Whitepaper

Double Junction Thermocouples

The accuracy of the CJC sensor in a temperature indicator is critical in order to make accurate measurements with thermocouples

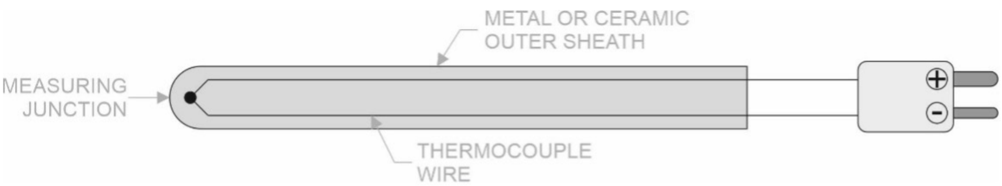
The use of a DJT provides a test thermocouple with a RJ which is inherently more accurate than using an electronic internal CJC system

PART 1: Double Junction Thermocouple What is it and how can it be used?

The Thermocouple

In simple terms a thermocouple is made up of two wires of different metals welded together to form a measuring junction, the wires are insulated with PTFE, ceramic or compressed mineral (MIMS) and the wires are terminated in a plug whose connectors are manufactured from the same material as the wire.

Note: *A thermocouple only generates an output when a temperature gradient exists across the length of the wire.*



Thermocouple are invariably used with some form of temperature indicator.

Cold Junction Compensation (CJC)

As the thermocouple above is connected to a temperature indicator the wires of the thermocouple are connected to the copper input terminals of the temperature indicator. This connection is made at ambient temperature.

Considering the note above, the measurement at the input terminals will be as follows;

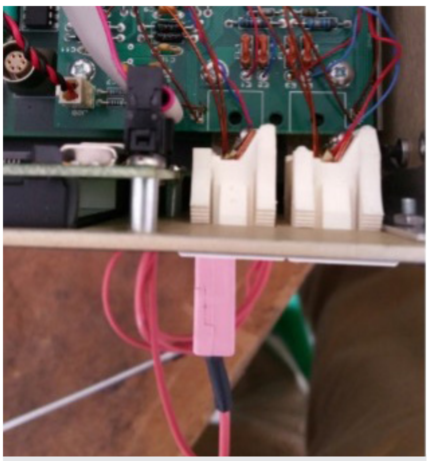
tm (= tg) = tp – ta

Where;
tm = Measured temperature
tg = Temperature gradient along the thermocouple wires
tp = Process temperature
ta = Ambient temperature

81 °C = 100 °C – 19 °C

As can be seen the measured temperature is in error by the equivalent of ambient temperature, therefore a correction or compensation needs to be made.

Temperature indicators do this using a temperature sensor positioned in close physical and thermal proximity to its copper input terminals. This sensor is usually an RTD, thermistor or diode and is used to pick up the temperature of the input terminals.



CJC temperature sensor embedded into the rear of a thermocouple input connector of a temperature indicator

The electronics of the indicator then adds this Cold Junction Compensation (CJC) temperature value to the measured value on its inputs to provide compensation for this ambient error.

The measured temperature can now be described as;

tm (= tg) = tp – ta + tc

Where;
tm = Measured temperature
tg = Temperature gradient along the thermocouple wires
tp = Process temperature
ta = Ambient temperature
tc = CJC temperature

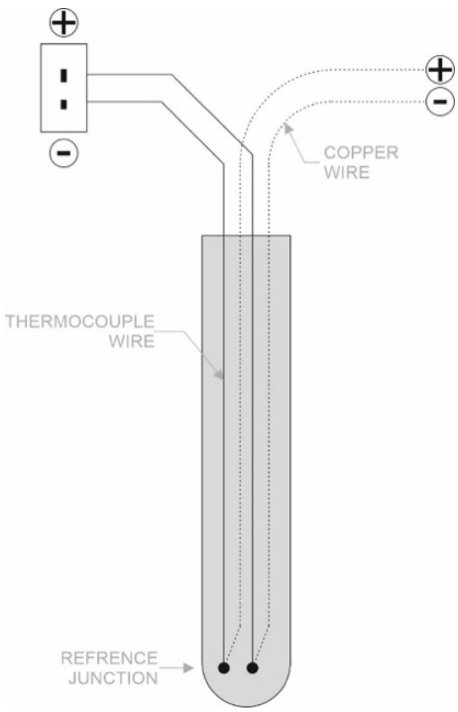
100 °C = 100°C – 19 °C + 19 °C

As can be appreciated the accuracy of this CJC sensor is critical in order to make accurate measurements with thermocouples (to be discussed in Part 2).

