

1. INTRODUCTION

1.1 What is Thermocouple Wire?

Wire that is used in a thermocouple from the point of sensing to the point of cold junction compensation (cjc end) where the signal is measured. A thermocouple is a sensor for measuring temperature that consists of two dissimilar metals that are joined together at the sensing end. Different thermocouple types (e.g. J, K, T, E, etc) use different mixtures of metals in the wire. At the cjc (cold junction compensation) end, the millivolt value provided by the thermocouple represents the difference in temperature of the sensing end as compared to the cjc end (also called the reference end). Alternatively, a thermocouple wire is a temperature-measuring instrument consisting of two wires of different metals joined at each end. One junction is placed where the temperature is to be measured, and the other is kept at a constant lower (reference) temperature. A measuring instrument is connected in the electrical circuit. The temperature difference causes the development of an electromotive force (EMF) that is approximately proportional to the difference between the temperatures of the two junctions. Temperature can be read from standard tables, or the instrument can be calibrated to display temperature directly.

1.2 How is insulated thermocouple wires identified?

The insulation on thermocouple wire is color coded for identification. Common guidelines include that the negative lead in insulated thermocouple wire is red. The positive lead has the color of the thermocouple as well as the overall color of insulated extension grade wire. The outer jacket of thermocouple grade wire is typically brown. For high temperature wire, it is common to have a color coded tracer thread in the white material.

1.3 What is the difference between Standard and Special Limits of Error (SLE) wire?

Standard vs. SLE (special limits of error) wire has to do with accuracy of the wire. SLE wire is the same as standard wire with the added feature of having a little better accuracy spec. Accuracy of thermocouples vary with thermocouple types. E.g. For the lower temperature ranges type T, composed of copper wire in the positive lead and constantan (copper-nickel mixture) for the negative has good accuracy specifications.

1.3 What is the difference between Thermocouple grade and Extension grade wire?

Thermocouple grade wire is wire that is used to make **the sensing point** (or probe part) of the thermocouple. Extension grade wire is only used to extend a thermocouple signal from a probe back to the **instrument reading the signal**. The extension grade wire typically will have a lower ambient temperature limit in which the wire may be used. Namely, it may pass a signal representing a higher temperature as received from the probe, but the wire physically may not be exposed to higher temperatures. Thermocouple wire may be used as extension wire, but extension grade wire may not be used in the sensing point (or probe part) of the thermocouple. Part numbers for extension wire typically begin with an "EX" prefix.

1.4 What is the maximum length of thermocouple wire?

There are many factors that can impact the usable length of a thermocouple. As a guideline, less than 100 feet with 20 AWG or thicker wire in an area free of **electromagnetic interference** usually is fine. Two of the main factors in determining useable thermocouple length are **total loop resistance** and preventing electrical noise getting into the signal. Because different thermocouple wires are made of different materials, the resistance will vary based on the **type** as well as the **wire diameter** and length. The allowable loop resistance is affected by the input resistance of the amplifier circuit to which it is attached. But as a guideline, typically the objective is to keep the total loop resistance under 100 ohms. Loop resistance is determined by multiplying the length in feet by the resistance per double feet (remember 1 foot length of run includes 1 foot from each of the two t/c wires) as shown in "Resistance Vs Wire Diameter" table for thermocouple type and gauge. Remember in your calculations to include the probe (when used/applicable) in addition to the wire length. The second major factor in running a thermocouple wire is to keep it away from any **electromagnetic fields**. Thermocouple wire creates a low voltage signal and should not be run near power wires, motors, etc. To help minimize noise pickup, a metal over braid or twisted shielded wire is commonly used.

1.5 Some Common Thermocouple Wire Types

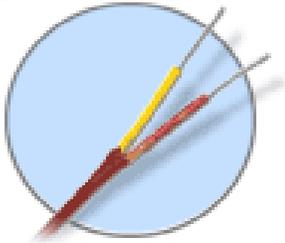
Bare Thermocouple Wire



*Bare
Thermocouple Wire*

Bare Thermocouple Wire is wire without any insulation. Normally it is sold on a spool and ordered as a pair. Usage is typically for making a small thermocouple in applications requiring special considerations.

Duplex Insulated Thermocouple Wire



*Duplex Insulated
Thermocouple Wire*

Duplex Insulated Thermocouple Wire is probably the most common type of thermocouple wire. The type of thermocouple, insulation, and size are all some of the parameters considered for the application.

