WIRE MATERIALS

Almost any wire can be incorporated into SEMPAK®. The great versatility of SEMPAK® with a choice of ceramic insulators and even larger selection of sheath materials opens an even broadening spectrum of use.

Some applications of SEMPAK®:

- Thermocouples
- Thermocouple Cable
- Heaters
- Resistance Detectors
- Nuclear Detectors
- Nuclear Instrumentation Cables
- Coaxial Cable
- High Temperature Electric Cable
- Accelerometer Cable
- Fire Detection Cable
- Turbine Engine Wire Harnesses
- Cable for Explosive Environments
- Liquid Metal Immersion Heaters

The largest use of SEMPAK® is for temperature measurement. The wire for use in thermocouple material is ordered bright, clean and unoxidized and is purchased with special accuracy limits (See Table 3). The wire pairs are calibrated in Metal Freezing Point Standards to insure accuracy of the beginning components. The choice of wires for thermocouples is large. For a description of some thermocouple wire pairs and their application see Table 4.

Type K (Chromel-Alumel)

The Chromel-Alumel alloys were developed by the Hoskins Manufacturing Company. Chromel P is an alloy having a nominal composition of 90% Ni and 10% Cr. Its thermoelectric power against platinum is higher than that of any other readily available alloy. Alumel is a nickel base alloy which was developed to have a nearly constant thermoelectric power with Chromel P.

The oxidation resistant characteristics of these alloys are better than those of the other base metal thermocouples in general use. They are the most widely used SEMPAK® thermoelements. Since the NIST published standard tables for this thermocouple, several other manufacturers have marketed similar alloys (See Table 5) that match the calibration tables. These alloy pairs are designated as “K” type thermocouples.

Type K alloys have low transmutation rates and are, therefore, stable in nuclear environments. Stainless steel sheathed thermocouples with Type K wire and MgO insulation have recorded MTBF histories in excess of 400,000 hours while operating in-pile at temperatures of about 1200°F. SEMPAK® with Type K wire has been successfully used for short term up to the melting temperature of the negative leg (2250°F). Hydrogen and reducing atmospheres should be avoided with Type K because of a tendency to exhibit emf drift.

Type J (Iron-Constantan)

Iron-Constantan is one of the oldest thermocouples in general use. Its use in the metal-sheathed ceramic packed configuration is usually because of the availability of instrumentation so calibrated. Iron-constantan is relatively low-cost making long wire runs economically advantageous. The recommended operating temperature range is below 1400°F.

Type N (Nickel-Silicon / Nickel-Chromium-Silicon)

Type N (Nicrosil-Nisil) exhibits a much greater resistance to oxidation-related drift at high temperatures than Type K, and has less of the instabilities of Type K and other base metal thermocouples to a degree. It can thus handle higher temperatures than Type K (1,280°C, and higher for short periods). Oxidation resistance is superior because of the combination of a higher level of chromium and silicon in the positive Nicrosil conductor. Similarly, a higher level of silicon and magnesium in the negative Nisil conductor form a protective diffusion barrier. The device also shows much improved repeatability in the 300°C to 500°C range. High levels of chromium in the NP conductor, and silicon in the NN conductor provide improved magnetic stability.

Type T (Copper-Constantan)

This wire pair is usually used in the –300°F to + 600°F range for higher accuracy or research type work. Good in moist atmospheres, vacuum, oxidizing, reducing or inert gasses to 700°F. Can be used as low as -420°F.

Geminol P and N

A Driver-Harris alloy pair that can be used in reducing atmospheres and neutron environments. An excellent choice for temperature measurement of hydrided nuclear fuel. It has a useful operating range to about 2200°F.

Type S and R (Pt-10Rh/Pt and Pt-13Rh/Pt)

Platinum is easily contaminated by lead, zinc, phosphorus, arsenic and silicon. Use in an inert or oxidizing atmosphere. Rhodium has a large nuclear cross-section and transmutes to palladium making it impractical for use in nuclear reactors where neutron flux densities are high. Type S thermocouple is used to determine the International Practical Temperature Scale from the freezing point of antimony to the freezing point of gold.

Type E (Chromel-Constantan)

This alloy pair has a high thermoelectric power and has a useful range up to about 1800°F. The Constantan is the temperature limiting alloy of the pair. Has been used as low as -420°F.

Type B (Pt-30Rh/Pt-6 Rh)

Slightly higher melting temperature than the pure platinum leg of the other Pt/Pt-Rh combinations (~1800°C). Has a very small emf in the normal ambient temperature range of 0 to 50°C so reference junction errors are small and in a practical sense, reference junction temperatures need not be controlled in most applications.

Platinel II (31 Pt-14 Au-55Pd vs Au-35 Pd)

A noble metal thermocouple system developed by Engelhard Industries to measure turbine inlet temperatures in gas turbine engines (hot oxidizing gas) above the useful range of Chromel-Alumel. Stability is good in air to 2200°F. Emf is close to Type K curves.

W/W26Re, W3Re/W25Re and W5Re/W26Re

Poor oxidation resistance. Measuring junctions are brittle after welding. Pure W exhibits a ductile to brittle transition at about 1100°C. Can be used in hydrogen, vacuum or inert atmospheres. Rhenium transmutes to osmium and tungsten transmutes to rhenium in a nuclear environment. The result is a large decalibration of signal. These alloys have high melting temperatures and a high useful operating range. Even with the transmutation and decalibration deficiency they have been used frequently in reactors for fuel temperature measurements because of their high melting temperatures.