Cold Junction (CJ) or Reference Junction (RJ)

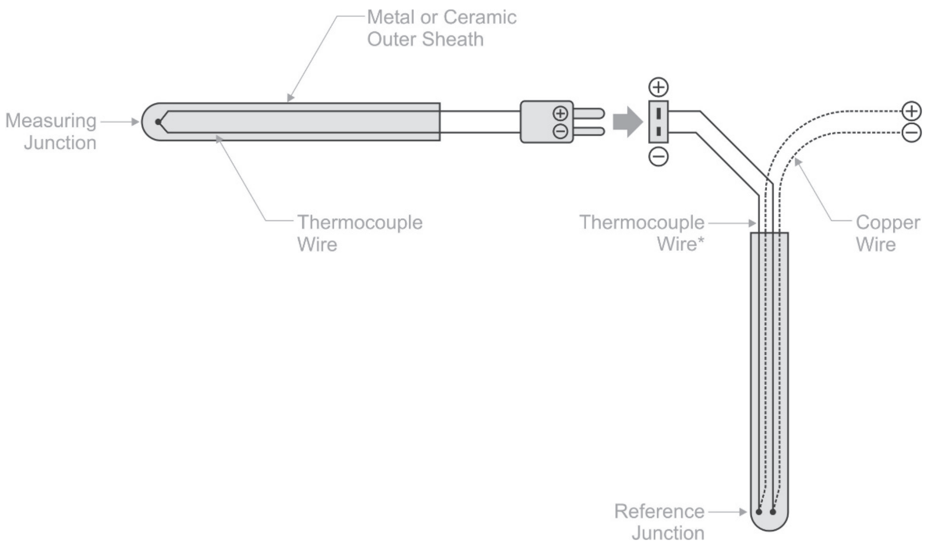
Where a user doesn't have access to a dedicated temperature indicator a measuring instrument such as a Digital Voltmeter (DVM) may be used. This type of instrument is unlikely to have the capability to provide internal CJC.

Under these circumstances the user will require additional equipment to measure the output of the thermocouple.



This is done by utilising a Double Junction Thermocouple (DJT).

The DJT consists of a length of thermocouple wire with copper wires welded to one end. This weld or junction is known as the Cold Junction (CJ) or Reference Junction (RJ), it will be referred to as RJ throughout this paper.



The open end of the DJT can be connected to the output of the test thermocouple via a suitable thermocouple plug/socket.

By maintaining the RJ at a known constant temperature (generally 0°C) the output of the thermocouple can be measured accurately via the copper wires connected to the DVM.

Isotech produce a Model 880 Double Junction Thermocouple which can be manufactured for any thermocouple type.

The measured temperature can now be described as;

tm = tp + tr

Where;
tm = Measured temperature
tp = Process temperature
tr = RJ temperature

100 °C = 100 °C + 0 °C

The method of using these DJT to provide the test thermocouple with a RJ is inherently more accurate than using an electronic internal CJC system.

However, to attain the ultimate accuracy, the errors associated with the DJT must be established and corrected for during use (to be discussed in Part 2).

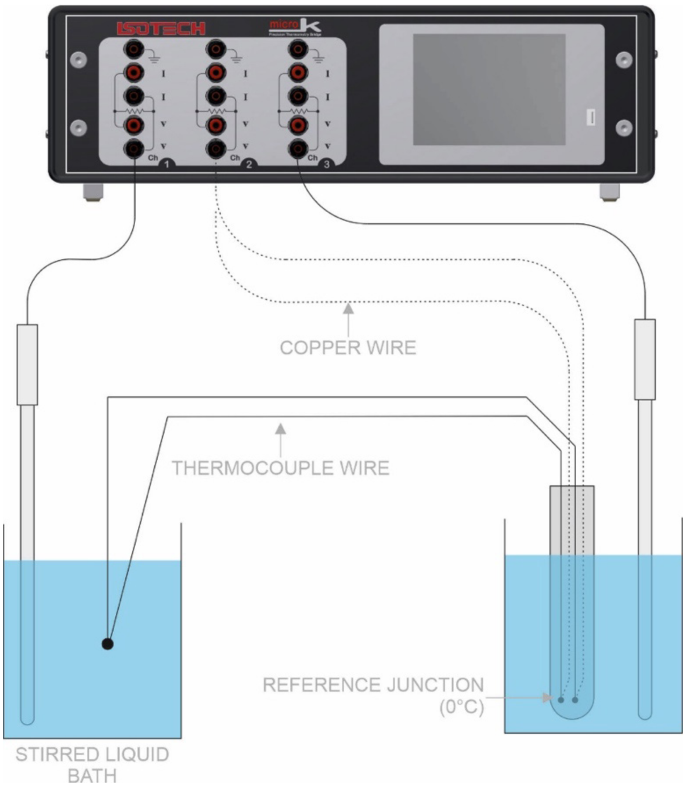
Calibration of a Double Junction Thermocouple (DJT)