Metal Sheathed Thermocouple Wire



*Metal Sheathed
Thermocouple Wire*

Metal Sheathed Thermocouple Wire is thermocouple wire that is surrounded by insulation material, typically magnesium oxide, and enclosed in a metal sheath. A key feature of this type of wire includes the ability to withstand vibration, high temperatures and pressures.

1.6 Principle of operation: thermocouple wire

In 1821, the German-Estonian physicist Thomas Johann Seebeck discovered that when any conductor (such as a metal) is subjected to a thermal gradient, it will generate a voltage. This is now known as the **thermoelectric effect or Seebeck effect**. Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original. Fortunately, the magnitude of the effect depends on the metal in use. Using a dissimilar metal to complete the circuit will have a different voltage generated, leaving a small difference voltage available for measurement, which increases with temperature. This difference can typically be between 1 and 70 microvolts per degree Celsius for the modern range of available metal combinations. Certain combinations have become popular as industry standards, **driven by cost, availability, convenience, melting point, chemical properties, stability, and output**.

It is important to note that thermocouples measure the temperature difference **between two points**, not absolute temperature. In traditional applications, one of the junctions — the cold junction — was maintained at a known (reference) temperature, while the other end was attached to a probe.

Thermocouples can be connected in series with each other to form a **thermopile**, where all the **hot junctions are exposed to the higher temperature** and all the **cold junctions to a lower temperature**. Thus, the voltages of the individual thermocouple add up, which allows for a larger voltage and increased power. An example can be when the radioactive decay (of transuranic elements) providing a heat sources this arrangement has been used to power **spacecraft** on missions too far from the sun to utilize solar power.

Having available a known temperature cold junction, while useful for laboratory calibrations, is simply not convenient for most directly connected indicating and control instruments. They incorporate into their circuits an artificial cold junction using some other thermally sensitive device (**such as a thermistor or diode**) to measure the temperature of the **input connections at the instrument**, with special care being taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction applied. This is known as **cold junction compensation (cjc)**.

Additionally, cold junction compensation can be performed by software. Device voltages can be translated into temperatures by **two methods**. Values can either be found in look-up tables or approximated using polynomial coefficients.

Usually the thermocouple is attached to the **indicating device** by a special wire known as the **compensating or extension cable**. The terms are specific. **Extension cable** uses

wires of **nominally the same** conductors as used at the thermocouple itself. These cables are **less costly** than thermocouple wire, **although not cheap**, and are usually produced in a convenient form for **carrying over long distances** - typically as flexible insulated wiring or multicore cables. They are usually specified for accuracy over a more restricted temperature range than the thermocouple wires. They are recommended for best accuracy.

Compensating cables on the other hand, are **less precise, but cheaper**. They use quite different, relatively low cost alloy conductor materials whose **net thermoelectric coefficients are similar** to those of the thermocouple in question (over a limited range of temperatures), but which **do not match them** quite as faithfully as extension cables. The combination develops similar outputs to those of the thermocouple, but the operating temperature range of the compensating cable is restricted to keep the mis-match errors acceptably small.

The extension cable or compensating cable must be **selected to match the thermocouple**. It generates a voltage proportional to the difference between the hot junction and cold junction, and is connected in the correct polarity so that the additional voltage is added to the thermocouple voltage, compensating for the temperature difference between the hot and cold junctions.

1.7 Different types

A variety of thermocouples are available, suitable for different measuring applications (**industrial, scientific, food temperature, medical research, etc.**). They are usually selected based on the **temperature range** and **sensitivity needed**. Thermocouples with low sensitivities (B, R, and S types) have correspondingly lower resolutions. Other selection criteria include the **inertness** of the thermocouple material, and whether or not it is **magnetic**. The thermocouple types are listed below with the **positive electrode** first, followed by the **negative electrode**.

a) Positive Electrode Thermocouple types

Type K: Chromel (Nickel-Chromium Alloy) / Alumel (Nickel-Aluminium Alloy), this is the most commonly used **general purpose** thermocouple. It is inexpensive and, owing to its popularity, available in a **wide variety of probes** or uses. They are available in the $-200\text{ }^{\circ}\text{C}$ to $+1200\text{ }^{\circ}\text{C}$ range. The type K was specified at a time when metallurgy was less advanced than it is today and, consequently, characteristics vary considerably between examples. Another potential problem arises in some situations since one of the constituent metals is magnetic (Nickel). The characteristic of the thermocouple undergoes a step change when a magnetic material reaches its **Curie point** (the temperature at which the molecules of a material can be altered when subjected to a magnetic field. In optical material, it is approximately 200 degrees Celsius). This occurs for this thermocouple at $354\text{ }^{\circ}\text{C}$. Sensitivity is approximately $41\text{ }\mu\text{V}/^{\circ}\text{C}$.

