Rapport BIPM-95/3

BUREAU INTERNATIONAL DES POIDS ET MESURES

Statistical Summary of the Temperature Characteristics of 1 Ω and 10 kΩ Resistors Measured at the BIPM

Mai 1995

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Statistical Summary of the Temperature Characteristics of 1 Ω and 10 kΩ Resistors Measured at the BIPM

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I. INTRODUCTION

This report summarizes the temperature characteristics of the 1 Ω and 10 kΩ resistors measured at the BIPM, including resistors sent to the BIPM for comparisons and calibrations and the BIPM's own resistors. It is intended to provide information to aid in the consideration by the Comité Consultatif d'Electricité of values of temperatures to use as reference temperatures and as physical temperatures in the comparisons and calibrations carried out by the BIPM. The analysis of the data assumes that the temperature behavior of a standard resistor in the region within 10 K to 20 K to either side of the reference or physical temperatures is given by

$$R_t = R_r\,(\,1 + \alpha\,(\,t - t_r\,) + \beta\,(t - t_r)^2\,) \qquad (1)$$

where R_t is the value of the resistance at temperature t, R_r is the value of the resistance at the reference temperature t_r, α is the linear coefficient of temperature (usually expressed in parts in 10^6 / K) and β is the quadratic coefficient of temperature (usually expressed in parts in 10^6 / K^2). According to Eq. (1), the value of the resistance is maximum at the temperature, t_{max}, given by

$$t_{max} = t_r - 2 \cdot \alpha / \beta\,. \qquad (2)$$

This is also the temperature at which dR_t / dt is zero. The derivative of R_t is conveniently written as

$$(1/R_r) \cdot dR_t/dt = \alpha + 2 \cdot \beta\,(t - t_r)\,. \qquad (3)$$

The right side of Eq. (3) is sometimes written as α_{tr}.

II. RESULTS

This report is concerned with 1 Ω and 10 kΩ standard resistors, the values most commonly used at the highest accuracy. Table 1 lists the relevant parameters for over 300 resistors of 1 Ω value. As the goal of this summary is to present typical results, a few outlying data were deleted. Column 1 lists the types or resistors, beginning with all types and continuing with those types most often measured at the BIPM. Column 2 gives the number of resistors in each group and column 3 lists the mean and standard deviation of the value of t_{max} for the corresponding group. Columns 4 to 6 list values of $(1/R_r) \cdot dR_t/dt$ at three reference temperatures commonly used in electrical metrology laboratories. Clearly t_{max} is the optimal temperature to use as a reference and to physically maintain for measurement purposes. It is seen that t_{max} varies as a function of type of resistor. If a single standard temperature had to be chosen for all 1 Ω resistors, columns 4 to 6 may be helpful in choosing a temperature that would represent a compromise among various resistor types. Figure 1 presents the data for t_{max} in the form of histograms. The data have been divided into the same groups as those of Table 1. To give some appreciation of the veracity of one statistical model of the data, normal probability distributions are drawn for each group.

Table 2 lists the relevant parameters for 91 resistors of 10 kΩ values. As in the previous table, column 1 lists the types of resistors, beginning with all types and continuing with those types most often measured at the BIPM. Column 2 gives the number of resistors in each group and column 3 lists the mean and standard deviation of the value of t_{max} for the corresponding group. Columns 4 to 6 list values of $(1/R_r) \cdot dR_t/dt$ at three reference temperatures commonly used in electrical metrology laboratories. About half of the 10 kΩ resistors are of the two types listed in rows 2 and 3. Again the values in column 3 indicate that t_{max} varies as a function of type of resistor. It should be noted that ESI model SR104 resistors are intended to be used in air. At the BIPM, they are measured in an air enclosure regulated at 20 °C. In contrast, the ZIP model P321 resistors presently are measured in an oil bath also regulated at 20 °C. Figure 2 presents histograms of the data for t_{max} for 10 kΩ resistors. The resistors are divided into the same groups as those of Table 2. Normal probability distributions are drawn for each group.

