Thermal Conductance of Metallic Interface in Vacuum

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Introduction

In most heat transfer applications, the deposited heat is transferred by any of the following classical methods: conduction, convection, radiation, or any combinations of these three. Depending on how critical the nature is of the designed equipment, the response time must be short enough in order to safeguard the proper performance of the devices. For instance, currently at the National Synchrotron Light Source (NSLS), various hardware equipment are being designed to intercept or to stay intense radiation beams induced by insertion devices such as wigglers and undulators. Due to the nature of some of these designs, the deposited high flux thermal load must be transferred across unbound contact surfaces. Since any miscalculation would result in the disintegration of exposed material and therefore cause substantial problems, a true actual conductance measurement of the material in question is highly desirable. In the following three sections, background summary, the method of measurement, and the obtained results are discussed.

Background Summary

There are numerous data and mathematical methods available in the literature for obtaining heat resistance across interface in air. However, little information can be found for the case of vacuum environment and specifically for odd materials.

The thermal conductance between materials is defined by Eq. (1) and takes place as a result of conduction across real contact points (which generally are a small fraction of total area), conduction through entrapped fluid (if any), and radiation through interstitial gap.

\[
h_c = h_s + h_f + h_r = 1/R_c = q/A\Delta T \tag{1}
\]

where \(h_s\), \(h_f\), \(h_r\) are total conductance, conductance through solid points in contact, conductance through fluid, and radiation conductance respectively; \(R_c\) is the total thermal contact resistance, \(q\) is the heat flow rate, \(A\) is the total contact area perpendicular to the direction of heat flow and \(\Delta T\) the temperature drop across interface.

An expression for total heat conductance across parallel surfaces for pressure of \(\leq 1 \mu\text{Torr}\) is given by and is defined by Eq. (2):

\[
h_c = k_{s}/m/k_s + [(\gamma+1)/(\gamma-1)][R_0/8\gamma]^{1/2} p_a/(MT)^{1/2} + \alpha_{L-2}[T_1^4 - T_2^4] \tag{2}
\]

Method of Measurement

In designing this experimental setup, a few important criteria were kept in mind: 1) Obtaining a high vacuum which will cause sufficient resistance to heat flow, 2) Establishing a positive uniform force on the interface, 3) Maintaining a well controlled and stable thermal load source and, 4) Employing fast response time instrumentation for transferring and recording generated data.

The apparatus which is used in this experiment is shown in Fig. 1. The vacuum is achieved with the aid of a turbo-molecular pump, and the thermal heat is supplied to the interface blocks by a D.C. power supply when a vacuum of \(10^{-6}\) Torr or better is attained. To counter-balance the unwanted vacuum force on the bellows, some appropriate size compression springs are adapted. The contact pressure is applied by use of belleville spring washers stacked in such a way that the resulting compressed force is added up in a serial manner.
Various manufacturers provide a variety of mathematical as well as empirical methods on how to obtain load/deflection curve; however, in order to minimize the error, the curve for use in this study is produced by a universal tension/compression machine for a stack of 30 springs. It should also be noted that the use of a heat pipe system acts as a means of transferring heat from interface block to the condenser side, the later of which is eventually cooled by house water.

An IBM PC microcomputer, equipped with a multichannel temperature data acquisition system, is utilized in this test. Fast time response thermocouples take the sample temperature signal from inside to the outside of the vacuum chamber through the feedthroughs. An OMEGA thermocouple linearizer and a preamplifier provide a preprocess and cold junction compensation before the analog signal is converted to digital by ADC board. The steady state of the thermal interface is found by a temperature data acquisition software, based on real time assemble language subroutines, after each subsequent change of contact pressure.

**Results**

Figures 2 through 3 illustrate the results of thermal conductance as a function of contact pressure for copper, beryllium copper, and a combination of the two with platinum/indium pieces inserted between the interface. The conductance rate depends considerably on the surface conditions (12 μ inches for this experiment), the material properties, and the uniform contact pressure.

The design of a pinhole assembly for X1 beam line at the NSLS consists of beryllium copper as the thermal absorber and cooling blocks, and a thin platinum shim (100 μ thick) as pinhole piece. The results in Fig. 3 show that the conductance rate steadily increases with an increase in contact pressure, but the rate is smaller when compared with copper alone. This difference is due to lower thermal conductivity and also to a greater hardness of beryllium copper. The insertion of a platinum pinhole piece has increased the rate of conductance by 30%, to almost that of copper. As the hardness of the insertion piece decreases, as shown in the case of indium shim (Figs. 2 and 3), the conductance increases considerably.

**References**