Type E: Chromel / Constantan (Copper-Nickel Alloy), type E has a high output ($68 \mu\text{V}/^\circ\text{C}$) which makes it well suited to **cryogenic use** (the branch of technology concerned with the behavior of materials at very low temperatures, particularly temperatures near absolute zero. Applications of cryogenics include the storage and transport of liquefied gases, food preservation, cryosurgery, rocket fuels, and superconducting electromagnets). Additionally, it is non-magnetic.

Type J: Iron / Constantan, its limited range (-40 to $+750^\circ\text{C}$) makes type J less popular than type K. The main application is with **old equipment** that cannot accept modern thermocouples. J types cannot be used above 760°C as an abrupt magnetic transformation causes permanent decalibration. The magnetic properties also prevent use in some applications. Type J's have a sensitivity of $\sim 52 \mu\text{V}/^\circ\text{C}$.

Type N: Nicrosil (Nickel-Chromium-Silicon Alloy) / Nisil (Nickel-Silicon Alloy) have high stability and resistance to high temperature oxidation makes type N suitable for high temperature measurements **without the cost of platinum** (B, R, S) types. They can withstand temperatures above 1200°C . Sensitivity is about $39 \mu\text{V}/^\circ\text{C}$ at 900°C , slightly lower than a Type K. Designed to be an improved type K, it is becoming more popular.

b) Negative Electrode Thermocouple Types

Thermocouple types B, R, and S are all **noble metal** (a precious metal, usually one that does not readily oxidize, such as gold or platinum thermocouples and exhibit similar characteristics). They are the most stable of all thermocouples, but due to their low sensitivity (approximately $10 \mu\text{V}/^\circ\text{C}$) they are usually only used for high temperature measurement ($>300^\circ\text{C}$).

Type B: Platinum 30% Rhodium / Platinum 6% Rhodium, they are suited for high temperature measurements up to 1800°C . Type B thermocouples (due to the shape of their temperature-voltage curve) give the same output at 0°C and 42°C . This makes them useless below 50°C .

Type R: Platinum 13% Rhodium / Platinum is suited for high temperature measurements up to 1600°C . Low sensitivity ($10 \mu\text{V}/^\circ\text{C}$) and high cost makes them unsuitable for general purpose use.

Type S: Platinum 10% Rhodium / Platinum is suited for high temperature measurements up to 1600°C . Low sensitivity ($10 \mu\text{V}/^\circ\text{C}$) and high cost makes them unsuitable for general purpose use. Due to its high stability, type S is used as the standard of calibration for the melting point of gold (1064.43°C).

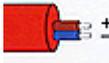
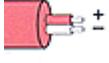
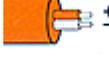
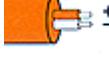
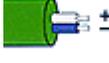
Type T: Copper / Constantan, is suited for measurements in the -200 to 350 °C range. Often used as a differential measurement since only copper wire touches the probes. As both conductors are non-magnetic, type T thermocouples are a popular choice for applications such as **electrical generators** which contain strong magnetic fields. Type T thermocouples have a sensitivity of $\sim 43 \mu\text{V}/^\circ\text{C}$.

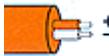
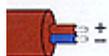
Type C: Tungsten 5% Rhenium / Tungsten 26% Rhenium, is suited for measurements in the 32 to 4208°F (0 to 2320°C). This thermocouple is well-suited for vacuum furnaces at extremely high temperatures and must never be used in the presence of oxygen at temperatures above 500°F .

Type M: Nickel Alloy 19 / Nickel-Molybdenum Alloy 20, this type are used in the **vacuum furnaces** as well for the same reasons as with type C above. Upper temperature is limited to 2500°F ($\sim 1400^\circ\text{C}$).

c) Identification

Thermocouple types can be identified based on wire insulation color.