III. DISCUSSION

In view of the preceding data, the present temperature of 20°C used by the BIPM as the reference temperature for all non-thermostated resistors is too low except for 1 Ω resistors of the CSIRO type. One ohm resistors require oil baths which are expensive and voluminous so that the idea of using several baths at several different temperatures is not very attractive. A compromise temperature of 23 °C would reduce the mean temperature-related uncertainty for 1 Ω resistors by only about 40 % and would result in a mean temperature coefficient of (3.8×10^{-6}) /K. For 10 kΩ resistors, a 23 °C reference temperature would reduce the mean temperature coefficient to (0.36×10^{-6}) /K without increasing the uncertainty for any single type of resistor.

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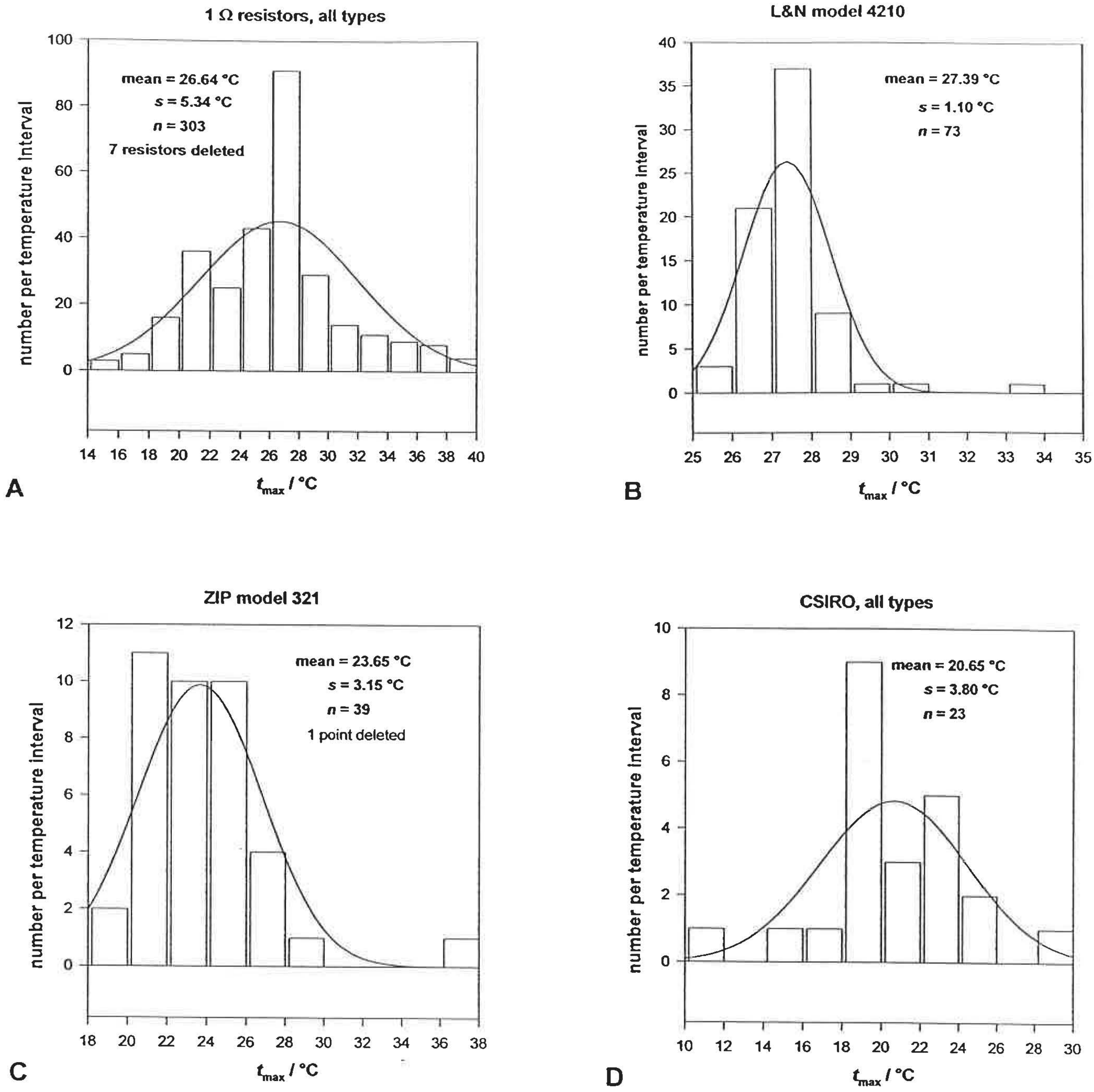
Table 1. SUMMARY OF TEMPERATURE STATISTICS ON 1 Ω RESISTORS