To establish the error associated with the DJT the thermocouple must be calibrated.

In order to do this the open end of the DJT must be welded together to create a measuring junction.

A typical calibration set up is shown below.

The measuring junction is placed into a stirred liquid bath and the RJ is placed into ice/water or in a TRU (thermocouple reference unit) or similar device.



Both baths should be stable and measured with calibrated thermometers. The output of the DJT is measured on a calibrated DVM. Alternatively, all three measurements could be accommodated simultaneously on a microK.

By converting the temperature of the stirred liquid bath to equivalent Voltage using IEC 60584-1 (for the specific thermocouple type being calibrated), this value can then be compared to the DJT output to establish its error.

As the DJT will only ever be connected to a test thermocouple at ambient temperature then the temperature of interest and hence the calibration points should span ambient, 15 °C to 25 °C.

Example results:

Measured liquid bath temperature °C	Equivalent Type J Voltage (IEC 60584-1) µV	Reference junction temperature °C	Measured output of Type J DJT µV	Double junction error (DJT output - Equivalent IEC 60584-1) µV
15.00	762	0.00	763	+1
20.01	1020	0.00	1021	+1
24.99	1277	0.00	1278	+1

Once calibrated the error associated with the double junction thermocouple can be corrected for during use.

PART 2: Double Junction Thermocouple What is it and how can it be used?

We have seen in Part 1, the different ways in which Cold Junction Compensation can be provided when making measurements with thermocouples.

It was explained how the use of a simple calibrated Double Junction Thermocouple (DJT) could offer a superior accuracy Reference Junction (RJ) (or Cold Junction, CJ).

The following sections show the versatility of the DJT.

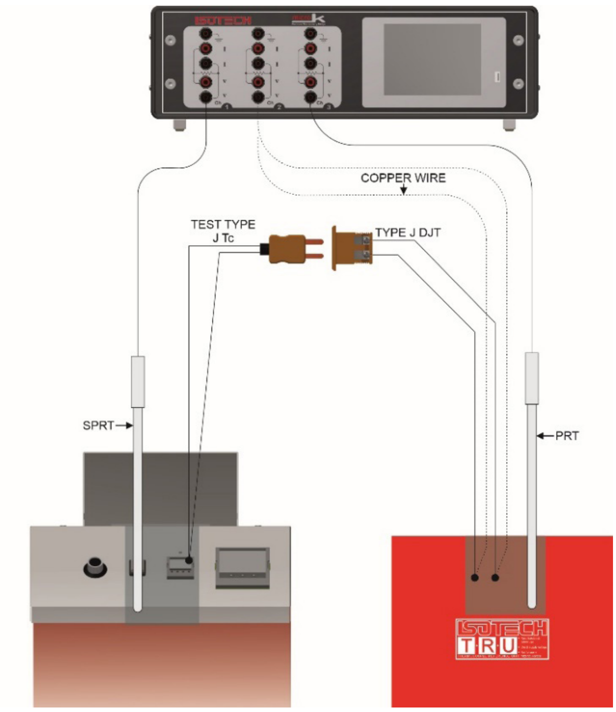
An accurate Reference Junction (RJ) for a test thermocouple

When calibrating thermocouples there is an obvious need to provide some form of referencing in order to correctly and accurately measure the output of the thermocouple.

The easiest option as described in Part 1 is to use a Temperature Indicator with internal Cold Junction Compensation (CJC), however this method is not ideal.

RJ sensors used in these Temperature Indicators are low quality and as such are prone to error during calibration. Any error here directly correlates to an error in the measured output of the thermocouple.