Type	Temperature range °C (continuous)	Temperature range °C (short term)	Tolerance class 1 (°C)	Tolerance class 2 (°C)	IEC Colour code	BS Colour code	ANSI Colour code
K	0 to +1100	-180 to +1300	-40 to +375 ± 1.5 °C, 375 to 1000 $\pm 0.004*[t]$ °C	-40 to +333 ± 2.5 °C, 333 to 1200 $\pm 0.0075*[t]$ °C			
J	0 to +700	-180 to +800	-40 to +375 ± 1.5 °C, 375 to 750 $\pm 0.004*[t]$ °C	-40 to +333 ± 2.5 °C, 333 to 750 $\pm 0.0075*[t]$ °C			
N	0 to +1100	-270 to +1300	-40 to +375 ± 1.5 °C, 375 to 1000 $\pm 0.004*[t]$ °C	-40 to +333 ± 2.5 °C, 333 to 1200 $\pm 0.0075*[t]$ °C			
R	0 to +1600	-50 to +1700	0 to +1100 ± 1.0 °C, 1100 to 1600 $\pm (1+0.003 (t-1100))*[t]$ °C	0 to +600 ± 1.5 °C, 600 to 1600 $\pm 0.0025*[t]$ °C			Not defined.

S	0 to 1600	-50 to +1750	0 to +1100 $\pm 1.0^\circ\text{C}$, 1100 to $1600 \pm$ $(1+0.003(t-1100))*[t]^\circ\text{C}$	0 to +600 \pm 1.5°C , 600 to 1600 \pm $0.0025*[t]^\circ\text{C}$	 \pm  \pm	Not defined.	
B	+200 to +1700	0 to +1820	Not Available	600 to 1700 \pm $0.0025*[t]^\circ\text{C}$	No standard use copper wire	No standard use copper wire	Not defined.
T	-185 to +300	-250 to +400	-40 to +125 $\pm 0.5^\circ\text{C}$, 125 to 350 \pm $0.004*[t]^\circ\text{C}$	-40 to +133 $\pm 1.0^\circ\text{C}$, 133 to 350 \pm $0.0075*[t]^\circ\text{C}$	 \pm  \pm		
E	0 to +800	-40 to +900	-40 to +375 $\pm 1.5^\circ\text{C}$, 375 to 800 \pm $0.004*[t]^\circ\text{C}$	-40 to +333 $\pm 2.5^\circ\text{C}$, 333 to 900 \pm $0.0075*[t]^\circ\text{C}$	 \pm  \pm		

1.8 Applications

Thermocouples are most suitable for measuring over a large temperature range, up to 1800 K. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0–100 °C with 0.1 °C accuracy. For such applications, **thermistors** (a resistor made of semiconductors having resistance that varies rapidly and predictably with temperature) **and RTDs** (a thermometer in which the sensing element is a resistor whose resistance is an accurately known function of temperature), are more suitable.

a) Steel Industry

Type B, S, R and K thermocouples are used extensively in the **steel and iron industry** to monitor temperatures and chemistry throughout the steel making process. Disposable, immersible, Type S thermocouples are regularly used in the electric arc furnace process to accurately measure the steel's temperature before tapping. The cooling curve of a small steel sample can be analyzed and used to estimate the carbon content of molten steel.

b) Heating appliance safety

Many gas-fed heating appliances like ovens and water heaters make use of a pilot light to ignite the main gas burner as required. If the pilot light becomes extinguished for any reason, there is the potential for un-combusted gas to be released into the surrounding area, thereby creating both risk of fire and a health hazard. To prevent such a danger, some appliances use a thermocouple as a fail-safe control to sense when the pilot light is burning. The tip of the thermocouple is placed in the pilot flame. The resultant voltage, typically around 20 mV, operates the gas supply valve responsible for feeding the pilot. So long as the pilot flame remains lit, the thermocouple remains hot and holds the pilot gas valve open. If the pilot light goes out, the temperature will fall along with a corresponding drop in voltage across the thermocouple leads, removing power from the valve. The valve closes, shutting off the gas and halting this unsafe condition.

