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APPARENT STRAIN AND SELF-TEMPERATURE COMPENSATED STRAIN GAGES

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The paper deals with the problem of strain gage response under the occurrence of temperature changes. Procedures of apparent strain corrections are briefly discussed. Results of experiments carried out are presented.

1. Introduction

Thermally induced apparent strain is potentially one of the more significant sources of error and uncertainty in stress analysis work. This situation arises because the origins of apparent strain are unrelated in any way to the magnitude of the actual strain being measured. These deviations from ideal behaviour can be important under certain circumstances (e.g. for transducer construction), and can cause significant errors in the case of static strain measurements if not properly accounted for. In the case of purely dynamic strain measurements, temperature-induced apparent strain may be of no consequence.

The apparent strain should not be confused with thermal drift, which is a non-reversible process, but which is also superimposed on the temperature response.

2. Apparent Strain and its Compensation

When temperature variations occur after a gage has been attached to the object under test, the resulting measurements also show variations. Three factors contribute to this state:

1. the coefficient of thermal expansion α_S of the material under test,
2. the coefficient of thermal expansion α_G of the grid material,
3. the resistive temperature coefficient β_G of the grid material.

The net temperature-induced apparent strain can be expressed as the sum of the resistivity and differential expansion effects:

$$\varepsilon_{app} = \left[\left(\alpha_S - \alpha_G\right) + \frac{\beta_G}{k}\right].\Delta T = \left(\frac{\beta_G}{k} - \alpha_G\right).\Delta T + \alpha_S.\Delta T \qquad (1)$$

where k ... gage factor
ΔT ... temperature change.

It is necessary to keep in mind that - generally - all of the coefficients within the brackets are themselves functions of temperature. Apparent strain exhibited with temperature change depends not only upon the nature of strain gage, but also upon the material to which the gage is bonded. Apparent strain data are then meaningful only when referred to a particular gage (grid alloy) bonded to a specified substrate material.

The error due to apparent strain can be extremely large as temperature deviates from the arbitrary reference temperature (usually, room temperature).

In general only three methods exist to eliminate apparent strain from the indicated strain:

The simplest method is to ensure that the temperature of the strain gage and test specimen does not change once the strain indicator has been zeroed. If the temperature remains unchanged, any output due to temperature change or free thermal expansion is not possible.

The second method utilizes compensating gage which is mounted on an unstrained specimen made from the identical material as the test part and subjected to the same temperature as the active gage. The leadwires to the active and compensating gage must be of the same length and must be subjected to the same temperature change. The compensating gage can often be bonded on the test specimen itself so as to provide two active gages which undergo the same temperature variations while the sensing strains are opposite in sign and of known ratio.

The third method is based on application of strain gages made of specially processed alloys - self-temperature-compensated gages. The purpose of self-temperature-compensation is to minimize both the effect of temperature change and free thermal expansion on the output of gages. This can be achieved by adding corrective alloying ingredients to the material of the grid and also by heat treatment. For example, the strain gages produced by HBM are self-compensated for ferritic steel ($\alpha = 10{,}8.10^{-6}/K$), aluminium ($23.10^{-6}/K$) and plastic ($65.10^{-6}/K$), and on request for austenitic steel ($16.10^{-6}/K$), titanium ($9.10^{-6}/K$), molybdenium ($5{,}4.10^{-6}/K$) and quartz ($0{,}5.10^{-6}/K$). In general, the closer the match between the self temperature compensation number and the coefficient of linear thermal expansion, the smaller will be the apparent strain that is produced when a temperature change occurs after the instrument has been zero-balanced.

3. Correction for Apparent Strain

Correction for apparent strain can be accomplished easily using the technical data given in each package of self-temperature-compensated strain gages. Let us assume, that the strain indicator was balanced for zero strain at temperature T_0 and the test was performed at the temperature T_t. The strain indication corrected for apparent strain (but not for gage factor variation) is then

$$\varepsilon_{cor}^{a} = \varepsilon_{ind} - \varepsilon_{app} \tag{2}$$

where ε_{ind} is uncorrected strain registered by indicator.
The apparent ε_{app} strain is then

$$\varepsilon_{capp} = \left[\left(\varepsilon_{app} \right)_{Tt} - \left(\varepsilon_{app} \right)_{To} \right] \tag{3}$$

where $(\varepsilon_{app})_{To}$, $(\varepsilon_{app})_{Tt}$ are apparent strains from the package technical data sheet at the temperatures T_0 and T_t.

