Nicrosil/Nisil Type N Thermocouples

The Nicrosil/Nisil Type N thermocouple offers better stability than existent base-metal Types E, J, K and T. It is now available and in widespread use worldwide.

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The ANSI standard base-metal thermocouples, designated E, J, K and T (Ref. 1), show inherent thermoelectric instability related to time- and/or temperature-dependent instabilities in several of their physical, chemical, nuclear, structural and electronic properties. This paper reviews the major thermoelectric properties of the new nickel-base thermocouple system Nicrosil *versus* Nisil (designated type N), in which very high thermoelectric stability has been achieved by a judicious choice of elemental component concentrations.

INSTABILITY OF CONVENTIONAL BASE-METAL THERMOCOUPLES

There are three principal characteristic types and causes of thermoelectric instability in the standard base-metal thermoelement materials:

1. A gradual and generally cumulative drift in thermal EMF on long exposure at elevated temperatures. This is observed in all base-metal thermoelement materials and is majnly due to compositional changes caused by oxidation, in particular internal oxidation (Figures 1 and 2), and to neutron irradiation which can produce transmutation in nuclear reactor environments.

2. A short-term cyclic change in thermal EMF on heating in the temperature range about 250º to 650ºC, which occurs in types KP (or EP) and JN (or TN and EN). This kind of EMF instability is thought to be due to some form of structural change like magnetic short-range order (Figures 3 and 4).

3. A time-independent perturbation in thermal EMF in specific temperature ranges. This is due to composition-dependent magnetic transformations which perturb the thermal EMF's in type KN in the range of about 25º to 225ºC (Figure 5), and in type JP above about 730ºC.

ULTRA-HIGH STABILITY OF NICROSILINISIL (TYPE N) THERMOCOUPLE

Nicrosil and Nisil thermocouple alloys (Ref. 2) show greatly enhanced thermoelectric stability (Ref. 3) relative to the other standard base-metal thermocouple alloys because their compositions (Table 1) are such as to virtually eliminate or substantially reduce the causes of thermoelectric instability described above. This is achieved primarily by increasing component solute concentrations (chromium and silicon) in a base of nickel above those required to cause a transition from internal to external modes of oxidation, and by selecting solutes (silicon and magnesium) which preferentially oxidize to form a diffusion-barrier, and hence oxidation inhibiting films.

The thermal EMF instabilities of the short-term cyclic kind occurring in KP and JN alloys have virtually been eliminated in nicrosil (NP) by setting the chromium content at 14.2 weight-%.

The increase in the silicon content of nisil (NN) to 4.4 weight-% has suppressed the magnetic transformation of this new alloy to below room temperature.

Virtual freedom from nuclear transmutation effects is achieved by eliminating such elements as manganese, cobalt and iron from the specified compositions of both alloys.

The very high thermoelectric stability of the Nicrosil/Nisil (type N) thermocouple is illustrated in Figures 1 and 2. The influence of thermoelement conductor cross-sectional area upon the thermal-EMF constancy of Nicrosil/Nisil is shown in Figure 6.

