ADNOC GAS PROCESSING

Temperature Instrument Devices

Best Practice

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This module is prepared for training purpose

Best practice to understand temperature instrument devices

The temperature transmitter is an instrumentation device to transmit signal from temperature element such as RTD or Thermocouple to monitoring devices or controlling devices such as Controller, PLC, DCS or Display box. The role of temperature transmitter is to convert the temperature sensor specific unit to a signal standard 4-20 mA, it is required since the majority of industrial equipment used is formatted to communicate within this signal range. Refer to illustration below, show a temperature transmitter full loop from sensor to monitoring device.

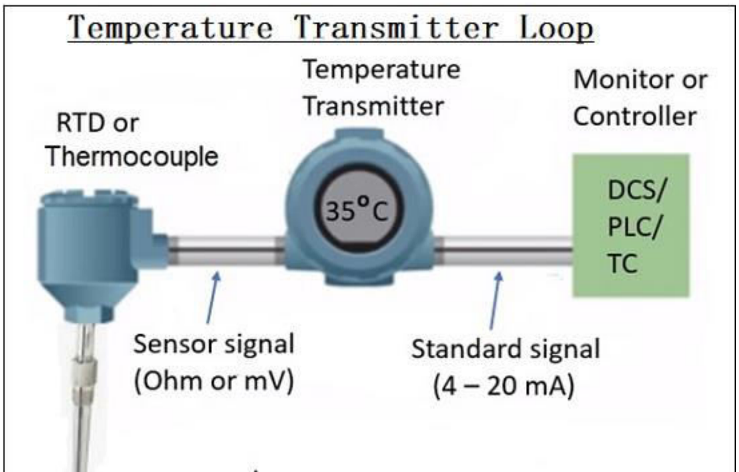
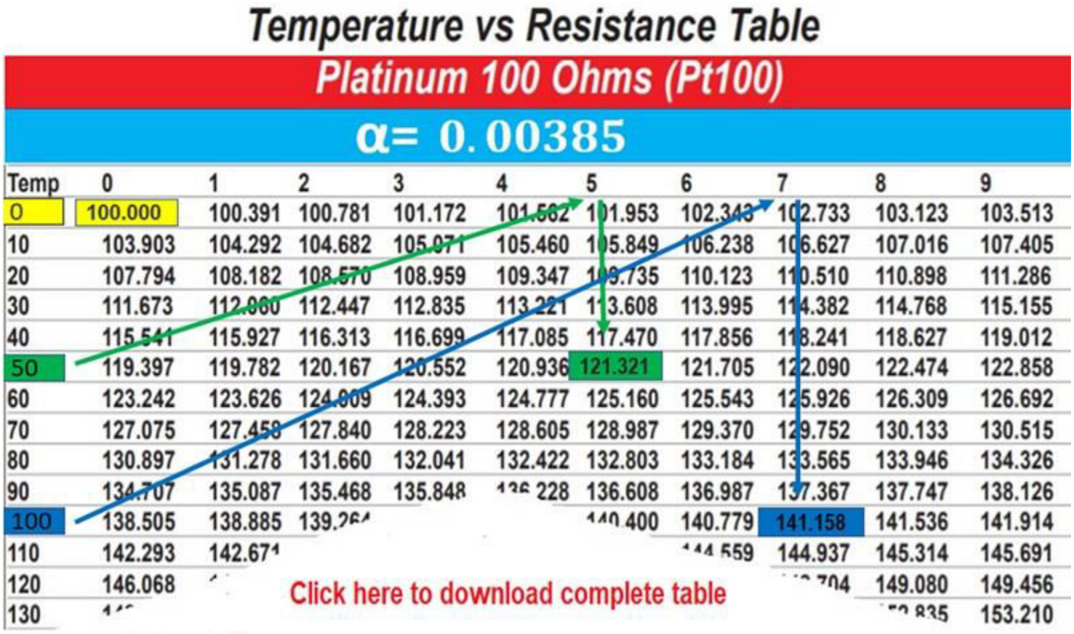


Fig-1*

RTD sensor

RTD (Resistance Temperature Detector) produce an output in resistance value, the amount of resistance depend on specification of bulb material, for instance PT-100 means resistance value is 100 Ohm when temperature at 0°C, PT-500 means 500 ohm resistance will be generated when temperature at 0°C, etc.