A further improvement in the accuracy of the apparent strain correction can be obtained by accounting for the fact that the test-temperature gage factor k_T is slightly different from the room-temperature value k ; usually the gage factor tends to change (increase or decrease) linearly with temperature :

$$\frac{k_T}{k} = \frac{1 + \Delta k}{k} = 1 + \frac{\Delta k}{k} = 1 + \alpha_k . \Delta T \tag{4}$$

In the data sheet there is given either percent variation in the gage factor $\Delta k/k$ or temperature coefficient of gage factor α_k . The value of α_k is about 100.10^{-6} /K; then for $\Delta T = 100$ °C is $k_T = 1,01\, k$.

Thus the correction for the gage factor variation with temperature is

$$\varepsilon_{cor} = \varepsilon_{cor}^{a} \cdot \frac{k_{ins}}{k_T} \tag{5}$$

where k_{ins} is strain indicator gage factor setting,

$$k_T = k\left(1 + \alpha_k . \Delta T\right)$$

Combining the two corrections

$$\varepsilon_{cor} = \left(\varepsilon_{ind} - \varepsilon_{app}\right) . \frac{k_{ins}}{k_T} \tag{6}$$

When a strain gage is applied on a material other than that used in obtaining the manufacturer's apparent strain data, self-temperature-compensation mismatch occurs. If the difference in thermal expansion coefficients between the apparent strain calibration material and the material to which the gage is bonded is great, the published apparent strain curve cannot be used directly. Let us consider strain gage calibrated for apparent strain $\varepsilon_{app,1}$ on material with a constant expansion coefficient $\alpha_{S,1}$. To find the approximate apparent strain characteristics $\varepsilon_{app,2}$ for gage bonded on the material with a constant expansion coefficient $\alpha_{S,2}$ Eq. (1) can be used:

$$\varepsilon_{app,1} - \alpha_{S,1} . \Delta T = \varepsilon_{app,2} - \alpha_{S,2} . \Delta T$$

and then

$$\varepsilon_{app,2} = \varepsilon_{app,1} + \left[\left(\alpha_{S,2} - \alpha_{S,1}\right) . \Delta T\right] \tag{7}$$

Matching of self-temperature compensated strain gages to the component material's thermal expansion is optimum for flat mounting surfaces; deviations occur with curved surfaces of small radius - see [1], [2] .

Temperature compensating strain gages cannot be produced for inhomogeneous materials like e.g. fiber reinforced synthetics.

4. Laboratory tests

The following laboratory test (which was inspired by [3]) is one from the laboratory exercises arranged in the course of Experimental Mechanics for students from specialization Applied Mechanics. The aim of this exercise is to create opinion about response of strain gages due to the changes of ambient temperature, to define the term apparent strain, to obtain quantitative idea about the values of apparent strains, to be informed about the necessity of their compensations or corrections, and to be familiar with compensation and correction methods for apparent strain.

The test samples (in the form of plates with dimensions 40 x 60 x 4 mm) were made of three different materials - steel, aluminium and PVC (novodur). Their coefficients of thermal expansion were determined by means of dilatometer DI-20 ADAMEL; the results are as follows: for steel (in the interval 20-100 ^{0}C) $12,62.10^{-6}\,/K$, for aluminium (in the interval 20-100 ^{0}C) $23,88.10^{-6}\,/K$, for PVC (in the interval 20-60 ^{0}C) $64,28.10^{-6}\,/K$.

Strain gages from HBM of the following types were used: 3/120 LY 11 (temperature compensated for $\alpha = 10,8.10^{-6}\,/K$), 6/120 RY 43 (temperature compensated for $\alpha = 23.10^{-6}\,/K$) and 3/120 LY 58 (temperature compensated for $\alpha = 65.10^{-6}\,/K$). On each plate there were bonded all three types of strain gages (except for PVC, where the gage 6/120 RY 43 was not applied). The gages were protected by silicon rubber SG 250.

The temperature of samples were measured by Fe - Ko thermocouples.

The signals from strain gages (in three-wire connection) and thermocouples were conditioned by digital amplifier system DMC 9012A (HBM) and processed by personal computer (see Fig. 1).

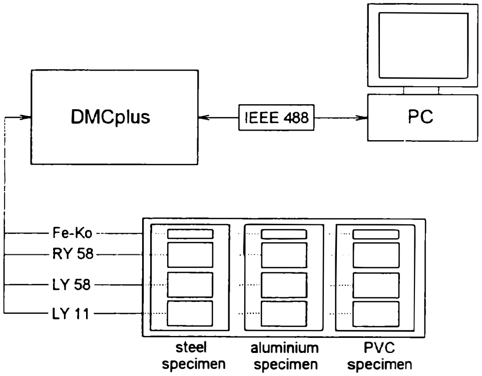

Fig. 1

The step-wise controlled heating up on the electrical plate TERMOKON-1 in the temperature range from room-temperature up to 70 ^{0}C for metallic samples or up to 40 ^{0}C for PVC was then performed and the apparent strain was measured (see Figs. 2 - 4).