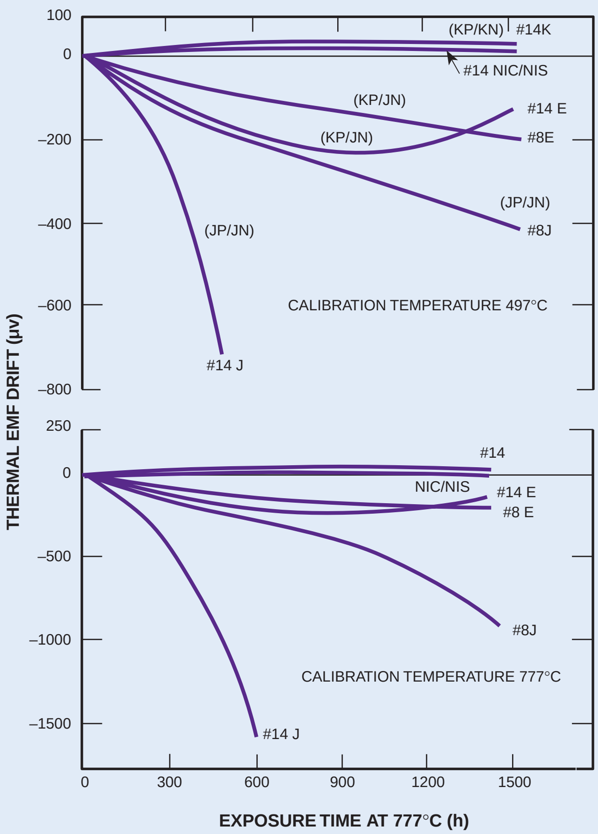

FIGURE 1. Long-term thermal-EMF drifts in air, at two calibration temperatures, for 14 AWG (#14) Nicrosil/Nisil (N) and E, J and K T/Cs. Thermal-EMF drifts for 8 AWG (#8) E and J T/Cs are also given. The drifts are changes from EMF output values existent after 20 hrs of exposure at constant aging temperature of 777°C (Ref. 3).

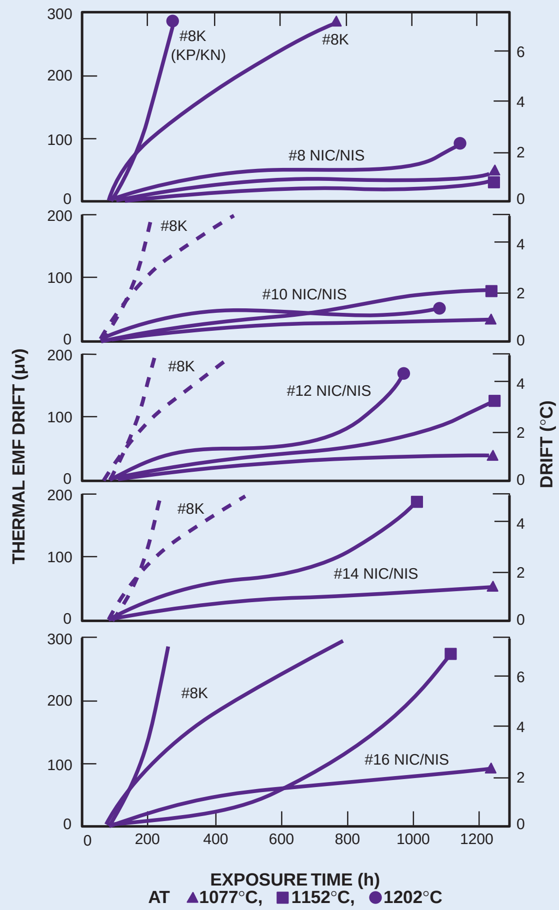

FIGURE 2. Long-term thermal-EMF drifts in air, at three constant aging (and calibration) temperatures for Nicrosil/Nisil T/Cs in five wire gauges (#). Corresponding thermal-EMF drifts for 8 AWG (#8) type K T/Cs at two of these temperatures are also given. The drifts are changes from EMF output values existent after 80 hours of exposure at the constant aging temperature (Ref. 3).

As Figure 2 shows, 8 AWG type K thermocouples appear to be markedly more unstable as temperatures progressively exceed about 1050°C. In contrast, it is clear from Figure 6 that type N thermocouples, in a range of wire sizes finer than 8 AWG, can be used reliably for extended periods of time at temperatures up to at least 1200°C. Indeed, it has recently been demonstrated (Ref. 4) that, in oxidizing atmospheres, the thermoelectric stability of the Nicrosil/Nisil thermocouple, in wire sizes not finer than 10 AWG, is about the same as that of the noble-metal thermocouples of ANSI types R and S up to about 1200°C.