Each resistance versus temperature relation for an RTD is qualified by a term known as “alpha”. “Alpha” is the slope of the resistance between 0°C and 100°C. This is also referred to as the temperature coefficient of resistance, with the most common being 0.00385 Ω/Ω/°C.



Temperature vs Resistance Table

Platinum 100 Ohms (Pt100)

α= 0.00385

Temp	0	1	2	3	4	5	6	7	8	9
0	100.000	100.391	100.781	101.172	101.562	101.953	102.343	102.733	103.123	103.513
10	103.903	104.292	104.682	105.071	105.460	105.849	106.238	106.627	107.016	107.405
20	107.794	108.182	108.570	108.959	109.347	109.735	110.123	110.510	110.898	111.286
30	111.673	112.060	112.447	112.835	113.221	113.608	113.995	114.382	114.768	115.155
40	115.541	115.927	116.313	116.699	117.085	117.470	117.856	118.241	118.627	119.012
50	119.397	119.782	120.167	120.552	120.936	121.321	121.705	122.090	122.474	122.858
60	123.242	123.626	124.009	124.393	124.777	125.160	125.543	125.926	126.309	126.692
70	127.075	127.458	127.840	128.223	128.605	128.987	129.370	129.752	130.133	130.515
80	130.897	131.278	131.660	132.041	132.422	132.803	133.184	133.565	133.946	134.326
90	134.707	135.087	135.468	135.848	136.228	136.608	136.987	137.367	137.747	138.126
100	138.505	138.885	[illegible]			140.400	140.779	141.158	141.536	141.914
110	142.293	[illegible]					144.559	144.937	145.314	145.691
120	146.068	[illegible]						[illegible]	149.080	149.456
130	[illegible]								[illegible]	153.210

Click here to download complete table

Fig-2*

It is important to understand how to read temperature vs resistance conversion table. Refer to Fig-2 above.

Red indicates sensor type is PT100, its means 100 Ohm at 0°C.
Blue indicates temperature coefficient value (Alpha value).
Yellow indicates correlation between temperatures to resistance at 0°C; the resistance value for 0°C is 100 Ohm.
Green indicates correlation between temperatures to resistance at 55°C: the resistance value for 55°C is 121.321 Ohm.
Dark blue indicates correlation between temperatures to resistance at 107°C: the resistance value for 107°C is 141.158 Ohm.

From the Fig-2 above we noticed there is linear correlation between temperature vs resistance value, this can be explained by the following formula:

RT = Rref[1 + α(T − Tref)]

Where:
RT = Resistant value corresponding to known temperature
Rref = Resistance reference value (shown as 100 Ω in Fig.1)
A = Temperature coefficient (shown as 0.00385 in Fig-1)
T = Known temperature value
Tref = Temperature reference (shows as 0°C in Fig-1)
The below question and answer are example how to use resistance vs temperature formula, with this formula we will able to find a temperature

value that is equivalent to a known resistance or in other way we can find a resistance value which is equivalent to a known temperature.

Question1

One RTD sensor use for measuring process temperature which is actual temperature known by thermometer is 10°C. The RTD specification based on datasheet is PT-100 type with alpha=0.00385. What is the resistance value for this measurement? Use suitable conversion table to verify the answer.

Answer:

$RT = Rref[1 + \alpha(T - Tref)]$
$RT = 100\ \Omega[1 + (0.00385)(100 - 0)]$
$RT = 100\ \Omega[1 + 0.385]$
$RT = 100\ \Omega[1.385]$
RT = *138.5 Ω (it is the value for 10°C as shown in conversion table)*

Question2

One RTD sensor type PT-100 with Alpha value 0.00385 use for measuring unknown temperature process. There is thermometer available in place and showing some reading, in order to confirm what actual temperature, RTD output to be measured and calculation using formula to be performed, the answer below show a calculation result.