Many systems (Millivolt control systems) extend this concept to the main gas valve as well. Not only does the voltage created by the pilot thermocouple activate the pilot gas valve, it is also routed through a thermostat to power the main gas valve as well. Here, a larger voltage is needed than in a pilot flame safety system described above, and a thermopile is used rather than a single thermocouple. Such a system requires no external source of electricity for its operation and so can operate during a power failure, provided all the related system components allow for this. Note that this excludes common forced air furnaces because external power is required to operate the blower motor, but this feature is especially useful for un-powered convection heaters.

A similar gas shut-off safety mechanism using a thermocouple is sometimes employed to ensure that the main burner ignites within a certain time period, shutting off the main burner gas supply valve should that not happen.

Out of concern for wasted energy, many newer appliances have switched to an electronically controlled pilot-less ignition, also called intermittent ignition. This eliminates the need for a standing pilot flame but loses the benefit of any operation without a continuous source of electricity.

c) Thermopile radiation sensors

Thermopiles are used for measuring the intensity of incident radiation, typically visible or infrared light, which heats the hot junctions, while the cold junctions are on a heat sink. It is possible to measure radiative intensities of only a few $\mu\text{W}/\text{cm}^2$ with commercially available thermopile sensors. For example, laser power meters are based on such sensors.

d) Radioisotope thermoelectric generators (RTGs)

Thermopiles can also be applied to generate electricity in radioisotope thermoelectric generators.

2. INTERNATIONAL MANUFACTURING DYNAMICS

The importance of stable and reliable sensors to measure high temperatures is well known. A large portion of these sensors are letter-designated thermocouples with standardized emf-to-temperature conversion functions. One advantage of these sensors is their ability to be manufactured and purchased internationally from many vendors all conforming to the same standardized table. Because the sensors are thus constrained to meet this standardized curve the **manufacturers must maintain tight control on raw material and production processes** adding to the cost and decreasing the availability of the sensors.

Even the simplest of thermocouple temperature sensors requires a high level of skill to produce. Starting with the melting of the alloy all the way to the junction formation each step to the final product can result in an unacceptable calibration leaving scrap material. At the alloy caster a **prescribed recipe of various elements is used** to achieve the final product with some of the thermocouple alloys requiring up to 8 constituents. With variance in the melting process each melt must be tested for **thermoelectric output** before pouring and wire drawing operations. Volatility of the alloying elements while molten allows for only brief testing and slight adjustment before pouring. If the producer has been unable to attain the desired thermoelectric properties the entire melt becomes scrap.

The cast ingot of alloy is then **rolled, drawn and annealed** to form large spools of bare thermocouple alloy. Again variation in this process of drawing and annealing can produce calibration shifts which move the alloy wire out of tolerance. Sensor manufacturers can compensate for this somewhat by matching the positive and negative thermoelements of the thermocouple but of course this complicates the manufacturing process. And even matching thermoelements can still be plagued by inhomogeneity from end to end of a coil of wire requiring not only a constraint on the calibration of the raw materials but also homogeneity constraint within one lot of material.

This simple example of a bare wire thermocouple becomes much more complicated in the manufacture of **mineral insulated** metal sheathed (MI) thermocouple cable. MI cable is manufactured by inserting thermocouple thermoelements into mineral based insulators and then encasing this assembly in a metal sheath. This then is reduced in size and compacted through a series of reduction and annealing processes. In some cases there can be as many as 20 reduction and anneal steps with anneal temperatures over 1,000°C. These steps can change both the metallurgy and chemistry of the thermoelements and thus shift the calibration. Most manufacturers have a high degree of control over their process to make MI cable, but these controls are not perfect and can lead to scrap material. Also the process shift varies among manufacturers requiring that the alloy suppliers offer a wide range of calibrations to satisfy the various MI cable producers.

All of these problems are the result of calibration constraints placed on the finished product as supplied to the final user. Separating these electrical property constraints from basic material performance constraints would ease the manufacturing process resulting in lower cost, increased availability, and reproducibility. One way of separating the two is through the use of **smart sensing technology**. Combining the advantages of **modern digital electronics** with advances in high temperature alloy materials opens a door to a new era in **thermocouple thermometry**.

3. BACKGROUND OF A NEW/ BREAKTHROUGH INVENTION

The smart thermocouple system consisting of nonstandard thermocouples coupled with a memory to a compatible data acquisition system will overcome some of the material problems associated with thermocouple thermometry including raw material and processing issues. Firstly, the **problems with the thermocouple processing** that arise from the material and processing constraints will be explained and then the **instrumentation issues** that allow for this new approach to thermocouple thermometry will be addressed.