Type N Thermocouples

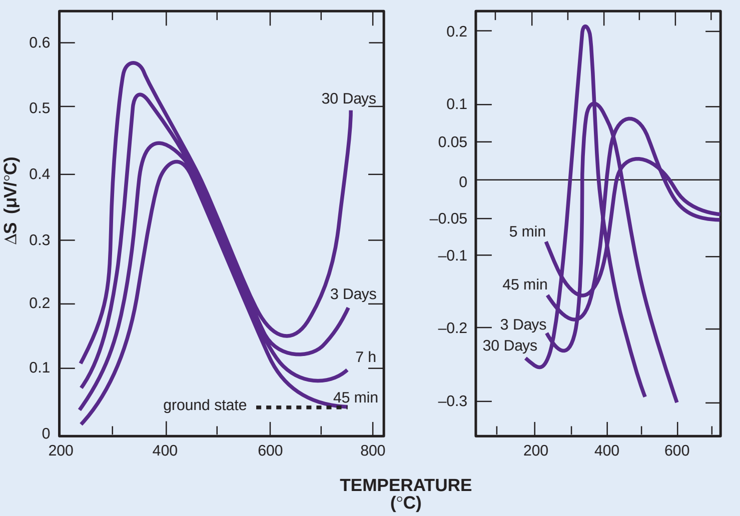

FIGURE 3 (Left). Changes in the Seebeck coefficient (ΔS) of a typical type KP thermoelement vs. platinum on initial heating, as a function of constant aging temperature for the indicated times (Ref. 3).

FIGURE 4 (Right). Similar changes of a type JN thermoelement (Ref. 3).

TABLE.1- NOMINAL COMPOSITIONS OF ANSI STANDARD BASE-METAL THERMOELEMENT ALLOYS, AND NICROSIL AND NISIL ALLOYS

ALLOY ANSI (1) DESIGNATION	**CHEMICAL COMPOSITION (WEIGHT-%)** Cr	Si	Mn	Al	Co	Mg	Cu	Ni	Fe
(+)KP, EP	9.5	0.4						bal	
(-)KN		1.0	3.0	2.0	0.4	0.015		bal	
(+)JP			0.3						bal
(-)JN, EN, TN			1.0		0.5		54	44	0.5
(+)TP							100		
(+)NP (nicrosil)	14.2	1.4						bal	
(-)NN (nisil)		4.4				0.10		bal	

TABLE 2-VARIANTS OF TYPE KN

ALLOY	**CHEMICAL COMPOSITION (WEIGHT-%)** Mn	Al	Si	co	Ni
KN1	3.02	1.90	1.19	0.41	balance
KN2	1.67	1.25	1.56	0.72	balance
KN3	-	-	2.50	1.00	balance
KN4	0.43	-	2.39	0.23	balance

PROMULGATION AS A STANDARD

No new thermocouple will survive for universal adoption and use unless it is formally promulgated by national standards authorities around the world. It is fortunate that the Nicrosil/Nisil thermocouple system is in vigorous process of being so promulgated.

The ASTM, through its Committee E-20 on Temperature Measurement, has shown considerable interest in Nicrosil *versus* Nisil, and has kept matters relating to the development, availability and use of the new thermocouple under continual review.

Recently, relevant subcommittees of ASTM E-20 have produced several publications containing information on the properties and characteristics of the Nicrosil *versus* Nisil thermocouple. A document quoting several of the EMF-temperature tables from NBS Monograph 161 (Ref. 2) was published (Ref. 6) for information. A formal ASTM Standard (E1223) is promulgated, while Type N data is now included in ASTM Standard E230. Again, in the recently published third edition of the ASTM Manual on the Use of Thermocouples (Ref. 8), various properties and characteristics of Nicrosil *versus* Nisil are summarized.