A more accurate solution is shown below.



The example above shows a calibrated type J DJT fitted with a thermocouple socket. The type J thermocouple under test is connected to the DJT via a thermocouple plug and the output is measured on the copper wires of the DJT by a microK (reference voltmeter or instrument who's internal CJC can be switched off).

The output of the test thermocouple can simply be corrected, for the error in the DJT.

The corrected output voltage of the test thermocouple can be described as;

vco = vm - vr

Where;
vco = Corrected output voltage of the test thermocouple
vm = Measured output voltage
vr = DJT error at 20 °C from its calibration

Example;
The temperature in a calibration bath as measured by a Standard Platinum Resistance Thermometer (SPRT) = 100.23 °C
The temperature in the laboratory (where the test thermocouple is connected to the DJT) = 20.00 °C
The measured output voltage = 5290 μV
The DJT error at 20 °C from its calibration = +1 μV
vco = 5290 μV – 1 μV
vco = 5289 μV

From this the error of the test thermocouple can be calculated.

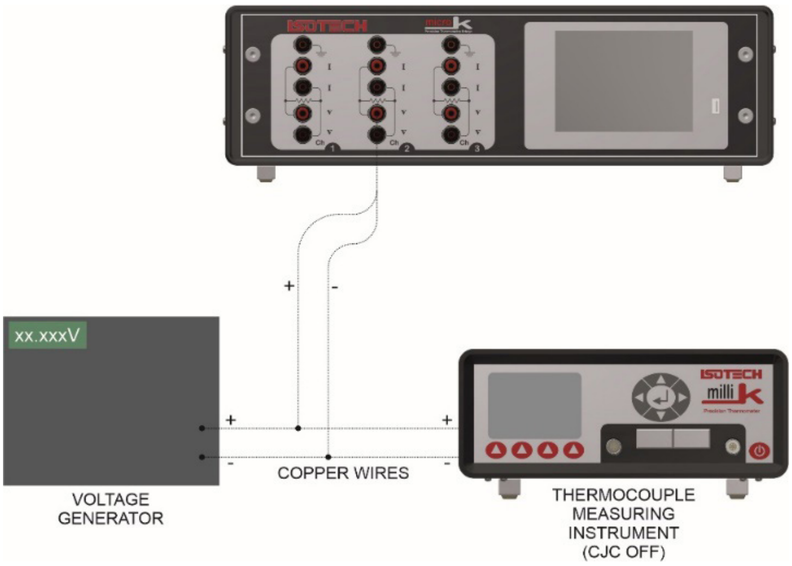
Calibration Temperature (°C)	Equivalent type J Tc μV (using IEC 60584)	Measured output voltage of test type J TC (μV)	Type J DJT error at 20°C (μV)	Corrected output voltage of test type J Tc (μV)	Error of test type J Tc (μV)	Error of test type J Tc in °C (using IEC 60584)
100.23	5281	5290	1	5289	8	0.15

Electrical Simulation of Thermocouple Measuring Instruments using a DJT

Some thermocouple measuring instruments have the ability to switch the internal CJC on or off. This choice is dependent on whether the thermocouple being measured his fitted with its own RJ or not.

Invariably these instruments require some form of traceable calibration in order to quantify any measurement error.

With the CJC switched off the electrical calibration is simple.



The voltage generator is set to output a voltage that is equivalent to a specific temperature for a particular thermocouple type. The international standard IEC 60584 can be used for these values.

The output voltage from the generator can be accurately set by using a microK (or reference voltmeter) connected across its outputs.

With the measuring instrument under test set to the same thermocouple type and with its internal CJC switched OFF it will indicate the voltage and/or converted temperature that has been applied.

Test Temperature (°C)	Equivalent Type J μV set on Voltage Generator (IEC 60584)	Test Instrument Indicated Voltage (μV)	Test Instrument Voltage error (μV)	Test Instrument Indicated Temperature (°C)	Test Instrument Temperature error (°C)
100.00	5269	5270	1	100.02	0.02

This method of calibration establishes the voltage and/or temperature error of the instrument.

However, the error associated with the internal CJC sensor of the instrument is still unknown.

This will require a separate calibration.