Special Applications

Pt-5% Mo / Pt-0.1% Mo
Useful in a nuclear environment because both platinum and molybdenum have low transmutation rates. Very sensitive to oxidizing atmospheres (callibration shifts). Stable in graphite and helium environments.

Pt6Ru / Pt
A likely candidate for a nuclear environment because of love transmutation rates for both platinum and ruthenium. Cannot be used in oxidizing atmosphere because of preferential oxidation of ruthenium.

Ir/401r-60Rh, Ir/50Ir-50Rh, and Ir/601r-40Rh
Becomes brittle after exposure to elevated temperatures (welding measuring junction). The only thermocouple wires that can be used in air to 2000°C for short periods of time. Becomes brittle after long use in reducing atmospheres. Use inert or weakly oxidizing atmospheres. Care is required in handling the wires because they cannot stand much cold work without breaking.

Pallador (40 Pd-Au vs 10 Ir-Pt)
A noble metal system with high electrical output (approximately like iron-constantan) that can be used up to 1000°C. Less corrosive than iron-constantan in some atmospheres.

"PIP" (Pt-15lr vs Pd)
Developed by WADD and GE for use above the range of the more common base metal thermocouples. Has high output on the same order as base metal couples. Useful for gas turbine engine temperature measurements.

High Melting Elements

W / Ir
Both temperatures are embrittled after exposure to high temperatures. Iridium is more difficult to work than rhodium but is the most corrosion resistant element known. The tungsten element oxidizes rapidly above 700°C so should be used only in an inert or vacuum atmosphere.

W / Re
The tungsten element becomes embrittled after exposure to temperatures above ~ 1100°C. Rhenium is very ductile but oxidizes rapidly above 600°C. Seldom used because of the development of the tungsten-rhenium alloy thermocouple system.

Mo / Re
Emf vs temperature sensitivity decreases at elevated temperatures. Molybdenum forms an oxide which volatilizes at moderate temperatures.

Mo / Nb
Thermocouples made of these low neutron capture cross-section elements should be relatively drift free in a nuclear environment. Emf vs temperature sensitivity decreases at higher temperatures by has an output large enough to be useful.

Factors that may affect wire accuracy (stability in use)

- Alloys at temperatures tend to change their composition because of the different volatilities of the constituents.
- During nuclear radiation, transmutation may cause a change of elements and thus the emf.
- At temperature, the ceramic insulator starts to become electrically conductive and shunts part of the signal.
- Some ceramics become more conductive than others at high temperatures and introduce a parallel thermoelectric signal.
- Compositional changes take place because chemical reaction rates and diffusion rates are large at high temperatures.
- The operating gaseous environment may diffuse into and change the material compositional or crystalline structure.
- Compatibility of the insulator with the wire is important. Small amounts of contamination affect the composition and properties of the materials.
- Differences in reaction rates of the constituents of the thermocouple alloy can cause compositional and therefore calibration changes.
- Small diameter wires, because the ratio of surface area to mass is large, exhibit drift faster than large diameter wires.

Thermocouples For A Nuclear Environment

For reactor instrumentation and control, accuracy and reliability of the temperature sensor are of utmost importance. Thermocouples are presently the only practical method of achieving in-core temperature measurements reliably. The accuracy of the thermocouple is directly related to the wire composition and to the time, temperature and exposure level to which it is subjected.

Neutron fluxes can cause compositional changes in the thermocouple wires. This reaction and transmutation of elements to different elemental isotopes causes changes in the thermoelectric output of the thermocouple. The amount of transmutation (change of one element to another) depends upon neutron velocity, neutron flux density, absorption cross-section of the wire, the exposure time and the half-lives of the isotopes. In general, the slower the neutron, the higher the probability of absorption. Thus, fast neutrons have loser chance of absorption and cause very little compositional change in the wire being irradiated when compared to an equivalent dose of thermal neutrons. They may be instrumental in causing lattice defects and temporary emf changes but these generally anneal out.

The probability of absorption has been measured experimentally for most elements and isotopes and can be expressed as neutron capture cross-section. This thermal neutron capture cross-section listing (Table 6) expressed in barns, shows only the relative probability of neutron absorption by that element. Transmutation from one element to another results when a nuclear reaction produces a radioactive isotope which decays into an isotope of a different element. Exact calculations of the transmutation products for the various elements found in thermocouples become involved because of the various multiple transmutations and half-lives of the isotopes involved.

Some calculated* effects of changes in the major elemental constituents used in common thermocouple materials are listed in Table 7. From this tabulation it can be seen that Chromel (90 Ni-10 Cr) and Alumel (94% Ni) are quite stable while Constantan (55 Ni – 45 Cu) is not so stable with about 10% of the copper converting to nickel and zinc over the 10 year period. The alloys with rhenium, for example (W-W26Rd, W%-W26Re, W3W25Re) are poor and so are the platinum-rhodium alloys because of the rapid transmutation of rhenium and rhodium.

Listed also in Table 6 are densities. Internal heating will occur in any material by absorption of gamma rays. This heating effect is proportional to the material mass (and thus density for a given configuration). In-core gamma heating rates of 5-15 watts/gm are common and should be considered in the thermocouple design. A qualitative guide for thermocouple selection is given in Table 8.

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