Based mainly on the above information, several crucial actions now have been taken by the supreme standardizing bodies in several important countries:

1. The Instrument Society of America (ISA), in October 1983, promulgated the Nicrosil/Nisil system as a U.S. Standard Thermocouple bearing the letter-designation “type N.”

2. The British Standards Institute (BSI) has recently promulgated a standard on the type N thermocouple identified as B.S.4937: Part 8.

3. The Japan Society for the Promotion of Science, through its Committee TC19 (Temperature), is nearing the conclusion of its deliberation on type N, leading to the issue of a Japan Industrial Standard (JIS).

These actions have ensured that the type N thermocouple and its allied pyrometric instrumentation and ancillary circuitry elements are now commercially available in a number of major countries around the world.

DISCUSSION

The various types of thermoelectric instability described in this paper can cause substantial changes in thermoelectromotive force and, hence, calibration in ANSI-standard letter-designated base-metal thermocouples types E, J, K and T. In the case of Nicrosil/Nisil, however, thermoelectric instability due to these causes is virtually eliminated or substantially attenuated over the entire temperature range up to 1230°C. ANSI-standard base-metal thermocouples types E, J, K and T can, therefore, be regarded as obsolescent. Their replacement by Nicrosil/Nisil thermocouples would lead, in most cases, to demonstrable technological and economic advantages for science and industry at large. Indeed, the enhanced calibration stability and longevity of the type N thermocouple, taken into account with its ability to operate at considerably higher upper operating temperatures than conventional base-metal thermocouples, make it ideally suited to scientific, technological and industrial applications where temperature measurements are critical.

Use of type N thermocouples in several countries has already demonstrated a number of advantages: enhanced pyrometric accuracy, improved product quality and performance, lower reject rates, enhanced energy utilization, lower pyrometric maintenance costs, and improved productivity.

REFERENCES

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**The NBS is now NIST (National Institute of Standards and Technology).*

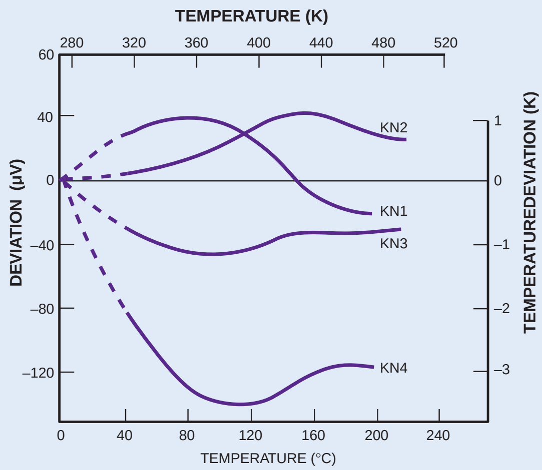

FIGURE 5. Deviations of the measured values of the thermal EMFs of several type KN thermoelements vs. platinum from reference table values (Ref. 5). Variants of type KN are given in Table 2.

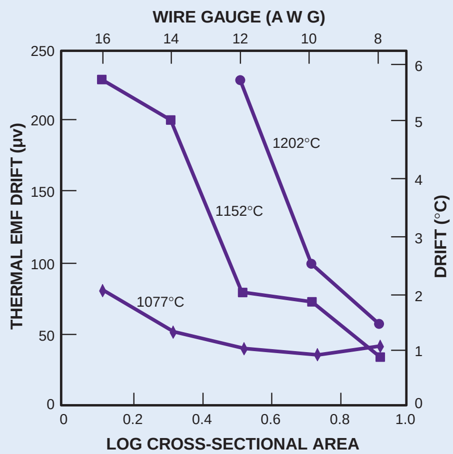

FIGURE 6. Relationship between total thermal-EMF drift (after 1000 hrs of exposure in air at each of three test temperatures) and cross-sectional area of Nicrosil/Nisil T/C wires. The drifts are changes from EMF output values existent after 80 hours of exposure (Ref. 3).

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