Answer:

The RTD output measured by Multimeter is119 Ω, subtitute this value into formula

$RT = Rref\ [1 + \alpha\ (T - Tref)]$

$119 = 100\ [1 + (0.00385)\ (T - 0)]$

$\frac{119}{100} = [1 + (0.00385)\ (T)]$

$\frac{119}{100} - 1 = 0.00385 \times T$

$1.190 - 1 = 0.00385 \times T$

0.190 = 0.00385 X T

$$T = \frac{0.190}{0.00385}$$

T= 49.35°C (use conversion table to verify relationship, thermometer may show between 49°C to 51°C depend on reliability)

Thermocouple sensor

A thermocouple consists of two metal made of different electrical conductors that are connected together at one end.
Thermocouple produce an output in millivolt, the amount of millivolt determined by the amount of metal between the terminal points and by the configuration of the element.

Different metal combinations will produce different types of thermocouples, as we can see in the table below:

Type	Positive wire	Negative wire
B	70% Platinum 30% Rhodium	96% Platinum 6% Rhodium
E	Chromel	Constantan
J	Iron	Constantan
K	Chromel	Alumel
N	Nicrosil	Nisil
R	87% Platinum 13% Rhodium	Platinum
S	90% Platinum 10% Rhodium	Platinum
T	Copper	Constantan

Fig-3*

Each Thermocouple type has a specific temperature conversion table, Fig-4 below show an example a conversion table for Thermocouple type K, (showing partially to help delve deeper into the subject).

REOTEMP INSTRUMENTS

ITS-90 Table for Type K Thermocouple (Ref Junction 0°C) http://reotemp.com

Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096

Figure-4*

Refer to Thermocouple conversion table above, we can see *a note* ***'Ref Junction*** **0°C'** then we can read relation between temperatures to millivolt reading, example how to read the table show here below;

Green color highlighted, show 0°C equal to 0.000 mV,
Yellow color highlighted, show 50°C equal to 2.023 mV,
Blue color highlighted, show 95°C equal to 3.889 mV,

Now let see the illustration in Fig-5 below

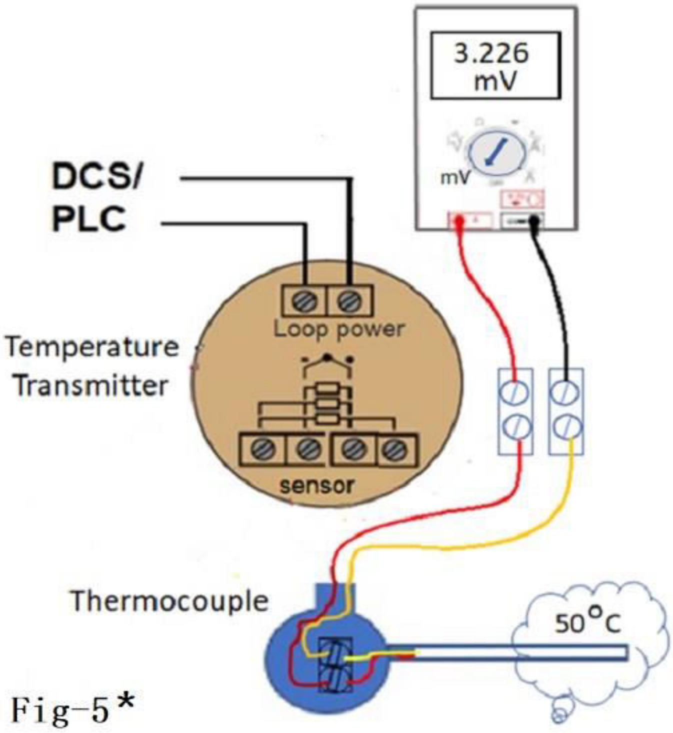


Fig-5*

In this picture TC type K use for measuring process, the actual temperature known about 50°C, the millivolt measured by multimeter show 3.226mV, if we look to the table for temperature 50°C should have output 2.023 mV, why we get different millivolt reading here, what is wrong?