3.1 Thermocouple Manufacturing; Raw Materials

Crushable ceramic insulators, metal tubing, and thermoelement alloys are combined to manufacture MI cable, the materials chosen based on the intended application. A large number of the MI (Mineral Insulated) cable applications use a type **K thermocouple** with MgO insulation and alloy 600 sheath. Even though the condition of the thermoelements is by far the major factor in the calibration of the finished thermocouple, the other components also can contribute to the calibration performance over time. The choice of **sheath material** can increase the diffusion potential of some of the alloying elements in the thermocouple. A sheath material that is more compatible with the thermoelements will exhibit less shift in calibration over time at temperature. Usually sheath material is determined by the intended application so only material availability and process compatibility limit choices. Unfortunately since standardized letter designations are the only option there are few design alternatives available to the sensor manufacturer in selecting the thermoelement alloys. The design is limited to matching the calibration of the wire pair in most applications. The positive and negative thermocouple wires are matched based on their emf calibration so that the combination of the two wires will be a successful thermocouple after processing.

Because of shifts that occur during processing a slight offset of the raw material thermoelement alloy calibration is desirable and the amount of this offset varies with **sheath material selection, manufacturer, and alloy wire vendor**. Supplies of this offset material are available on a limited basis from the alloy vendors. Unfortunately the

number of thermocouple alloy vendors is small and getting smaller. The recent loss of vendors such as **Hoskins and Harrison** and the reorganization of Specialty Metals have reduced the number of suppliers and sent shock waves through the industry as MI cable manufacturers have needed to adjust their processing to accommodate material from new suppliers. While the remaining suppliers are robust, the thermocouple alloy business of companies such as **Carpenter, Isabellenhutte and Kanthal** represents a small portion of their overall business. In the past alloy suppliers provided custom material to meet the processing requirements of their customers. This has changed and now the MI cable manufacturers purchase stock material based on calibration information. Because of the uncertain availability of acceptable alloy the cable manufacturers purchase large stockpiles of wire alloy when an acceptable batch is located. Obviously this leads to suboptimal manufacturing.

3.2 Thermocouple Manufacturing; Processing

The manufacture of MI thermocouple cable consists of a number of **swage or draws and anneals** steps done on a sheathed assembly containing at least two thermoelements electrically insulated with crushable ceramic insulators. Each draw step reduces the diameter of the sheath and elongates the entire assembly. The cold work done in this draw process is then removed by an anneal step done at high temperature in a prescribed environment. Every draw and anneal step may be a source of calibration shift from either a change in the metallurgical structure of the thermoelements or a change in the chemistry of the thermoelements. In particular the **most popular thermocouple** for high temperature thermometry, type K, has a multitude of alloying elements. These alloying elements react and diffuse during the manufacturing process leading to decalibration and inhomogeneity. A common test for inhomogeneity is a flame test where the cable is pulled through a torch flame to provide a sharp thermal gradient over the wire. Inhomogeneity and low insulation resistance are detected in this test. Low alloyed thermocouples such as type J consisting of iron and a nickel/copper alloy leg rarely fail the flame test. Type K MI cable thermocouples fail this test occasionally and one mechanism for these failures is the diffusion and reaction of the alloying elements in type K. Reducing the number or alloying elements or their effect on the emf output would remove this failure mechanism from MI thermocouples.

3.3 Digital and electronic signal conditioning

In the early days of thermocouple temperature measurement the instruments used to read the sensors was analog design. Because of this the early thermoelements were designed to not only be robust but also to have a linear output. While these thoroughbred alloys are marvels of engineering the sacrifices made to meet the linearity constraint reduced some of the performance capabilities of the alloys. **Now that digital instrumentation** is the standard device the linearity requirement is obviated but the legacy of standardized conversion tables has not allowed the constraints to be relaxed. The industry still relies on alloys developed in the early 1900s in spite of the availability of new high temperature

alloys not specifically designed for the temperature sensor applications but suitable nevertheless.

