A stress-free sample holder for low-temperature studies

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Also the velocity-induced skewness \( S = \frac{T_m^3}{T_m^2} \) can be calculated as
\[
S = \frac{3}{2\sqrt{2}} \frac{M\omega}{1 + M^2\omega^2} \leq \frac{3}{4\sqrt{2}} a
\] (10)
where the bar denotes a time average.

From (9) it may be seen that the measured temperature \( T_m \) recovers the ambient temperature \( T_a = \cos \omega t \) but in addition contains a second harmonic with amplitude
\[
a \frac{M\omega}{2(1 + \omega^2 M^2)^{1/2}} \leq \frac{a}{2}
\]
and a velocity-induced mean temperature change
\[
a \frac{M\omega}{2(1 + \omega^2 M^2)^{1/2}} \leq \frac{a}{4}
\]

The second harmonic can exceed 5% of the fundamental if \( a > 0.1 \), corresponding to velocity fluctuations larger than 20%. This is less serious than the corresponding generation of a second harmonic in a frequency-compensated constant-current anemometer by large velocity fluctuations. Furthermore, while the constant-current anemometer contains algebraic nonlinearities, the thin-wire resistance thermometer is, within the framework of this simple theory (equation (1)), inherently linear.

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A stress-free sample holder for low-temperature studies

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Abstract We describe a simple sample holder for low-temperature experiments which was constructed to reduce stresses placed on samples by thermal cycling.

1 Introduction
It is known that stresses affect the transport properties of metals (e.g. Bass 1972). In particular, stresses arising from thermal cycling of a sample which is clamped to a holder made from a material having a thermal expansion coefficient different from that of the sample can influence significantly the sample properties to be measured.

The sample holder described in this note was used in a study of the flux flow resistance in type II (lead alloy) superconductors (Thompson 1975, Habbal 1978). Because these samples were very thin, \( 10^{-4} \) m or less, the differential contraction between these samples and an ‘uncompensated’ sample support manifested itself in a slight bowing of the sample due to the larger coefficient of thermal expansion (CTE) of the holder relative to that of the sample. Thermal cycling of samples mounted this way produced a considerable amount of plastic deformation that was revealed in the voltage-current \((V-I)\) characteristic curves of the samples. These effects became negligible when the sample holder described below was used.

2 The sample holder
Figure 1 shows the sample holder. The sample support SS was made from a cryogenically compatible resin rod (Hysol

Figure 1 Drawing of the sample holder. A, holes through which voltage and current leads pass; B, current contacts; C, movable voltage probes; S, sample; R, quartz rods to which the sample support SS is clamped.

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Corpor. Olean, New York) machined in the shape of half a right-circular cylinder which was then cut in two along its mid-plane. Two holes were drilled along the axis of the two pieces of the support. These pieces were held together by clamping each section to quartz rods R inserted in the longitudinal holes. Clamping points (not shown in figure 1) consisted of an array of holes tapped through the bottom of the sample support such that they extended perpendicularly into the longitudinal holes for the quartz rods. Clamping was achieved by tightening small brass screws, placed in selected tapped holes, against the quartz rods.

Quartz rods were chosen because of their lower CTE relative to the sample or the resin rod. By adjusting the point of clamping along the quartz rods, the combined thermal expansion of an appropriate portion of these rods and that fraction of the resin rod between the clamping point and the end of the rod could be made to match the thermal expansion of the sample. This point can be understood simply by considering the following. We assume that each end of the sample (length \( l \) at room temperature) is attached rigidly to the ends of the sample holder. If \( \alpha_s(T) \) is the temperature-dependent CTE of the sample, then the sample will contract upon cooling, by an amount \( \int_{LT}^{RT} \alpha_s(T) \, dT \) where \( LT \) denotes the low-temperature and \( RT \) the room-temperature limit. For there to be no differential contraction between the sample and the holder, the contraction of the sample must match the combined contraction of the quartz rods between clamping points, \( \int_{LT}^{RT} \alpha_s(T) \, dT \), and that portion of the resin sample holder between the ends of the holder and the clamping points, \((l-r) \int_{LT}^{RT} \alpha_s(T) \, dT \). That is

\[
\int_{LT}^{RT} \alpha_s(T) \, dT = r \int_{LT}^{RT} \alpha_s(T) \, dT + (l-r) \int_{LT}^{RT} \alpha_s(T) \, dT.
\]

To determine the distance between clamping points on the quartz rods, we have

\[
r = \frac{l \int_{LT}^{RT} \alpha_s(T) \, dT - \alpha_s(LT) (l-r)}{\int_{LT}^{RT} \alpha_s(T) \, dT - \alpha_s(LT)}
\]

Provided that the temperature dependences of the CTEs are known, equation (1) can be used to calculate exactly the location of the clamping points. However, in the absence of this information, we can assume to a first approximation that the total contraction upon cooling to liquid helium temperatures is proportional to the room-temperature CTE (Rose-Innes 1973). This assumption is certainly valid for many metals and alloys with the proportionality constant being about 190 (Clark 1968). If we further assume that the proportionality constant is the same for all three components, equation (1) reduces simply to

\[
r \approx l(\alpha_s - \alpha_s(LT))/(\alpha_s - \alpha_s(LT)).
\]

In practice we have found that these assumptions are justified. Assuming typical room-temperature values for \( \alpha_s \) around \( 2.9 \times 10^{-6} \, K^{-1} \), \( \alpha_s \approx 6.8 \times 10^{-6} \, K^{-1} \) and \( \alpha_s \approx 7 \times 10^{-6} \, K^{-1} \) (Jensen et al 1962), we find that \( r \approx 0.6 \) for there to be no net stress placed on the sample. Because of the different temperature dependences of the various CTEs and different thermal masses of the constituent materials it is probable that some minimal stress will be present in the sample during cool-down. We have attempted only to account approximately for the integrated thermal contraction between ambient and operating temperatures.

We cycled samples mounted in this ‘compensated’ sample support several times between room and liquid helium temperatures and found no apparent bowing or changes in their \( V-I \) characteristics. We therefore conclude that this sample holder can reduce considerably stresses resulting from thermal cycling.

For our resistivity measurements, the clamps B which hold the sample to the support were made of copper and were used to supply the current to the sample. The voltage signal was detected by two copper probes C which were narrow pins conically shaped in the region of contact with the surface of the sample. The voltage probes were mounted in a track cut along the sample support. These probes could be moved along the foil but held firmly in contact with the sample by a leaf-spring mechanism. The ability to vary the position of the voltage probes permits testing for the existence of any material inhomogeneities.

3 Conclusions

Whereas this sample holder was used successfully for resistivity measurements, the utility of its design could be applied to other low-temperature experiments in which the temperature of the sample is varied and minimum stresses are desired. In addition, the holder could be modified easily to accommodate other than rectangular sample geometries.

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