Application of double modulation for measurement of the thermal expansion coefficient of liquid metals

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Abstract. The first results of the thermal expansion coefficient measurement obtained for liquid conductors using a new modulation method are presented. The method is based on a superposition of two periodical influences on a liquid metal. The thermal expansion coefficient \( \alpha_p \) is determined by means of measuring the amplitudes of oscillations of electric current power \( \sim w \) and pressure \( \sim p \). In the present work the K-Na alloy of the eutectic composition was used as a sample. Distinction of the experimental data obtained by authors from the literature data is 30 to 40%. Such a difference is in the range of error of determination of \( \alpha_p \) from the density data of K-Na alloy. The method allows direct determination of the thermal expansion coefficient of liquid conductors in absolute units.

1. Introduction

Investigation of the phase transition in liquid cesium [1] stimulated creation a new method of measurement of the thermal expansion coefficient of conducting liquids. The method based on the double modulation was suggested in 1994 [2]. A liquid conducting sample is subjected to influence of the periodic change of pressure at a frequency \( \omega \) and simultaneously to the influence of the periodic electric current at the same frequency. The temperature response of the sample to the periodic change of pressure at a frequency \( \omega \) according to Thomson’s formula is:

\[
\theta_1 = \frac{T \alpha_p}{c_p d} \sim p \ g_1 ,
\]

where \( \theta_1 \) is the amplitude of the temperature oscillation, \( \alpha_p \) is the thermal expansion coefficient, \( \sim p \) is the amplitude of the pressure oscillation, \( c_p \) is the specific heat capacity, \( d \) is density, \( g_1 \) is a correction factor taking into account the imperfect adiabatic condition. If the sample is subjected to the influence of the periodic electric current at the same frequency, the temperature response will be

\[
\theta_2 = \frac{\sim w}{c_p V \omega} g_2 .
\]

Here \( \sim w \) is the amplitude of the Joule heating power, \( V \) is the volume of the sample, \( g_2 \) is the correction factor. The amplitudes \( \sim p \) and \( \sim w \) can be chosen in such a way that \( \theta_1 \) will be equal to \( \theta_2 \). In this case we obtain from (1) and (2):

\[
\frac{T \alpha_p}{c_p d} \sim p \ g_1 = \frac{\sim w}{c_p V \omega} g_2 .
\]

One can suggest that \( g_2 \approx g_1 \), because both the influences can be considered as volume sources of periodic heating. Consequently, (3) can be rewritten
It is necessary to select a phase shift between the pressure oscillation and the Joule heat oscillations in such a way that the temperature oscillations of the medium at the frequency \( \omega \) will completely suppressed, i.e. the suitable temperature responses are equal in value and opposite in sign.

Recently the double modulation was used for studying of thermal expansion of a dielectric liquid sample [3]. In the present work we study the eutectic K-Na alloy. The corresponding set-up is briefly described below.

2. Experimental procedure and results

Fig. 1 shows a block-scheme of a set-up for measuring the thermal expansion coefficient of liquid metals. The set-up consists of two cells filled with the liquid under consideration (1-liquid metal) and the standard liquid (2-isooctane), the generator of the periodic component of pressure, a unit forming the modulation signal and measuring unit, which includes nanovoltmeter for registration of the sample temperature oscillation. The cell for the liquid metal is manufactured of a dielectric material. Castor oil with a fairly high viscosity is used as a working liquid in the generator of the pressure periodic component (5). The periodic pressure variations are transmitted by bellows to the investigated liquids (3, 4). The unit forming the modulation signal includes a device generating the timing pulses at a frequency of 110 Hz (6). These timing pulses stimulate generation of the sinusoidal signal at a frequency of 2.4 Hz in the computer (in a digital form). A digital-to-analog converter and an amplifier generate a periodic voltage of the power necessary for appearance of the noticeable temperature oscillations of the conducting sample. The temperature oscillations of a liquid sample are registered by a thermocouple, which is placed inside a stainless steel sheath and isolated from the sheath with \( Al_2O_3 \) powder. A diameter of the sheath is less than 1 mm. The set-up for measurement of the thermal expansion coefficient of liquid metals includes a calibrated pressure sensor (“Mediamate-1000”). The calibration of the sensor was performed using a weight-piston manometer. The analogue multiplier receiving both two signals measures electric power dissipated in the sample. The first signal is proportional to electric current in the sample and another one to the voltage on the measuring cell.

The output signal of the multiplier is proportional to power dissipated in the sample. This signal comes to a circuit of degenerative feedback; therefore the alternative component of the power repeats the form of the input signal. For the multiplier calibration a standard resistor was switched on instead of the sample.

Nanovoltmeter (“Unipan-233b” or “Unipan-237”) measures the sample temperature oscillations. It can be used as a balance indicator too. The operating temperature of the sample is measured by
microvoltmeter. Switch 7 in Figure 1 connects the thermocouple either with the nanovoltmeter or with the microvoltmeter.

The theory of the method is valid for harmonic pressure oscillations only. Unfortunately, in our set-up these oscillations are not exactly harmonic (Figure 2). So it is necessary to use an artificial (ersatz) technique for temperature signals compensation. We plotted two amplitude characteristics: one of them was a dependence of a temperature response of the thermocouple on pressure oscillation amplitude; the second was a dependence of a temperature response of the thermocouple on electric current power oscillation amplitude. These characteristics enable to find the pressure amplitude and the power amplitude corresponding to identical temperature amplitudes. Afterwards, using the found values of $p_\text{w}$ and $w_\text{w}$, the thermal expansion coefficient $\alpha_p$ was calculated according to (4). Taking into account that the pressure oscillations are inharmonious we extracted the first Fourier-component of the pressure sensor signal. The power oscillations formed by the computer are quasi-harmonic. Nevertheless, the first Fourier-component was extracted from the power signal too. The temperature oscillations were also subjected to Fourier analysis.

![Figure 2. Form of the pressure oscillations.](image)

We have measured $\alpha_p$ of the eutectic K-Na melt. Experimental results are shown in Fig. 3. Their deviation from a literature data is near 30 to 40%. Such a difference is in frames of accuracy of $\alpha_p$ determination from density data recommended for K-Na eutectics in [4].

Accuracy of our measurement can be improved when using a pressure generator with harmonic pressure oscillations and automatic compensation of the temperature response of a sample.
The method allows the direct determination of the thermal expansion coefficient of liquid conductors in absolute units. One of its advantages is an opportunity of measurement of a local thermal expansion coefficient (because the amplitude of the temperature oscillations is about 0.1 K), instead of the average value of $\alpha_p$ corresponding to some temperature interval. This is especially important at $\alpha_p$ measurements near a phase transition point where its value changes sharply.

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