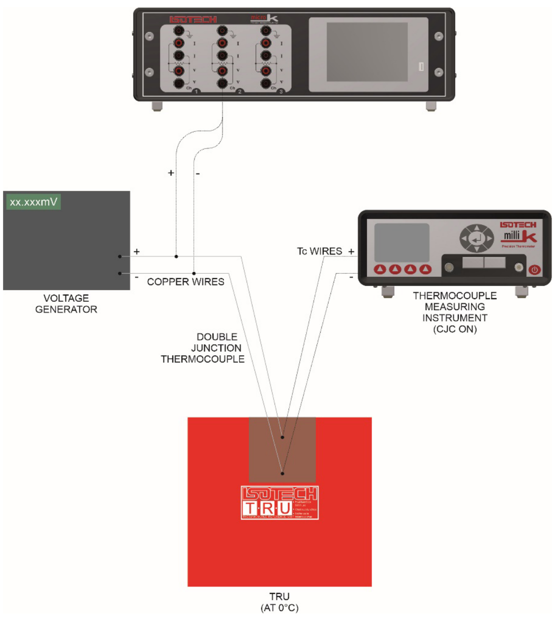
For this calibration some thermocouple measuring instruments will allow the internal CJC sensor to be automatically calibrated by the application of a known temperature on its inputs, some instruments may just indicate the live internal CJC sensor temperature, whilst other instruments may not offer either of these.

Regardless of the functionality of the instrument under test a DJT can be used to simulate a known temperature on the inputs. This will either allow the automatic calibration to take place or the indicated temperature can be compared to the simulated input temperature to establish the internal CJC error.

Throughout this calibration the internal CJC of the measuring instrument under test should be switched ON.

The required simulated temperature for most instruments employing automatic CJC calibration is 20.00 °C as this is a good approximation of the CJC temperature of an instrument during use. This temperature is also suitable for calibrating the internal CJC of more basic instruments.

The test set up is similar to that above but with the addition of a calibrated DJT.



The RJ of the DJT is maintained at 0°C in a Thermocouple Referencing Unit (TRU) and the copper wires of the DJT are connected to the voltage generator.

The output from the voltage generator can be accurately set using a microK (or reference voltmeter), to a voltage equivalent to 20.00 °C for a particular thermocouple type taking into account the calibration error of the DJT.

The required voltage generator output to take into account the DJT error can be described as;

vgo = vt + vr

Where;
vgo = Voltage generator set output
vt = IEC 60584 test temperature equivalent voltage
vr = DJT error at 20 °C from its calibration

For this sort of calibration, it is best to use a DJT type which has a large Seebeck coefficient such as type J or type E, this gives more sensitivity to the calibration.

Example set of results.

Test Temperature (°C)	Equivalent Type J μV (IEC 60584)	Type J DJT error at 20 °C (μV)	Set output of Voltage Generator (Corrected for DJT error) (μV)	Indicated Temperature (°C)	Internal CJC sensor Error (°C)
20.00	1019	1	1020	20.10	0.10

The error in the table above is dominated by the internal CJC error but it also includes the measurement capability of the instrument itself.

The advantage of this technique is that with one measurement a user can establish the overall measurement error of the thermocouple measuring instrument being used.

This same method can be used to simulate any temperature by simply adjusting the voltage generator set output and of course any thermocouple type can be tested by the use of different DJT type.

The Isotech Model 880 Double Junction Thermocouple is available in a variety of thermocouple combinations and has been designed with these different applications in mind.

These Model 880 DJT's are used extensively in the range of thermocouple reference systems manufactured by Isotech.

Thermocouple Referencing Systems

These reference systems house a stable, temperature controlled isothermal block in which a large number of DJT's are permanently fitted.

Thermocouples in process requiring accurate referencing can be connected to these systems. The output voltage from each thermocouple can in turn be measured with a microK or reference voltmeter and the DJT error corrected for as shown previously.

For added confidence these systems are fitted with a calibrated Pt100 in order to establish the exact temperature and stability of the isothermal block (RJ) during use therefore further eliminating more sources of error.

TRU Model 937 Thermocouple Reference Unit

TRURAC Model 847 & ISORAC Model 844

HOTBOX Model 830

Help and Advice

If you need low uncertainty measuring systems we can help, contact us for free advice and consultation. We have proven solutions at all levels in temperature metrology, from high accuracy cost effective industrial measurements systems to the lowest uncertainty systems for primary metrology used by the world's leading National Metrology Institutes.

If you have any questions, if you need any advice, if you would like a free consultation then please get in touch.

ISSUE 01 09/20

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