Remember working principle of thermocouple; a thermocouple consists of two metal with different electrical conductors that are connected together at one end, that is the end (junction) we want to use to measure the temperature with.

When we measure the thermocouple voltage using multimeter, we have to connect ***wires*** into the multimeter, these wires connection have different material than the thermocouple material, its mean at these point two new thermocouples are created, that why multimeter not showing voltage 2.023 mV as shown in table for temperature 50°C. This millivolt deviation occurs due to the cold junction effect, let's continue to understand what a cold junction is.

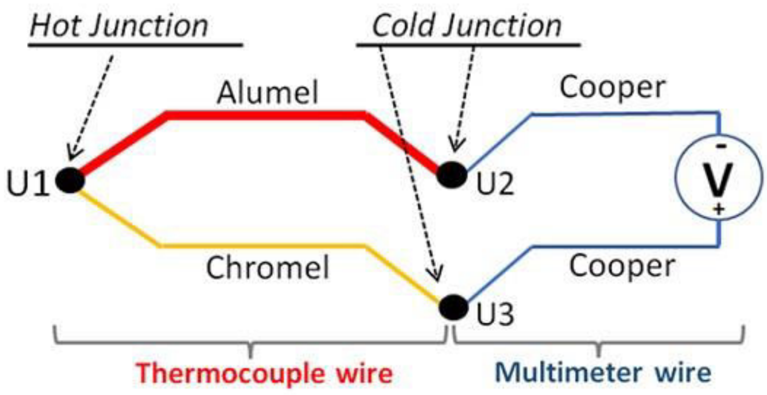
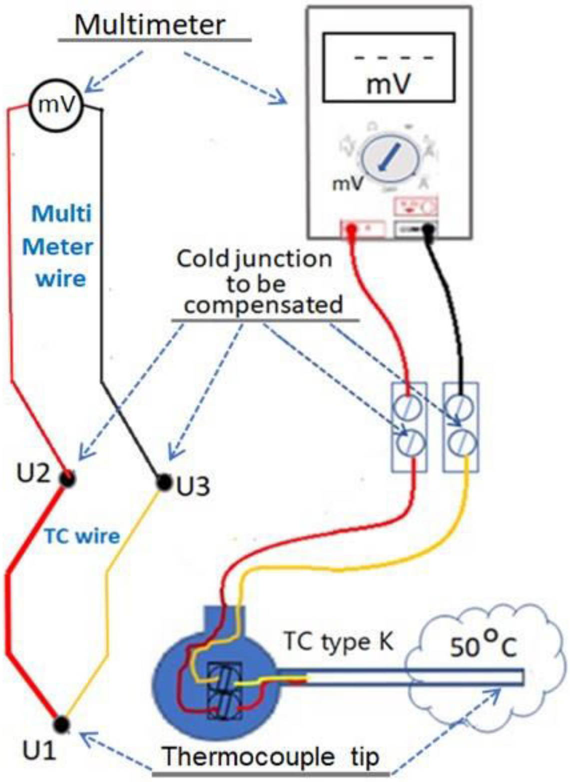


Fig-6*

In the above picture: “U1” is the hot junction of thermocouple, the point that is used to measure temperature, while point “U2” and “U3” are the cold junctions, which are generate voltage also, so multimeter in this loop measuring the thermovoltage of three thermocouples connected in series, this penomena does not comply with the basic principle of using TC as a temperature detector, TC should only detect temperature in the thermocouple junction which is known as a thermocouple tip.