3.4 A new approach

Nonstandard Thermoelements

Current thermocouple thermometry is done almost strictly with standard letter designated thermoelements such as the Cr/Ni and Al/Si/Mn/Ni based alloys of the type K thermocouple, the Fe and Cu/Ni of type J, the Si/Ni and Cr/Si/Ni of type N, and the Pt and Pt/Rh of the noble R, S, and B among others. Although the chemistry of the thermoelement is not specified in the standard the alloys from suppliers vary little from the nominal compositions. These alloys were developed for a multitude of reasons including their high temperature stability. One of these other reasons, the linearity of the output signal over a broad temperature range, was due mainly to the analog instrumentation available at the time. The proliferation of digital instrumentation has removed this linearity requirement for thermoelement alloys and opened up a broad range of high temperature alloys for use as thermoelements. Alloys such as the 300 series stainless steels, Inconel 600 and 601, Haynes 214, 230, 188, and 556, and Hastelloy X all have characteristics that make them robust materials at high temperatures. Some elemental thermocouples have other performance or application advantages. For instance the Pt/Au thermocouple has been shown to have advantageous stability properties and the Mo/Nb and Al/Ni thermocouples are suitable for thin film applications.

3.5 Smart Sensing

Various implementations of smart sensing exist in the marketplace today. Some manufacturers of smart sensing utilize bar codes or floppy disks to transfer information about the sensor from the vendor to the user. Others utilize more automated means such as memory chips or information keys while still others integrate signal conditioning electronics with the sensor element onto the same substrate. In all cases the basic concept is to tie information with the sensor

Most manufacturers of **high temperature thermocouple temperature sensors** have the ability to perform precision calibration of the finished sensor. From this calibration data a **custom conversion function** can be developed to describe the emf-to-temperature relation for a particular sensor. For metal thermocouples **polynomials or spline functions** provide adequate characterization. The coefficients for these functions can be calculated using **least squares techniques** on the calibration data. These coefficients then become the information to characterize the sensor in a **smart system**. This custom calibration information then becomes the tool **that allows the material constraints to be removed**.

3.6 In a nutshell

Industrial thermocouple temperature measurement can be improved through the availability of suitable high temperature alloys and smart electronics. An MI thermocouple constructed of alloy 600 and NN thermoelements in an alloy 600 sheath is more stable in high temperature environments than the standard letter designated, nickel based thermocouples. Coupling **smart sensing electronics** with these nonstandard thermocouples improves the performance characteristics and the manufacturing processes for these high temperature industrial thermocouples.

4. INTERNATIONAL SUPPLY AND DEMAND STATISTICS: AN APPROXIMATION

Instrument Parts & Accessories:

- Non-ferrous Metal Alloy
- Other Wires, Cables & Cable Assemblies
- Temperature Instruments
- View less
- Parts & Accessories
- Sensors
- Other Electronic Components
- Other Electrical Equipment
- Electrical Wires
- Electronic & Instrument Enclosures

Manufacturing Region:

- China (mainland) (266)
- India (33)
- Hong Kong (3)
- Malaysia (3)
- United States (3)
- Japan (2)
- Spain (2)
- Taiwan (2)
- Egypt (1)
- Indonesia (1)
- Iran (Islamic Republic of) (1)
- Netherlands (1)
- Russian Federation (1)
- Saudi Arabia (1)
- Turkey (1)

- United Arab Emirates (1)
- United Kingdom (1)

Main Export Markets:

- North America (303)
- South America (294)
- Western Europe (304)
- Eastern Europe (280)
- Eastern Asia (280)
- Southeast Asia (248)
- Mid East (307)
- Africa (266)
- Oceania (238)

Business Type:

- Manufacturer (288)
- Trading Company (107)
- Agent (11)
- Distributor/Wholesaler (12)
- Association (2)

Contract Manufacturing:

- OEM (Original Equipment Manufacturer) Service Offered (247)
- Design Service Offered (121)
- Buyer Label Offered (62)

5. VALUE CHAIN ANALYSIS: WITH LIMPOPO’S MINERAL RESERVE AS A FOCUS

Letter designations and compositions for standardized thermocouples:

Type designation	Materials
B	Platinum-30% rhodium/platinum-6% rhodium
E	Nickel-chromium alloy/a copper-nickel alloy
J	Iron/another slightly different copper-nickel alloy
K	Nickel-chromium alloy/nickel-aluminum alloy
R	Platinum-13% rhodium/platinum
S	Platinum-10% rhodium/platinum
T	Copper/a copper-nickel alloy

Schematic Representation of the value chain:

