which strengthened its resistance.

B. Microstructural Analysis:

. A technique for microstructural analysis of the CSJT materials has been implemented in the present work to identify the surface morphology and to confirm the match of the thermocouple elements. A Philips XL-30 Scanning Electron Microscope (SEM) has been used for this purpose.

C. Chemical Characterisation:

An Energy Dispersive X-ray (EDX) detector for chemical characterization has been used in the current study to qualitatively identify the composition of each constituent of CSJTs' materials. The EDX point analysis has verified the presence of the chromel and the constantan composition over the entire surface of the coaxial thermocouples.

D. CSJT's Thermal Properties Selection:

Since one of the objectives of the current work is to accurately measure the time-varying surface heat flux using the CSJTs', the needs to precisely know the thermal properties of the substrate or more precisely the value of the thermal product (β) are necessary.

E. Specification of E-type Thermocouple

Model - E type
Material used - Chromel / constantan
Outer diameter of the sensing end - 2 mm
Range of the Thermocouple - (0 – 1720) K
Response Time of the thermocouple - 2 µs
O/P for per degree rise - 30 µvolts

Since the output of the sensor is very low for the temperature rise, we need to amplify it with a minimum gain of 1000.

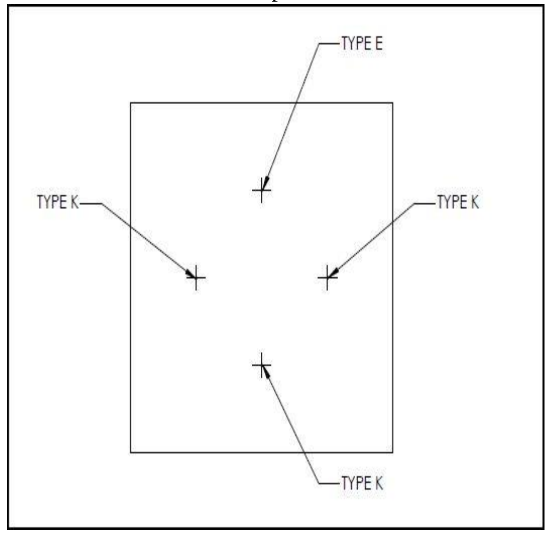
As we know that the output of the thermocouple will be a small signal so we need to amplify otherwise it will be more sensitive to errors. So the amplification and filtering of the circuits are done which is explained in the below heading.

F. Amplification and filtering electrical circuits:

The signal from a thermocouple is relatively small (0.798 mV) at 20 °C for a type E thermocouple. Because of this signal is so small, the thermocouples are sensitive to errors caused by noise. Thus, the noise on a thermocouple signal can be excluded by use either low pass filter to exclude the high frequencies, or a high-pass filter to exclude the low-frequency noise. A combination of these can be used to exclude together the low-and high frequency noises.

G. Calibration of Type-E thermocouple using Type-k thermocouple:

We calibrated the type E thermocouple by using 3 pre Calibrated type K thermocouple as shown in the fig . We connected all the Thermocouples to the data logger. Using IR lamp as the heat source and varying the voltage with the help of dimmer ,the Data logger plotted the graph as shown in fig 5 and the 27 samples are recorded at a sampling rate of 30 seconds. The recorded samples are shown in the table 1.



Specifications of the Data Acquisition:

Make - Agilent technologies
Model - 34972 LXI Data Acquisition
Description - Data Logger
No. of Inputs can be given - 17
LAN - 1GBit
USB connectivity - 2.0
LXI Data Acquisition - 3 slots
6.5 digits DMM (22 bit)
8 plug-in module

Ch.	CH022	CH023	CH024	CH025
msec	°C	°C	°C	°C
0.0	25.8	25.8	25.5	25.5
0.0	25.6	25.6	25.5	25.6
0.0	25.5	25.4	25.3	25.4
0.0	25.3	25.4	25.3	25.4
0.0	25.6	26.0	25.8	25.6
0.0	26.1	25.9	26.3	26.6
0.0	27.1	26.6	26.8	27.1
0.0	28.3	28.1	28.1	28.3
0.0	30.6	30.6	30.6	30.6
0.0	33.3	32.6	32.9	33.3
0.0	36.3	35.4	35.7	36.4
0.0	39.7	38.8	38.8	39.7
0.0	43.4	42.5	42.4	43.7
0.0	47.2	46.3	46.3	47.8
0.0	51.2	50.2	50.0	51.8
0.0	55.2	54.2	53.4	55.8
0.0	59.4	58.3	57.4	60.0
0.0	62.8	62.1	61.2	64.5
0.0	67.0	66.0	65.1	68.4
0.0	72.1	70.8	70.3	73.8
0.0	78.3	76.4	76.4	80.5
0.0	85.9	83.1	82.7	87.5
0.0	95.9	90.8	93.8	96.5
0.0	99.3	97.6	96.9	100.0
0.0	103.1	104.6	99.7	107.8
0.0	109.1	110.8	103.3	112.1
0.0	109.7	118.7	107.1	120.3

Table:1 The above table show the reading taken from the graph from fig 5.

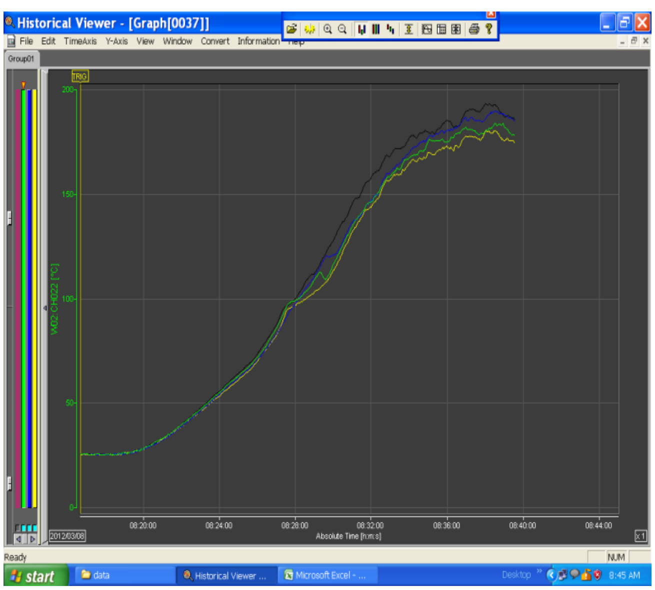


Fig5: shows the graph between Temperature Vs Time in IR lamp Warm up curve

V. CONCLUSION RESULTS AND DISCUSSION

A total of ten test runs were carried out using the new CSJT sensors in shock tube facility to demonstrate the performance of these sensors. The transient surface temperature was measured to deduce the heat transfer rate within the shock tube wall. The test conditions were based on measurements of the initial shock tube fill pressure and temperature. The remaining test section parameters, included the incident shock speed prior to reflection, reflected shock wave speed, the temperature and pressure of the reflected shock wave, are determined directly from the measured quantities using the ideal gas dynamics equations .The pressure transducers were used to measure the shock wave speed and to determine the precise time of the shock wave passed over the CSJT. Experiments indicate that the theoretical computed shock strengths are higher than those actually attained. Initially, the diaphragm burst delays the formation of a one-dimensional shock wave. Then, as the shockwave moves down the tube, it decreases due to boundary layer growth. Therefore, the shock speed must be measured to evaluate the actual shock strength. Shock speeds can be determined by finding the lapsed time of the wave as it passes two points.

VI. CONCLUSION

In this research work, we have developed a design and construction technique of hand-made, inexpensive, reliable, and rugged CSJTs' was described in this paper. It has been proved that these types of CSJTs' are suitable for using in transient facilities. The conclusions from this investigation, as discussed, are summarized as follows:

1. The construction technique produced CSJT's with the desired characteristics. By closely following the construction technique, an experienced investigator can produce a reliable, rugged, low cost, hand-made CSJT as required.
2. The preliminary shock tube tests have proved that the hand-made CSJTs' can be used to accurately measure the surface temperature and heat transfer rates in transient facilities.
3. The presented results have shown a relative success of the use of CSJTs' as transient surface temperature sensors with microsecond time response.

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