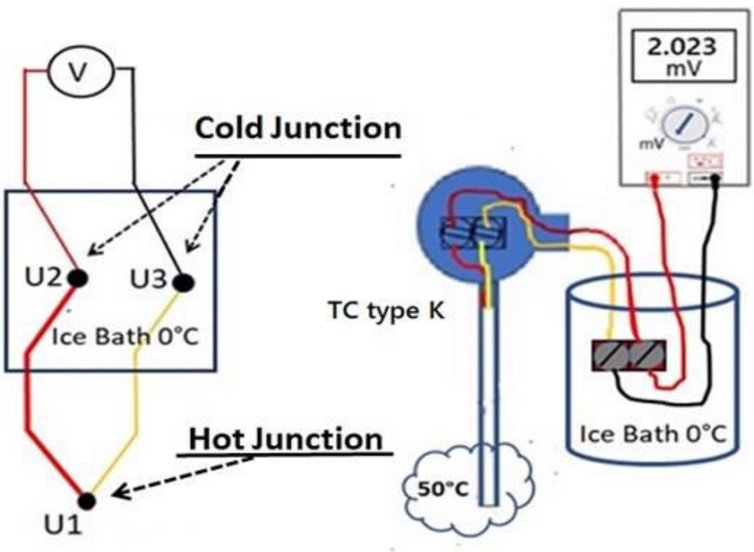
Fig–7*

The proper way known to be effective in solving these undesired effects is by “compensation method”.

Cold junction compensation methods

1. Cold junction compensation using ice-bath method.

Ice-bath is a device designed to make the condition of an area or container fix at 0°C. Refer to the below picture,



Fig–8*

In Fig-8 above we can see multimeter showing 2.023 mV for measuring 50°C, the same indication found in the conversion table.
In this scenario we can say “when the cold junction is maintained at zero degrees, the cold junction will not generate any voltage, therefore the output measured at the open end purely generated by a hot junction”.

This is the meaning of note ***“Ref junction 0 ° C***” usualy mentioned in the conversion table.

Below formula show relation between measured value versus hot junction and reference junction voltage.

$E = E_N(t_{U1}) – E_N(t_r)$
Where:
E = measured voltage
$E_N(t_{U1})$ = voltage generated in hot junction,
$E_N(t_r)$ = voltage generated in the cold (reference) junction.

Use TC type K conversion table then substitute relevant value

$$
\begin{aligned}
E &= E_N(t_{U1}) - E_N(t_r) \\
&= 2.023 \text{ mV} - 0 \text{ mV} \\
&= 2.023 \text{ mV}
\end{aligned}
$$

Using ice-bath is the best method to eliminate cold junction effect but this is not practical to be implemented at field side.
Ice-bath is only applicable for workshop activities.

2. **Cold junction compensation using fix value**.

Instrument device where thermocouple connected such as temperature transmitter or calibrator have a functionality to do calculation for compensating cold junction effect. There is configuration facility to set up cold junction parameter, user can choose the option.
One option we call MANUAL Cold Junction setting, in this method voltage value at cold junction to be identified, then this value will be enter into device using communication tool such as HART or PRM.

Below picture show an arrangement of tool and instrument device for set up cold junction parameter.

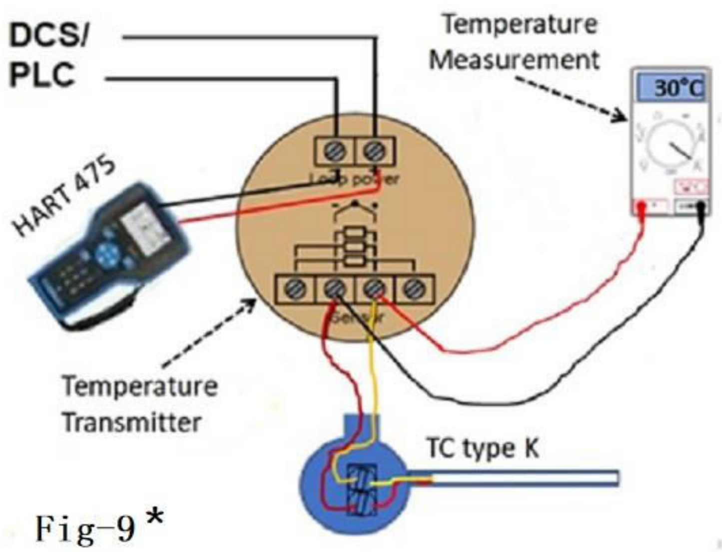


Fig-9 *

In this example Cold junction manually set as 30°C, then transmitter will calculate thermocouple output automatically.
Disadvantage of this method is a possibility of deviation between the Cold junction value manually entered and the actual ambient conditions, since the ambient temperature conditions may vary.

