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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Thermocouples –
Part 1: EMF specifications and tolerances

Couples thermoélectriques –
Partie 1: Spécifications et tolérances en matière de FEM

IEC 60584-1:2013

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

THERMOCOUPLES –

Part 1: EMF specifications and tolerances

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International Standard IEC 60584-1 has been prepared by sub-committee 65B: Measurement and control devices, of IEC technical committee 65: Industrial-process measurement,control and automation.

This third edition cancels and replaces the second edition published in 1995. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) IEC 60584-1:1995 and IEC 60584-2:1982 have been merged;

b) the standard is now explicitly based on the reference polynomials which express thermocouple EMF as functions of temperature. The tables derived from the polynomials are given in Annex A;

c) inverse polynomials expressing temperature as functions of EMF are given in Annex B, but inverse tables are not given;

d) the range of the polynomial relating the EMF of Type K thermocouples is restricted to 1 300 °C;

e) values of the Seebeck coefficients are given at intervals of 10 °C;

f) thermoelectric data (EMF and Seebeck coefficients) are given at the fixed points of the ITS-90;

g) some guidance is given in Annex C regarding the upper temperature limits and environmental conditions of use for each thermocouple type.

The text of this standard is based on the following documents:

FDIS	Report on voting
65B/873/FDIS	65B/888/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60584 series, under the general title *Thermocouples* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This International Standard relates the electromotive force (hereafter abbreviated as EMF) generated by the designated thermocouple types to temperature, based upon the International Temperature Scale of 1990 (ITS-90).

The reference polynomials for Types R, S, B, J, T, E, K and N are those used in the previous edition of this standard, IEC 60584-1:1995[1]. They were originally produced by the National Institute of Standards and Technology of the USA and published in NIST Monograph 175, 1993.

The major revision of this version is standardization of two kinds of tungsten-rhenium thermocouple, designated Type C and Type A. Both of them have been used in industry for a long time. Temperature versus EMF relationships for Type C and Type A are those published in the ASTM E230/E230-M12 and GOST R 8.585-2001 standards, respectively.

This edition merges two parts of the former IEC 60584 series, IEC 60584-1:1995 (*Reference tables*) and IEC 60584-2:1982 (*Tolerances*) and supersedes both standards. IEC 60584-3:2007 remains valid.

1 See Bibliography.

THERMOCOUPLES –

Part 1: EMF specifications and tolerances

1 Scope

This part of IEC 60584 specifies reference functions and tolerances for letter-designated thermocouples (Types R, S, B, J, T, E, K, N, C and A). Temperatures are expressed in degrees Celsius based on the International Temperature Scale of 1990, ITS-90 (symbol t_{90}), and the EMF (symbol E) is in microvolts.

The reference functions are polynomials which express the EMF, E in µV, as a function of temperature t_{90} in °C with the thermocouple reference junctions at 0 °C. Values of EMF at intervals of 1 °C are tabulated in Annex A.

For convenience of calculating temperatures, inverse functions are given in Annex B which express temperature as functions of EMF within stated accuracies.

This International Standard specifies the tolerances for thermocouples manufactured in accordance with this standard. The tolerance values are for thermocouples manufactured from wires, normally in the diameter range 0,13 mm to 3,2 mm, as delivered to the user and do not allow for calibration drift during use.

Annex C gives guidance on the selection of thermocouples with regard to temperature range and environmental conditions.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
thermoelectric effect
Seebeck effect
production of an electromotive force (EMF) due to a temperature gradient along a conductor

2.2
Seebeck coefficient of a thermocouple
change in EMF of a thermocouple combination per unit of temperature change, being the first derivative of EMF with respect to temperature.

Note 1 to entry: The Seebeck coefficient dE/dt_{90}, is expressed in µV/°C.

2.3
thermocouple
pair of conductors of dissimilar materials joined at one end and forming part of an arrangement using the thermoelectric effect for temperature measurement

2.4
measuring junction
junction of the thermocouple subjected to the temperature to be measured

2.5
reference junction
junction of the thermocouple at a known (reference) temperature

Note 1 to entry: For the specified EMFs of this standard, the reference temperature is 0 °C.

2.6
tolerance
maximum initial permissible deviation from the EMF specification of this standard

Note 1 to entry: The tolerance is expressed as the temperature equivalent in degrees Celsius Celsius (°C).

3 Thermocouple designations

When a thermocouple is identified by the materials of its conductors, the positive conductor shall be listed first, thus: ‘positive conductor / negative conductor’.

The positive conductor is the conductor having a positive electric potential with respect to the other conductor when the measuring junction is at a higher temperature than the reference junction.

Table 1 lists the thermocouple types for which EMFs are specified in this standard. Each letter designation of the table identifies the EMF-temperature reference function in the Tables 2 to 11. The designation may be applied to any thermocouple conforming to the relevant function within the stated tolerances specified in Clause 5, regardless of its composition.

Conformity with alloy specification listed in this clause does not guarantee conformity with the EMF-temperature relationship of this standard.

Table 1 – Thermocouple types

Letter designation	Elements and nominal alloy compositions by weight	
	Positive conductor	Negative conductor
R	Platinum – 13 % rhodium	Platinum
S	Platinum – 10 % rhodium	Platinum
B	Platinum – 30 % rhodium	Platinum – 6 % rhodium
J	Iron	Copper – nickel
T	Copper	Copper – nickel
E	Nickel – chromium	Copper – nickel
K	Nickel – chromium	Nickel – aluminium
N	Nickel – chromium - silicon	Nickel – silicon
C	Tungsten – 5 % rhenium	Tungsten – 26 % rhenium
A	Tungsten – 5 % rhenium	Tungsten – 20 % rhenium

NOTE

– Standard alloy compositions have not been established for base metal thermocouple alloys except Type N, but it should be noted that the compositions are not so critical as the matching of the positive and negative conductor. In particular, the negative conductor of Type J, Type E and Type T thermocouples are generally not interchangeable with each other. Likewise positive conductors of Type C and A are not necessary interchangeable.

– For Type N thermocouple the following composition (percentages of total by weight) is recommended in order to obtain the desired properties like good stability and oxidation resistance.

Positive conductor (known as Nicrosil): 13,7% to 14,7 % Cr%, 1,2 to 1,6 % Si, less than 0,15 % Fe, less than 0,05 % C, less than 0,01 % Mg, balance Ni.

Negative conductor (known as Nisil): less than 0,02 % Cr, 4,2 % to 4,6 % Si, less than 0,15 % Fe, less than 0,05 % C, 0,0 5% to 0,2 % Mg, balance Ni.

4 EMF – Temperature reference functions

The temperature and EMF relationships of this standard are defined by reference functions which give EMF, $E/\mu V$, as a function of the temperature, $t_{90}/°C$, with a reference temperature of 0 °C.

The reference function of polynomial form for each type of thermocouple, except for Type K in the temperature range from 0 °C to 1 300 °C, is defined by the following equation.

$$E = \sum_{i=0}^{n} a_i \times (t_{90})^i \qquad (1)$$

where

E is EMF, expressed in microvolts (µV);

t_{90} is ITS-90 temperature, expressed in degrees Celsius (°C);

a_i is the i^{th} coefficient of the polynomial;

n is the order of the polynomial.

The values of a_i and n are dependent on the type of thermocouple and temperature range. Those for each thermocouple are given in the Tables 2 to 11.

For the Type K in the temperature range from 0 °C to 1 300 °C, the reference function is defined by the following equation.

$$E = \sum_{i=0}^{n} \mathrm{a}_i \times (t_{90})^i + \mathrm{c}_0 \times \exp[\mathrm{c}_1 \times (t_{90} - 126{,}968\ 6)^2] \qquad (2)$$

where

E is EMF, expressed in microvolts (µV);

t_{90} is ITS-90 temperature, expressed in degrees Celsius (°C);

a_i is the i^{th} coefficient of the polynomial;

n is the order of the polynomial;

c_0, c_1 are constants given in Table 8.

Values of EMF are tabulated at intervals of 1 °C in Annex A.

Annex B gives inverse functions relating temperature to EMF within stated accuracies.

NOTE 1 Depending on the processing power available, rounding errors may arise in the calculations using these polynomials. This can be avoided by using the technique of nested multiplication. Thus, form the product $\mathrm{a}_n\ t$, add $\mathrm{a}_{(n-1)}$, multiply the result by t, etc, continuing through the series, finally adding a_0 to obtain the result:

$$E = (..((\mathrm{a}_n \cdot t_{90} + \mathrm{a}_{(n-1)}) \cdot t_{90} + \mathrm{a}_{(n-2)}) \cdot t_{90} + ... + \mathrm{a}_1) \cdot t_{90} + \mathrm{a}_0$$

Table 2 – Type R reference function

Polynomial coefficient	Temperature range		
	–50 °C to 1 064,18 °C (n = 9)	**1 064,18 °C to 1 664,5 °C (n = 5)**	**1 664,5 °C to 1 768,1 °C (n = 4)**
a_0	$0{,}000\ 000\ 000\ 00 \times 10^{0}$	$2{,}951\ 579\ 253\ 16 \times 10^{3}$	$1{,}522\ 321\ 182\ 09 \times 10^{5}$
a_1	$5{,}289\ 617\ 297\ 65 \times 10^{0}$	$-2{,}520\ 612\ 513\ 32 \times 10^{0}$	$-2{,}688\ 198\ 885\ 45 \times 10^{2}$
a_2	$1{,}391\ 665\ 897\ 82 \times 10^{-2}$	$1{,}595\ 645\ 018\ 65 \times 10^{-2}$	$1{,}712\ 802\ 804\ 71 \times 10^{-1}$
a_3	$-2{,}388\ 556\ 930\ 17 \times 10^{-5}$	$-7{,}640\ 859\ 475\ 76 \times 10^{-6}$	$-3{,}458\ 957\ 064\ 53 \times 10^{-5}$
a_4	$3{,}569\ 160\ 010\ 63 \times 10^{-8}$	$2{,}053\ 052\ 910\ 24 \times 10^{-9}$	$-9{,}346\ 339\ 710\ 46 \times 10^{-12}$
a_5	$-4{,}623\ 476\ 662\ 98 \times 10^{-11}$	$-2{,}933\ 596\ 681\ 73 \times 10^{-13}$	-
a_6	$5{,}007\ 774\ 410\ 34 \times 10^{-14}$	-	-
a_7	$-3{,}731\ 058\ 861\ 91 \times 10^{-17}$	-	-
a_8	$1{,}577\ 164\ 823\ 67 \times 10^{-20}$	-	-
a_9	$-2{,}810\ 386\ 252\ 51 \times 10^{-24}$	-	-

Table 3 – Type S reference function

Polynomial coefficient	Temperature range –50 °C to 1 064,18 °C (n = 8)	1 064,18 °C to 1 664,5 °C (n = 4)	1 664,5 °C to 1 768,1 °C (n = 4)
a_0	$0,000\ 000\ 000\ 00 \times 10^{0}$	$1,329\ 004\ 440\ 85 \times 10^{3}$	$1,466\ 282\ 326\ 36 \times 10^{5}$
a_1	$5,403\ 133\ 086\ 31 \times 10^{0}$	$3,345\ 093\ 113\ 44 \times 10^{0}$	$-2,584\ 305\ 167\ 52 \times 10^{2}$
a_2	$1,259\ 342\ 897\ 40 \times 10^{-2}$	$6,548\ 051\ 928\ 18 \times 10^{-3}$	$1,636\ 935\ 746\ 41 \times 10^{-1}$
a_3	$-2,324\ 779\ 686\ 89 \times 10^{-5}$	$-1,648\ 562\ 592\ 09 \times 10^{-6}$	$-3,304\ 390\ 469\ 87 \times 10^{-5}$
a_4	$3,220\ 288\ 230\ 36 \times 10^{-8}$	$1,299\ 896\ 051\ 74 \times 10^{-11}$	$-9,432\ 236\ 906\ 12 \times 10^{-12}$
a_5	$-3,314\ 651\ 963\ 89 \times 10^{-11}$	-	-
a_6	$2,557\ 442\ 517\ 86 \times 10^{-14}$	-	-
a_7	$-1,250\ 688\ 713\ 93 \times 10^{-17}$	-	-
a_8	$2,714\ 431\ 761\ 45 \times 10^{-21}$	-	-

Table 4 – Type B reference function

Polynomial coefficient	Temperature range 0 °C to 630,615 °C (n = 6)	630,615 °C to 1 820 °C (n = 8)
a_0	$0,000\ 000\ 000\ 00 \times 10^{0}$	$-3,893\ 816\ 862\ 1 \times 10^{3}$
a_1	$-2,465\ 081\ 834\ 6 \times 10^{-1}$	$2,857\ 174\ 747\ 0 \times 10^{1}$
a_2	$5,904\ 042\ 117\ 1 \times 10^{-3}$	$-8,488\ 510\ 478\ 5 \times 10^{-2}$
a_3	$-1,325\ 793\ 163\ 6 \times 10^{-6}$	$1,578\ 528\ 016\ 4 \times 10^{-4}$
a_4	$1,566\ 829\ 190\ 1 \times 10^{-9}$	$-1,683\ 534\ 486\ 4 \times 10^{-7}$
a_5	$-1,694\ 452\ 924\ 0 \times 10^{-12}$	$1,110\ 979\ 401\ 3 \times 10^{-10}$
a_6	$6,299\ 034\ 709\ 4 \times 10^{-16}$	$-4,451\ 543\ 103\ 3 \times 10^{-14}$
a_7	-	$9,897\ 564\ 082\ 1 \times 10^{-18}$
a_8	-	$-9,379\ 133\ 028\ 9 \times 10^{-22}$

Table 5 – Type J reference function

Polynomial coefficient	Temperature range –210 °C to 760 °C (n = 8)	760 °C to 1 200 °C (n = 5)
a_0	$0,000\ 000\ 000\ 0 \times 10^{0}$	$2,964\ 562\ 568\ 1 \times 10^{5}$
a_1	$5,038\ 118\ 781\ 5 \times 10^{1}$	$-1,497\ 612\ 778\ 6 \times 10^{3}$
a_2	$3,047\ 583\ 693\ 0 \times 10^{-2}$	$3,178\ 710\ 392\ 4 \times 10^{0}$
a_3	$-8,568\ 106\ 572\ 0 \times 10^{-5}$	$-3,184\ 768\ 670\ 1 \times 10^{-3}$
a_4	$1,322\ 819\ 529\ 5 \times 10^{-7}$	$1,572\ 081\ 900\ 4 \times 10^{-6}$
a_5	$-1,705\ 295\ 833\ 7 \times 10^{-10}$	$-3,069\ 136\ 905\ 6 \times 10^{-10}$
a_6	$2,094\ 809\ 069\ 7 \times 10^{-13}$	-
a_7	$-1,253\ 839\ 533\ 6 \times 10^{-16}$	-
a_8	$1,563\ 172\ 569\ 7 \times 10^{-20}$	-

The specified function for Type J (Table 5) extends up to 1 200 °C; however, it should be noted that when a Type J thermocouple has been used above 760 °C, its performance below 760 °C may not conform to the lower part of the function within specified tolerances.

Table 6 – Type T reference function

Polynomial coefficient	Temperature range	
	–270 °C to 0 °C (*n* = 14)	**0 °C to 400 °C (*n* = 8)**
a_0	$0{,}000\ 000\ 000\ 0 \times 10^{0}$	$0{,}000\ 000\ 000\ 0 \times 10^{0}$
a_1	$3{,}874\ 810\ 636\ 4 \times 10^{1}$	$3{,}874\ 810\ 636\ 4 \times 10^{1}$
a_2	$4{,}419\ 443\ 434\ 7 \times 10^{-2}$	$3{,}329\ 222\ 788\ 0 \times 10^{-2}$
a_3	$1{,}184\ 432\ 310\ 5 \times 10^{-4}$	$2{,}061\ 824\ 340\ 4 \times 10^{-4}$
a_4	$2{,}003\ 297\ 355\ 4 \times 10^{-5}$	$-2{,}188\ 225\ 684\ 6 \times 10^{-6}$
a_5	$9{,}013\ 801\ 955\ 9 \times 10^{-7}$	$1{,}099\ 688\ 092\ 8 \times 10^{-8}$
a_6	$2{,}265\ 115\ 659\ 3 \times 10^{-8}$	$-3{,}081\ 575\ 877\ 2 \times 10^{-11}$
a_7	$3{,}607\ 115\ 420\ 5 \times 10^{-10}$	$4{,}547\ 913\ 529\ 0 \times 10^{-14}$
a_8	$3{,}849\ 393\ 988\ 3 \times 10^{-12}$	$-2{,}751\ 290\ 167\ 3 \times 10^{-17}$
a_9	$2{,}821\ 352\ 192\ 5 \times 10^{-14}$	-
a_{10}	$1{,}425\ 159\ 477\ 9 \times 10^{-16}$	-
a_{11}	$4{,}876\ 866\ 228\ 6 \times 10^{-19}$	-
a_{12}	$1{,}079\ 553\ 927\ 0 \times 10^{-21}$	-
a_{13}	$1{,}394\ 502\ 706\ 2 \times 10^{-24}$	-
a_{14}	$7{,}979\ 515\ 392\ 7 \times 10^{-28}$	-