TYPE(S)	NUMBER	t_{max} / °C mean	std dev	(10^6 x $dR/R dt$) / °C at 20 °C mean	std dev	(10^6 x $dR/R dt$) / °C at 23 °C mean	std dev	(10^6 x $dR/R dt$) / °C at 25 °C mean	std dev
ALL	305	26.36	6.19	6.54	5.85	3.76	5.49	1.91	5.39
L&N 4210	73	27.39	1.10	7.57	0.86	4.48	0.89	2.42	0.94
ZIP P321	39	23.65	3.15	3.47	2.65	0.46	2.75	-1.55	2.87
CSIRO (ALL)	23	20.65	3.80	-0.01	0.03	-0.10	0.11	-0.15	0.16
BZ 13	16	22.00	2.60	1.78	1.82	-1.51	2.14	-3.69	2.42

Table 2. SUMMARY OF TEMPERATURE STATISTICS ON 10 kΩ RESISTORS

TYPE(S)	NUMBER	*tmax* / °C mean	std dev	(10^6 x dR/Rdt) / °C at 20 °C mean	std dev	(10^6 x dR/Rdt) / °C at 23 °C mean	std dev	(10^6 x dR/Rdt) / °C at 25 °C mean	std dev
ALL	91	24.32	4.84	1.43	3.78	0.36	3.43	-0.36	3.49
ESI SR104	32	23.09	3.20	0.14	0.13	-0.01	0.12	-0.11	0.12
ZIP P331	15	27.32	8.06	6.02	5.23	3.28	5.28	1.45	5.37



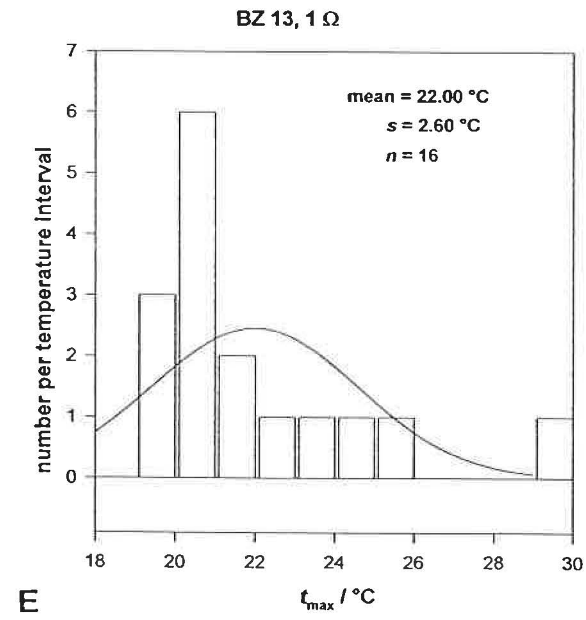
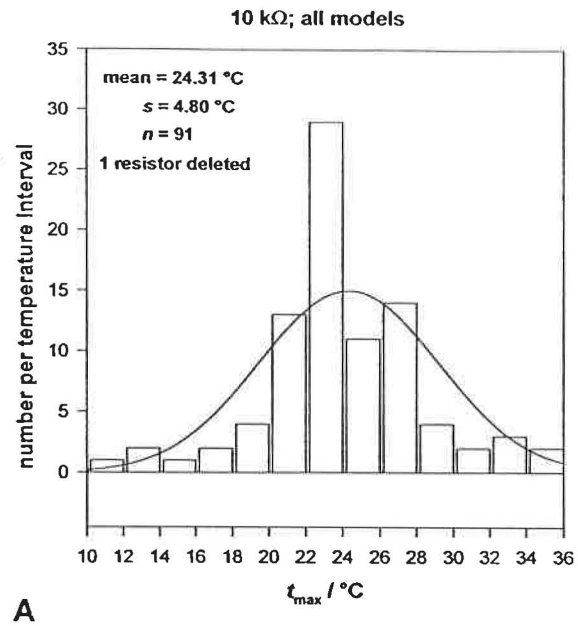