3. **Cold junction compensation by online measuring method**.

Two cold junction compensation method mentioned previously (ice-bath and fix value) have difficulties to be implemented in practical, the easy way is to leave the measuring device to do it automatically. The measuring device (being a transmitter, DCS input card or temperature calibrator) can be measuring the temperature of the cold junction all the time and automatically perform an on-line compensation of the cold junction error.

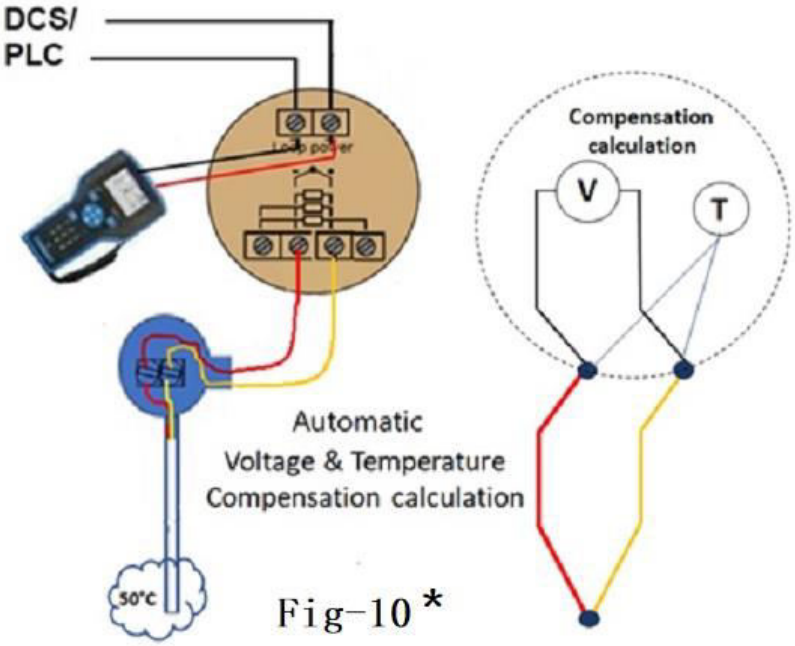


Fig-10 *

Since the transmitter also knows the thermocouple type by configuring a parameter, it can make the compensation aromatically and continuously. This is naturally the easiest and most practical way to compensate the cold junction in normal measurements and calibrations.

Measurement and simulation for performance verification

This chapter will explain the normal practice for doing measurement and simulation of RTD sensor and Thermocouple, this step normally performed during maintenance or trouble shooting.

RTD measurement is performed by removal wire connection from the transmitter, then measure resistance value and records it; proceed with verification step, which is to compare the resistance value with the number shown in the conversion table.

For simulation RTD signal to transmitter, it is performed using a tool that can generate resistance, such as a resistance box, the method for verification is to compare the indications appear on the transmitter with RTD conversion table.

Thermocouple measurement is performed by removal wire connection from the transmitter, then measure voltage using multimeter and records it; we should always consider cold junction effect and right polarity when working with thermocouple. As multimeter probe wires are different spec of wire, connection between thermocouple wire and multimeter wire will create reference voltage.

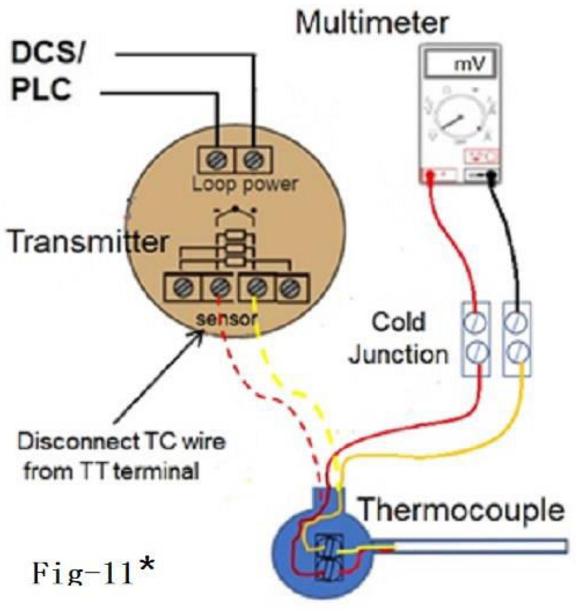


Fig-11*

Below step show a procedure to perform thermocouple simulation;