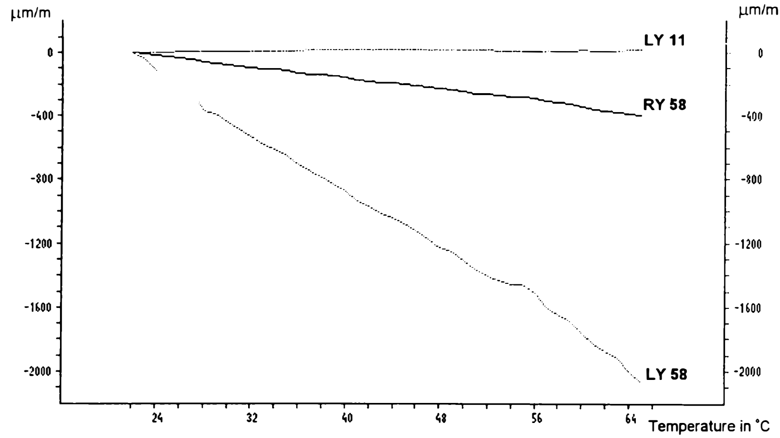

Fig. 2 Apparent strains measured on steel specimen

The discussion of results will be presented at the conference.

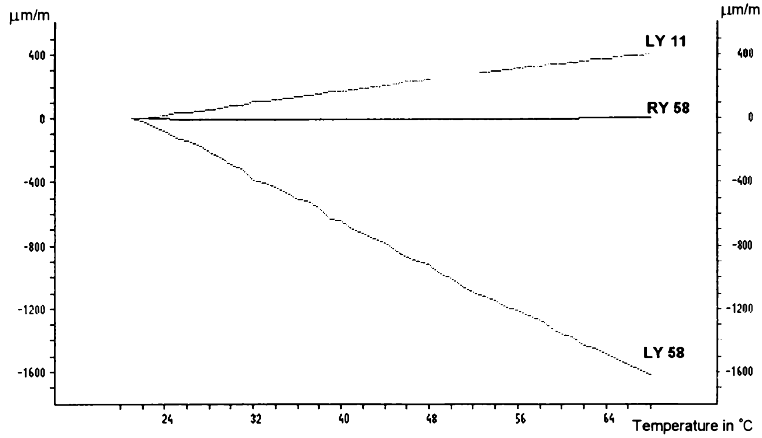

Fig. 3 Apparent strains measured on aluminium specimen

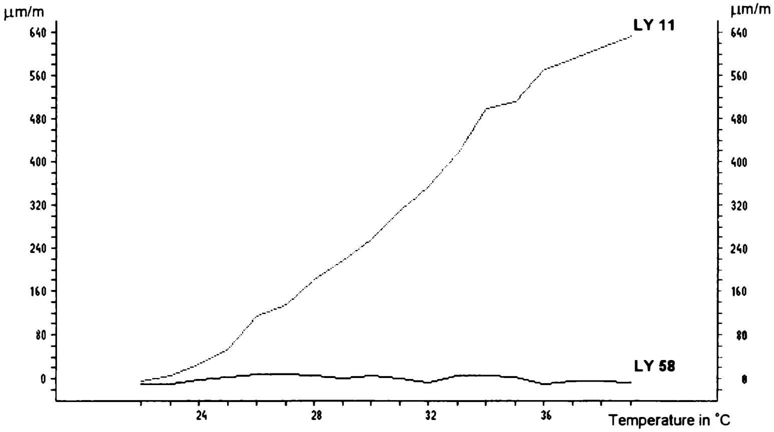

Fig. 4 Apparent strains measured on PVC specimen

References

[1] Hoffmann, K.: An Introduction to Measurements using Strain Gages. Hottinger Baldwin Messtechnik GmbH, Darmstadt 1989.

[2] Measurements Group Tech Note TN-504 „ Temperature-Induced Apparent Strain and Gage Factor Variation in Strain Gages“

[3] Stockmann, M.: Temperaturselbstkompensation von DMS - ein Praktikumversuch zur studentischen Ausbildung. HBM - Messtechnische Briefe, 31(1995), Heft 1, S.19-21.

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