Figure 1. Histograms of the values of t_{max}, the temperature for which $dR/dt = 0$, for 1 Ω resistors measured at the BIPM; A) all resistors; B) L&N model 4210; C) ZIP model 321; D) CSIRO, all types; and E) BZ model 13.



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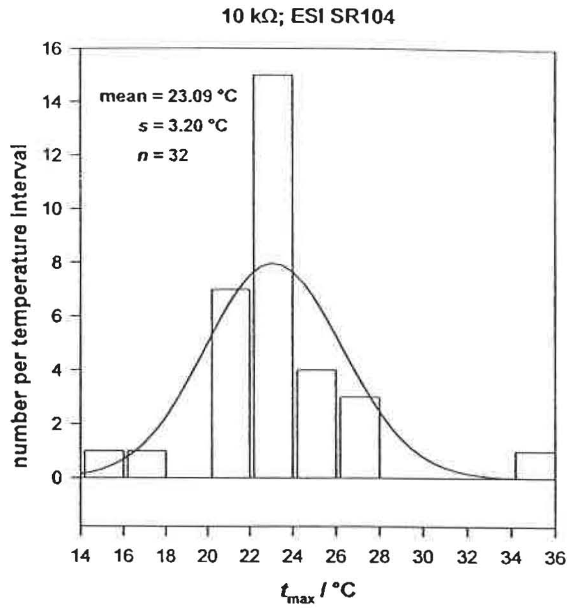

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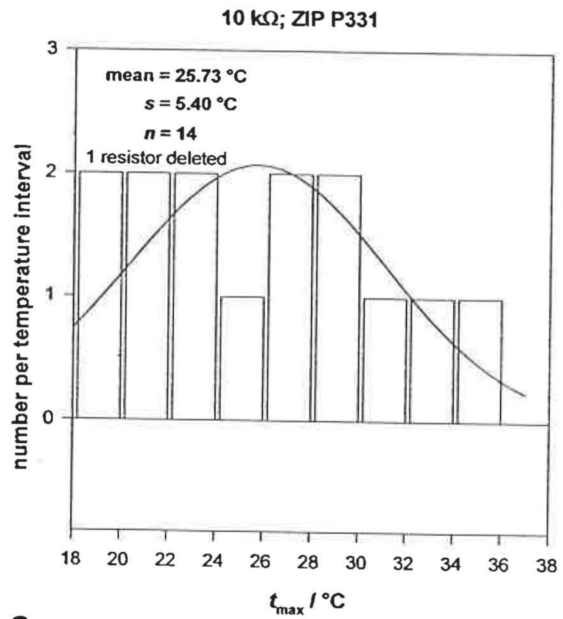

C

Figure 2. Histograms of the values of t_{max}, the temperature for which $dR/dt = 0$, for 10 kΩ resistors measured at the BIPM; A) all resistors; B) ESI model SR104; C) ZIP model P331.