a. Disconnect thermocouple wire from transmitter terminal, use a suitable temperature to mV table for reference.
b. Notify ambient temperature to determine Cold Junction (reference) temperature value.
c. Look up corresponding mV value for the ambient temperature (reference temperature)
d. Note down millivolt value displayed on multimeter, it will be subtracted later on.
e. Look up corresponding mV value for the ambient temperature (reference temperature)
f. Subtract millivolt recorded in step d by millivolt value in step c.
g. Use again temperature to mV table to find temperature correspond to millivolt in step f.
h. This is the indication of temperature measured by thermocouple, with minor error due to inherent inaccuracies of thermocouple and extension wire.

Thermocouple simulation is performed using a voltage generator. Whenever working for TC always remember to consider cold junction (reference temperature) at terminal connection.
In this exercise we are going to simulate temperature 50°C to transmitter.

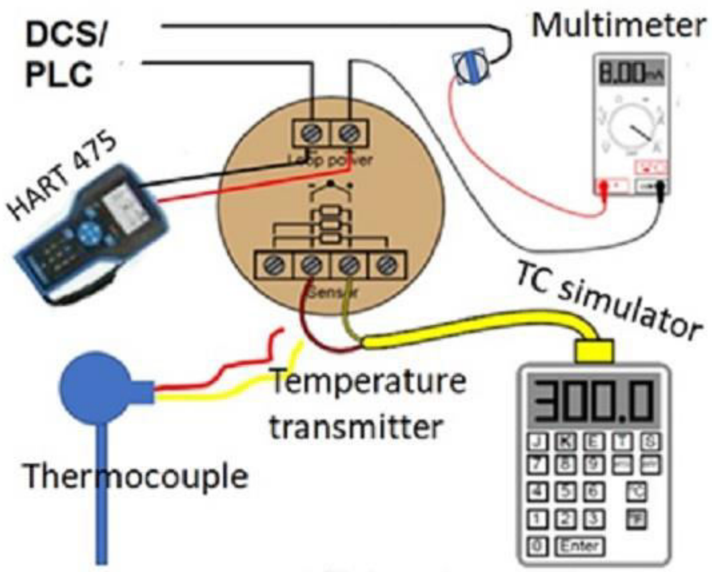


Fig-12*

Make tool arrangement as per figure-12 above then proceed with following step;

a. Configure sensor type at transmitter parameter, in this exercise we are going to utilize signal input of thermocouple type K. Use temperature to mV table type K for reference
b. Notify ambient temperature to determine Cold Junction (reference) temperature value. (in this example ambient temperature is 30°C) Look up corresponding millivolt value for the ambient temperature and record it. (example; 30°C correspond to 1.203mV)
c. Look up corresponding millivolt value for the temperature we are going to simulate. (in this example temperature going to simulate is 50°C and corresponding to 2.023mV)
d. Add millivolt value in step b with temperature value in step c.(found 3.226mV)
e. Adjust millivolt generator to produce output similar to step d (3.226mV). Then observe temperature indication on transmitter, it should read 50°C.

The above explanation is somewhat simplified, as the thermovoltage is actually generated by *the temperature gradients in the thermocouple wire*, all the way between the “hot” and “cold” junctions. So, it is not the junction points that actually generate the voltage, but the temperature gradient along the wire. It is easier to understand this by thinking that the thermovoltage is generated in the junctions, hot and cold ones. Depth explanation of the Thermocouple scientific theory will be provided in a separate article.