Table 7 – Type E reference function

Polynomial coefficient	Temperature range	
	–270 °C to 0 °C (*n* = 13)	**0 °C to 1 000 °C (*n* = 10)**
a_0	$0{,}000\ 000\ 000\ 0 \times 10^{0}$	$0{,}000\ 000\ 000\ 0 \times 10^{0}$
a_1	$5{,}866\ 550\ 870\ 8 \times 10^{1}$	$5{,}866\ 550\ 871\ 0 \times 10^{1}$
a_2	$4{,}541\ 097\ 712\ 4 \times 10^{-2}$	$4{,}503\ 227\ 558\ 2 \times 10^{-2}$
a_3	$-7{,}799\ 804\ 868\ 6 \times 10^{-4}$	$2{,}890\ 840\ 721\ 2 \times 10^{-5}$
a_4	$-2{,}580\ 016\ 084\ 3 \times 10^{-5}$	$-3{,}305\ 689\ 665\ 2 \times 10^{-7}$
a_5	$-5{,}945\ 258\ 305\ 7 \times 10^{-7}$	$6{,}502\ 440\ 327\ 0 \times 10^{-10}$
a_6	$-9{,}321\ 405\ 866\ 7 \times 10^{-9}$	$-1{,}919\ 749\ 550\ 4 \times 10^{-13}$
a_7	$-1{,}028\ 760\ 553\ 4 \times 10^{-10}$	$-1{,}253\ 660\ 049\ 7 \times 10^{-15}$
a_8	$-8{,}037\ 012\ 362\ 1 \times 10^{-13}$	$2{,}148\ 921\ 756\ 9 \times 10^{-18}$
a_9	$-4{,}397\ 949\ 739\ 1 \times 10^{-15}$	$-1{,}438\ 804\ 178\ 2 \times 10^{-21}$
a_{10}	$-1{,}641\ 477\ 635\ 5 \times 10^{-17}$	$3{,}596\ 089\ 948\ 1 \times 10^{-25}$
a_{11}	$-3{,}967\ 361\ 951\ 6 \times 10^{-20}$	-
a_{12}	$-5{,}582\ 732\ 872\ 1 \times 10^{-23}$	-
a_{13}	$-3{,}465\ 784\ 201\ 3 \times 10^{-26}$	-

Table 8 – Type K reference function

Polynomial coefficient	Temperature range	
	–270 °C to 0 °C (*n* = 10)	0 °C to 1 300 °C
a_0	0,000 000 000 0 × 10^{0}	–1,760 041 368 6 × 10^{1}
a_1	3,945 012 802 5 × 10^{1}	3,892 120 497 5 × 10^{1}
a_2	2,362 237 359 8 × 10^{-2}	1,855 877 003 2 × 10^{-2}
a_3	–3,285 890 678 4 × 10^{-4}	–9,945 759 287 4 × 10^{-5}
a_4	–4,990 482 877 7 × 10^{-6}	3,184 094 571 9 × 10^{-7}
a_5	–6,750 905 917 3 × 10^{-8}	–5,607 284 488 9 × 10^{-10}
a_6	–5,741 032 742 8 × 10^{-10}	5,607 505 905 9 × 10^{-13}
a_7	–3,108 887 289 4 × 10^{-12}	–3,202 072 000 3 × 10^{-16}
a_8	–1,045 160 936 5 × 10^{-14}	9,715 114 715 2 × 10^{-20}
a_9	–1,988 926 687 8 × 10^{-17}	–1,210 472 127 5 × 10^{-23}
a_{10}	–1,632 269 748 6 × 10^{-20}	-
c_0	–	1,185 976 × 10^{2}
c_1	–	–1,183 432 × 10^{-4}

In the temperature range 0 °C to 1 300 °C, for Type K (Table 8) use equation (2) with constants c_0,c_1 as given in the above Table.

Table 9 – Type N reference function

Polynomial coefficient	Temperature range	
	–270 °C to 0 °C (*n* = 8)	0 °C to 1 300 °C (*n* = 10)
a_0	0,000 000 000 0 × 10^{0}	0,000 000 000 0 × 10^{0}
a_1	2,615 910 596 2 × 10^{1}	2,592 939 460 1 × 10^{1}
a_2	1,095 748 422 8 × 10^{-2}	1,571 014 188 0 × 10^{-2}
a_3	–9,384 111 155 4 × 10^{-5}	4,382 562 723 7 × 10^{-5}
a_4	–4,641 203 975 9 × 10^{-8}	–2,526 116 979 4 × 10^{-7}
a_5	–2,630 335 771 6 × 10^{-9}	6,431 181 933 9 × 10^{-10}
a_6	–2,265 343 800 3 × 10^{-11}	–1,006 347 151 9 × 10^{-12}
a_7	–7,608 930 079 1 × 10^{-14}	9,974 533 899 2 × 10^{-16}
a_8	–9,341 966 783 5 × 10^{-17}	–6,086 324 560 7 × 10^{-19}
a_9	-	2,084 922 933 9 × 10^{-22}
a_{10}	-	–3,068 219 615 1 × 10^{-26}